DVB
Digital Video Broadcasting

DVB-T Field Trials

Around The World

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Contributions from the Validate and Motivate Partners,
Facts, Australia & the Singapore Broadcasting Authority
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RESULTS OF RF MEASUREMENTS WITH DVB-T CHIP-SET AND COMPARISON WITH ATSC PERFORMANCE

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INTRODUCTION

DVB-T, the terrestrial system developed as one member of the family of DVB standards, has turned from a paper specification into a system which has been introduced in certain countries of the world. DVB-T set-top boxes and integrated receivers have been made available in large quantities by several manufacturers. Prior to the formal introduction several companies and research consortia have evaluated the performance of DVB-T and have carried out field trials and pilot tests.

This booklet is a compilation of selected papers describing results of such evaluations. These papers were all published between Autumn 1997 and Spring 1999. They come from different countries - even from Australia and Singapore - and demonstrate that DVB-T is feasible for different applications. Among the most advanced developments in application scenarios for DVB-T is the one in which DVB-T is not only used for the supply of services to stationary and portable receivers but in which mobile receivers in buses, trains and cars are addressed. This example is an impressive proof of the fact that by evaluating the performance limits of DVB-T and by - in parallel to the evaluation - enhancing the performance of tuners, front-ends and signal processing in the receiver we are able and will continue to be able to reach a DVB-T performance which even exceeds the impressive capabilities which we have experienced so far. There is no doubt that in two years from now another selection of topical texts will show that what has been documented here is by far surpassed by what will become possible during the next 24 months.

It gives me a great pleasure to thank the partners of the two collaborative research projects VALIDATE and MOTIVATE for the idea and their help in the preparation of this booklet. I would also like to thank FACTS of Australia and the Singapore Broadcasting Authority for their contribution.

Braunschweig, May 1999

Prof. U. Reimers Chairman of the DVB Technical Module

EVALUATION OF A DVB-T COMPLIANT TERRESTRIAL TELEVISION SYSTEM

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ABSTRACT

The BBC, in common with other UK broadcasters, intends to start digital terrestrial television services in 1998. These services will be broadcast according to the DVB-T specification. BBC R&D has conducted a programme of laboratory tests and field trials, in preparation for the start of these services. These tests have verified the suitability of the DVB-T specification, and determined some of the key service planning parameters.

The laboratory tests have shown that modems can be built with a small implementation margin, and that the system is rugged against co-channel interference and echoes. They have also determined the protection ratios for existing PAL-I services interfered by DVB-T signals. The field tests have confirmed that the results obtained in the laboratory can be achieved in practice, and have shown that actual coverage achieved is generally at least as good as computer predictions suggested.

Pullen, J.E. Salter C. R. Noke

INTRODUCTION

The BBC, in common with other UK broadcasters, intends to start digital terrestrial television services in 1998. These services will be broadcast according to the DVB-T specification, which was approved by ETSI (1) earlier this year.

This specification uses orthogonal frequency division multiplexing (OFDM) with 1705 carriers ("2K") or 6817 carriers ("8K"). BBC R&D built the first DVB-T compliant modem (a 2K version) which was described by Stott (2). We have used this modem to conduct a programme of laboratory tests and field trials. This paper gives the results of these tests.

The purpose of this work was to verify the DVB-T specification and to determine key parameters required for service planning purposes. Some of these parameters are best measured under laboratory conditions, and others must be measured in the field because of the less predictable conditions of a real channel.

Detailed planning is required to ensure that the new DVB-T services will have the expected coverage and performance, without noticeably degrading existing PAL-I services. To give confidence in the computer prediction tools, some work is presented to compare predicted and measured coverage in a few areas.

Results of tests with other DVB-T compliant equipment have been reported by Morello et al (3) and Weck and Schramm (4).

LABORATORY TESTS

The laboratory tests were split into two main areas:

- Protection ratios for existing PAL-I services interfered by DVB-T
- Verification of modem performance including interoperability tests.

The large number of possible parameters that could have been varied has meant that only a limited set of tests have been conducted at the time of writing.

Protection Ratios For Existing PAL-I Services Interfered By DVB-T

Co-channel and adjacent channel interference from a DVB-T test source was applied to a laboratory PAL-I transmission system. Out-of-band emissions –intermodulation product (IP) shoulders – from the test transmitter could be varied. The measured IP shoulder level (see Figure 1) could be varied over the range -35 to -50 dB or filtered with an 8 pole channel filter.

Picture impairment was assessed by a subjective comparison method. A reference condition was set up by adding white Gaussian noise equivalent to Grade 3.5 according to Oliphant et al (5), to the PAL signal. The interference level was adjusted to produce a subjectively similar impairment.

Independent assessments were made by two observers on three different types of PAL-I receiver:

- A Grade 1 measuring receiver ('Measuring')
- A 'top of the range' domestic receiver ('NICAM')

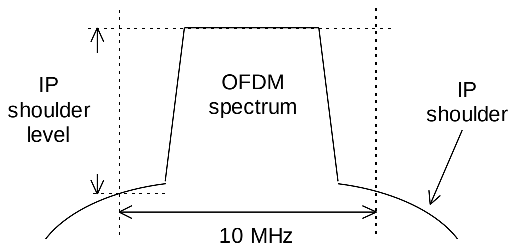


Figure 1 Measurement of IP shoulder level

- An inexpensive domestic receiver ('Portable')

Initially three different picture sources were used. However, the variation of results was found to be very small, so rationalisation to using only a test pattern picture source was made.

Degradation to PAL-I FM and NICAM sound was also measured but the results are not reported here as PAL-I vision was found to require the greatest protection. No quantitative measurement of the degradation to the generally robust Teletext service was made.

The frequency offset of the interfering DVB-T signal was limited to the co-channel (N) and adjacent channel (N±1) cases, with smaller frequency increments over a ± 250 kHz range for the latter. Introduction of these frequency offsets did not have significant benefit for protection of PAL-I services.

PAL-I vision protection ratio as a function of DVB-T IP shoulder level

Measurements were only made with the DVB-T signal in the lower adjacent channel (N-1) as this is the most critical case. Protection ratio measurements were made for a variety of out-of-band emission levels from the DVB-T test transmitter. The results are shown in Figure 2.

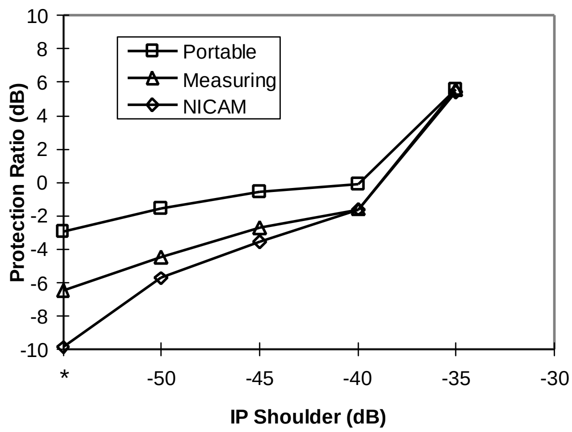
This shows that the upper IP shoulder encroaches into the PAL-I channel causing in-band interference. With high levels of IP shoulder this interference dominates and the protection ratio is independent of receiver selectivity. With lower levels of IP shoulder the adjacent channel interference dominates, and so the results are mainly dependent on receiver selectivity. Therefore, much more variation of results between receivers is seen.

Overall PAL-I vision protection ratio requirements

The results presented here are for a representative DVB-T interfering transmitter with -40 dB IP shoulders removed by an 8 pole channel filter. The protection ratio for picture impairments to grade 3.5 was measured for each receiver independently by two observers and averaged. The results are given as column (M') in Table 1. The degradation law due to DVB-T interference is similar in characteristic to that of Gaussian noise, so grades 3 & 4 were deduced. An allowance of +2.0 dB has been made for Grade 4 ('continuous'-C') and -1.5 dB for Grade 3 ('tropospheric'-T') interference.

Interfering digital signal in channel:	C'	M'	T'
(N-1)	–4.4	-6.4	–7.9
(N)	40.2	38.2	36.7
(N+1)	–6.0	-8	–9.5

Table 1 Protection ratios for wanted analogue signal in channel N



* Note: Values at this level are those for the case of -40 dB shoulders removed by an 8 pole channel filter.

Figure 2 PAL-I protection ratio versus level of IP shoulder from an interfering N-1 DVB-T source

Verification Of Modem Performance

A laboratory DVB-T 2K transmission system on UHF channel 28 was used throughout these tests. Co-channel interference from a PAL-I test source as well as additive white Gaussian noise could be applied at RF. In addition the RF signal could be degraded by an RF channel multipath simulator.

The DVB-T data consisted of test data inside MPEG packets. The BBC DVB-T demodulator is capable of checking the bit error ratio (BER) after the Viterbi decoder. The results are presented for degradation to a BER of 2×10^{-4} which is the Quasi Error Free (QEF) condition at the output of the Reed Solomon decoder. It should be noted that the slope of the BER curve versus impairment level is impairment dependent. For some impairments, increasing the level of the impairment does not quickly bring about a failure condition.

Performance with Additive White Gaussian Noise (AWGN)

The noise level was increased until the QEF condition was reached, and the noise source attenuator setting noted. The carrier-to-noise ratio was also measured directly by measuring the signal and noise sources independently with a power meter.

These results can be compared with the simulated figures in the DVB-T specification (1) - see Figure 3. The simulated figures do not take into account the implementation margin associated with a practical channel equaliser. The measured results are for a demodulator which includes a channel equaliser. Taking this into account, the demodulator performance is very close to the theoretical limit.

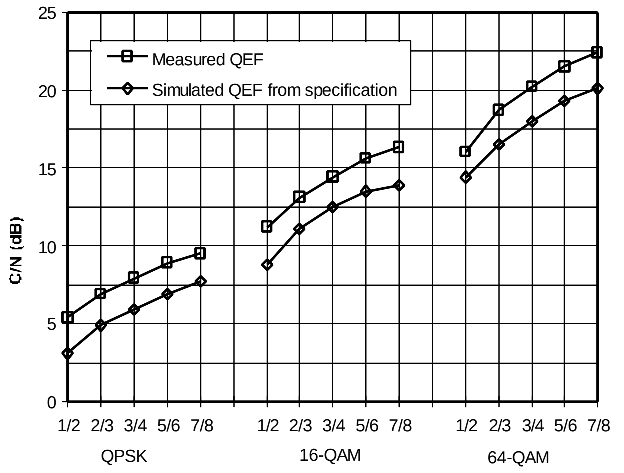


Figure 3 Performance with AWGN

Performance with co-channel PAL-I interference

The PAL-I vision modulation used throughout was 75% EBU colour bars. The FM sound carrier was modulated with a 1kHz tone. The NICAM sound carrier was modulated with PRBS data. The mean power level of this PAL-I test signal is conveniently -3.0 dB relative to the peak sync reference level.

For different modes and frequency offsets the level of PAL-I interference was increased until the QEF condition was achieved. The results are shown in Figure 4.

This shows that the DVB-T system is very robust against co-channel interference. The protection ratios observed are in line with the values assumed in the UK frequency planning study – see Maddocks et al (6). Note that for some of the QPSK and 16-QAM results the performance is limited by the ability of the modem to synchronise correctly under conditions where the power of the in-band unwanted signal is about 10dB greater than the wanted signal. It is likely that improvements to the synchronisation algorithms could improve these results still further.

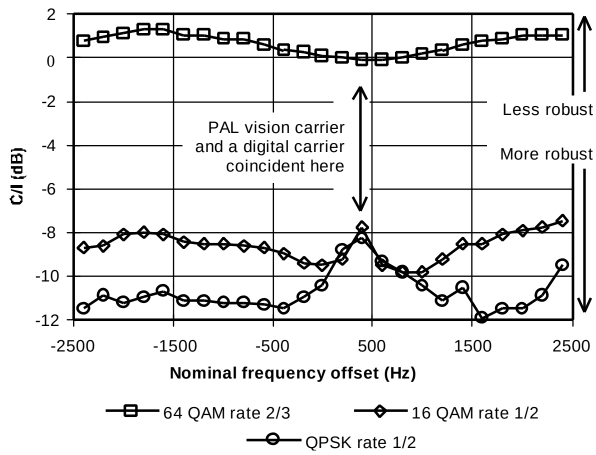


Figure 4 DVB-T carrier to co-channel PAL-I interference ratio for QEF

Performance in the presence of a single multipath echo

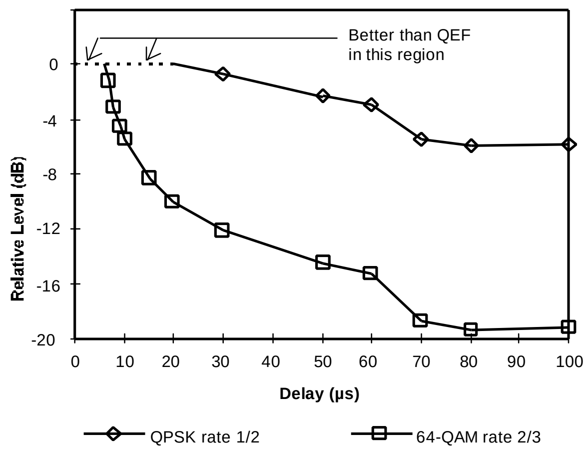


Figure 5 Maximum level of a single echo for QEF, with guard interval 7 µs.

Figure 5 shows the result of tests conducted with a single echo – it shows that the system is robust even for a 0 dB echo. With 64-QAM rate 2/3, and the chosen short guard interval, the limit to operation with a 0 dB echo is the guard interval duration. With a very rugged code, such as QPSK rate 1/2, the limiting factor is the performance of the channel equaliser – and operation with delays significantly outside the guard interval is possible. In both cases, for very long echoes, the effect of the echo becomes similar to Gaussian noise, and so the curves asymptote to the values from Figure 3.

Interoperability Tests

An important part of the testing of the BBC modem has been to ensure that it is fully compliant with the DVB-T standard. This has been checked as part of the VALIDATE project. Firstly, five different partners' software simulations of a modulated signal were compared. All five simulations agreed exactly. Next, the BBC modem was checked against this simulation – and was found to be identical. Finally, an interoperability test was conducted with the DVB-T modem built by Thomson Multimedia, CCETT and ITIS as part of the RACE dTTb project (the dTTb "second demonstrator"). In this test, it was shown that the modems worked with each other both ways round, for all modes that they operate in, and also with MPEG-2 coded audio and video. A similar test was conducted between the BBC modem and a DVB-T modem built by DMV, with the same results.

The above process has confirmed not only that the BBC modem is fully compliant with the DVB-T standard, but has also helped to clarify implementation pitfalls that could easily be made unless the standard is carefully applied. These were documented as an Informative Annex to the specification.

FIELD TRIALS

Transmitter Details

Signals were radiated on UHF Channel 28 from the Crystal Palace transmitting station in London, and on UHF Channel 59 from the Pontop Pike station in the North East of England. The transmitting equipment was as previously described by Oliphant et al (7). Two important differences between the two stations should be noted. First, the channel used at Pontop Pike was upper adjacent to one of the PAL-I services from the same site. This was not the case at Crystal Palace. Second, at Pontop Pike a high-power combiner was used to combine the digital and PAL-I signals, which were then radiated from the same antenna. At Crystal Palace a separate antenna was used for the digital signal.

Field-Trials Survey Vehicle

The field trials were carried out using a van which had been converted into a digital broadcasting survey vehicle by BBC R&D. The vehicle was equipped with a receiving antenna mounted on a 10 metre pneumatic mast. The antenna could be rotated through 360 degrees in the horizontal plane in order to point it in the direction of the transmitter.

The signal from the antenna was fed to a filter/distribution amplifier box. This provided separate feeds of the received signal for the DVB-T receiver, a field strength measuring receiver and a spectrum analyser. Power for the equipment was provided by a petrol generator carried in a trailer.

Minimum C/N

In planning a digital terrestrial network it is important to know the minimum carrier-to-noise ratio, (C/N), at which the system will operate. Measurements to determine this figure were made at both Crystal Palace and Pontop Pike, using the 16-QAM, rate 3/4 mode, with a guard interval of 7µs. According to the DVB-T specification the theoretical values for this mode were 12.5 dB for a Gaussian channel, 13.0 dB for a Ricean channel, and 16.7 dB for a Rayleigh channel.

Figure 6 shows the distribution of minimum C/N for a total of 58 measurement points where reception from Crystal Palace was possible. Analysis of the data files gives:

Lowest recorded minimum C/N value:	15.0 dB
Highest recorded minimum C/N value:	26.9 dB
Median value of minimum C/N:	17.8 dB

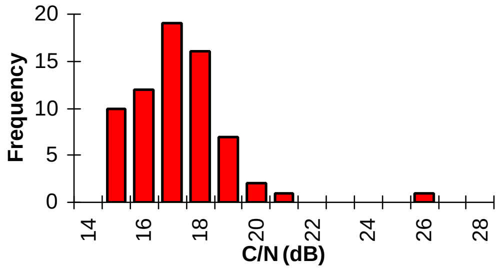


Figure 6 Distribution of minimum C/N measured at Crystal Palace

Figure 7 shows similar results made in the Pontop Pike area. Analysis of these results gives:

Lowest recorded minimum C/N value: 14.6 dB

Highest recorded minimum C/N value: 22.8 dB

Median value of minimum C/N: 16.7 dB

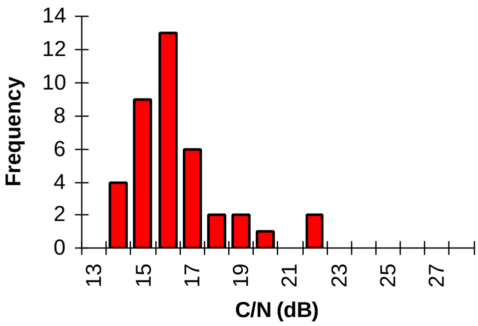


Figure 7 Distribution of minimum C/N measured at Pontop Pike

The Pontop Pike results are slightly better than those obtained at Crystal Palace. There is a reduction in the median value of about 1 dB. These differences are thought to be mainly due to improvements made to the modem between the periods of the Crystal Palace and Pontop Pike tests.

It is also significant that there is no apparent degradation in performance resulting from the use of a channel upper adjacent to a co-sited PAL-I service, or from the high power channel combiner.

Location Variation

In addition to the minimum C/N, it is important to determine the magnitude of field strength variation that can be expected in a small geographical area.

Measurements were made in a number of 1km by 1 km squares within the coverage areas of each transmitter. In each square, ten or more field strength measurements were made at points evenly distributed throughout the square. The measurement van was shunted by about half a metre at each point in order to maximise the signal. From these measurements, standard deviation values were calculated for each square. The average values calculated for all Crystal Palace squares and all Pontop Pike squares are given in Table 2.

Area	Standard Deviation (dB)
Crystal Palace	5.8
Pontop Pike	5.0

Table 2. Measured standard deviation values

Coverage Measurements

The values of 'Minimum C/N' and 'location variation' are important parameters in computer predictions of coverage. The planning of digital terrestrial services is based largely on these computer predictions. Consequently, a programme of work was undertaken to compare the predicted and measured coverage of the Crystal Palace and Pontop Pike transmitters within a few selected areas.

The results are presented inFigure 8 and Figure 9 as scatter plots of measured versus predicted coverage for the squares. Thus points above the diagonal line represent squares in which the measured coverage is better than predicted.

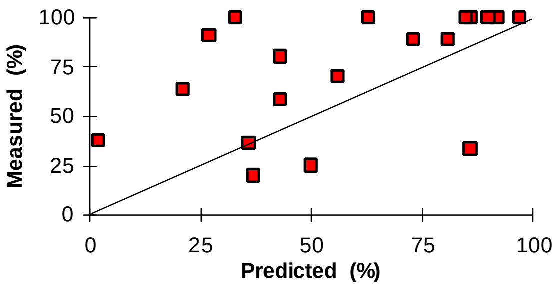


Figure 8 Measured versus predicted coverage at Crystal Palace

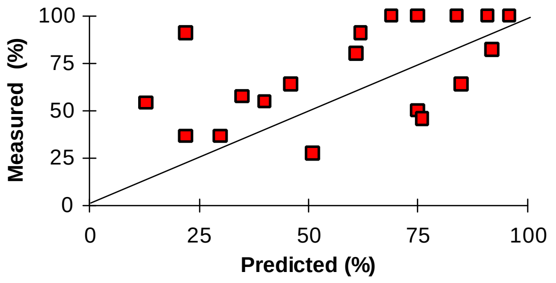


Figure 9 Measured versus predicted coverage at Pontop Pike

It is clear that in the majority of squares the measured coverage is at least as good as predicted. Though there are some squares in which the reverse is true, these are generally in areas where reception conditions are known to be poor. This is often due to high levels of ground clutter, high-rise buildings etc. Such effects are notoriously difficult to build into prediction models. In particular, five squares in the Pontop Pike survey gave a lower than predicted coverage figure. These squares were, however, in a particularly heavily built up industrial area in Middlesbrough.

Indoor Portable Reception

Portable reception is one of the key advantages of terrestrial broadcasting over other delivery means. In view of this, some work was undertaken with two basic aims:

- To measure the key parameters of building penetration loss, height gain, and location variation required for theoretical studies.
- To assess the coverage to set-top antennas at fixed locations in the houses and how this relates to the measured field strength outside at 10 metres.

A total of six residences were measured. Four of these were conventional houses, one was a first floor maisonette and one was a ground floor conversion flat. All of the buildings were of conventional brick construction. Measurements were made in different rooms inside the house. In general, for a normal two storey house, four rooms were measured – upstairs and downstairs on the sides nearest to and furthest from the transmitter.

Measurements were made to determine the ratio of the field strength measured outside at 10 metres to that measured inside the building. This overall building loss includes both the building penetration loss and height gain. The figure varied between about 16 and 29 dB for upstairs rooms, and 19 and 34 dB for downstairs rooms. The average values were 22 dB for upstairs rooms and 29 dB for downstairs rooms.

The standard deviation of the field strength variation within a room varied between about 2 and 4 dB.

The minimum C/N required for reception in upstairs rooms was, on average, 17dB, virtually identical to that obtained with a good directional antenna at 10 metres height. This is clear evidence of the ruggedness of the DVB-T system under adverse reception conditions such as those encountered inside buildings. For downstairs rooms the average value was about 18 dB for a room on the side of the house nearest to the transmitter, and about 21 dB for a room on the opposite side. The increased C/N value required in ground floor rooms and rooms on the opposite side to the transmitter probably reflects the increased level of multipath propagation.

On the basis of these C/N values the corresponding minimum field strength values at the receiving antenna are 42 dBµV/m for upstairs rooms, 44 dBµV/m for a downstairs room on the side nearest to the transmitter, and 46 dBµV/m for a downstairs room on the opposite side of the house.

On average a field strength of 70.5 dB µV/m at 10 metres should ensure reception at 90% of locations within an upstairs room. A field strength of between 77 dB µV/m and 82 dB µV/m at 10 metres would be required to provide similar coverage to downstairs rooms.

CONCLUSIONS

A programme of laboratory tests and field trials have been conducted with the BBC's DVB-T modem. This work has confirmed the validity of the DVB-T specification and established the key service planning parameters. The results support the values currently being used by the CEPT and in the UK frequency plan (6). Coverage measurements indicate that generally the coverage is at least as good as the planning study suggested.

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VALIDATE FIELD TRIALS OF DIGITAL TERRESTRIAL TELEVISION (DVB-T)

DVB-T-Feldversuche

im Europäischen ACTS-Projekts VALIDATE

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ABSTRACT

Since the completion of the European specification for digital terrestrial TV broadcasting, DVB-T[1][2], more equipment has become available and many field trials have been conducted in the framework of the ACTS project VALIDATE at different sites throughout Europe. This paper gives an overview on these trials and highlights some interesting results of the various test transmissions and the field work carried out so far.

Results from propagation measurements are summarised for signals from a single transmitter or from several transmitters, either by using gap-fillers, which work as on-channel repeaters, or explicitly within a single frequency network (SFN). Both outdoor and indoor reception are examined. Building penetration losses have been recorded and there is a brief report on the influence of a domestic gap-filler to improve the portable indoor reception within buildings.

Results on the system performance for different COFDM modes of the DVB-T system evaluated in the field are outlined for fixed as well as for portable reception and the possibilities for mobile reception are investigated, too. A few results are also available of the measured coverage probability in comparison to the service areas as predicted by computer simulations.

ZUSAMMENFASSUNG

Seit der Festschreibung der Spezifikation für digitales terrestrisches Fernsehen, DVB-T, sind vermehrt DVB-T-Übertragungsgeräte verfügbar geworden und es wurden europaweit im Rahmen des ACTS-Projekts VALIDATE viele Feldversuche durchgeführt. Ausgehend von einer Übersicht faßt der Vortrag die bisherigen, wichtigsten Ergebnisse der Unterarbeitsgruppe Feldversuche zusammen: Es handelt sich unter anderem um Ausbreitungsmessungen mit einem DVB-T-Signal von einem einzelnen Sender oder auch von mehreren Gleichwellensendern, wobei auch Füllsender betrachtet werden, die auf der gleichen Sendefrequenz empfangen und abstrahlen. Es wird sowohl der Empfang innerhalb und außerhalb von Gebäuden betrachtet und eine Möglichkeit untersucht, den portablen Empfang in Räumen trotz hoher Gebäudedämpfungen zu verbessern. Die Leistungsfähigkeit des DVB-T-Übertragungssystems wurde bei gerichtetem und ungerichtetem Empfang untersucht. Einige Erfahrungen liegen auch schon für den mobilen Empfang von DVB-T vor. Die Ergebnisse werden für verschiedene Übertragungsparameter der DVB-T-Spezifikation dargestellt. Erste Aussagen über den Vergleich der geplanten mit einer gemessenen DVB-T-Versorgungsfläche bestätigen die hohe Leistungsfähigkeit des Übertragungssystems.

1 INTRODUCTION

VALIDATE stands for 'Verification And Launch of Integrated Digital Advanced Television in Europe'. It is one of the ACTS projects, sponsored by the European Commission in the fourth Framework Programme 'Advanced Communication Technologies and Services'. The project VALIDATE [3], led by the BBC as prime contractor, started work in late 1995 and aims to verify the European DVB-T standard for digital terrestrial television broadcasting and to prepare for the launch of services. There are 19 partners in nine European countries, representatives from several broadcasters including broadcasting research centres and the European Broadcasting Union (EBU) as well as telecom and network operators and professional and consumer manufacturers. A detailed list of partners can be found together with the bibliographical references at the end of his paper.

In VALIDATE, first computer simulations and laboratory tests and later field trials were performed in various laboratories and from several transmitter sites all over Europe. In two VALIDATE task forces, the measurement procedures for lab tests and field trials were agreed and the measurement results were exchanged and compared in order to verify the specification and to achieve reliable planning parameters for future DVB-T services.

This report gives an overview of the extensive field work and demonstrations carried out in the VALIDATE project so far. The folowing list shows the sites for DVB-T field trials already existing in the project:

- United Kingdom, BBC, London area and North East of England
- France, CCETT, Rennes
- France, TDF, Metz
- Germany, Deutsche Telekom & TBerkom, Cologne and Berlin
- Germany, IRT, Munich
- Spain, Retevision, Madrid
- Italy, RAI, Torino
- Denmark, TeleDanmark
- Sweden, Teracom, Stockholm
- Ireland, RTE, Dublin
- The Netherlands, NOZEMA

Further transmitting sites and DVB-T pilot services are in preparation.

2 SCOPE OF FIELD TRIALS

The scope of field trials in VALIDATE is to confirm the extensive range of laboratory results and to investigate fully the overall performance of the DVB-T system for various transmission modes and various reception conditions, where the received signal is likely to suffer a combination of propagation and reception impairments that would be difficult to estimate in the laboratory.

Furthermore, field trials are required to answer questions of service planning, that is to evaluate the coverage probability for the different structures of transmitter networks and to investigate the different kinds of distortions of the transmission channel. Sufficient representative field-trial data has to be acquired to improve the accuracy of the values adopted for critical planning parameters (e.g. minimum field-strength and C/N, protection ratios, etc.) used within service prediction models. Investigation of the stability / reproducibility of measurements made at any given site over a period of time and under potentially different propagation and reception conditions (including the possible effects of periodic changes in climatic or atmospheric conditions) are still going on.

3 DVB-T SPECIFICATION

In the development and definition phase of the European DVB-T specification [4], the advantages of the multicarrier modulation outweighed those of the single-carrier methods in terms of broadcasting requirements (as it was likewise the case with EUREKA 147 DAB for digital sound broadcasting). The crucial factor in favour of the chosen COFDM method (Coded Orthogonal Frequency Division Multiplex) [5] is the ability to cope with strong echoes due to multipath propagation and the capability to set up single-frequency networks (SFNs), which offer network planners a higher network efficiency [6][7][8].

The specified DVB-T system offers a wide range of potential applications: conventional multi-frequency networks (MFNs), i.e. single transmitter applications, prohibited ("taboo") channel operation, etc. and single-frequency networks (SFNs). The service can be dedicated to stationary or portable reception or both using hierarchical transmission. The network operator can select technical parameters such as the number of OFDM carriers, the length of the guard interval (this is a cyclic continuation of the useful OFDM symbol), the degree of error protection and the modulation method. The last two parameters in particular allow the operator to reach an individual compromise between the number of programmes carried and their transmission reliability.

The transmitting system provides an MPEG-2 transport mechanism, a kind of data container whose size depends on the chosen transmission parameters (transmission mode). It allows for full flexibility with respect to the number of transmitted programmes, the content of any digital information or the kind of digital services (e.g. HDTV to LDTV, surround sound, data etc.).

The following transmission pa7rameters can be selected:

• BANDWIDTH:	8 MHz, 7 MHz, 6 MHz
• MODULATION:	4-PSK, 16-QAM, 64-QAM
• HIERARCHY:	4-PSK in 16-QAM or in 64-QAM
• CARRIERS:	6817 (8K-FFT), 1705 (2K-FFT)
SPACING:	1116 Hz (8K), 4464 Hz (2K)
• USEFUL SYMBOL	
DURATION:	896 ?s (8K), 224 ?s (2K)
• GUARD INTERVAL:	1/4, 1/8, 1/16, 1/32
DURATION:	224, 112, 56, 28, 14, 7?s
• INNER CODE RATE:	1/2, 2/3, 3/4, 5/6, 7/8

The latter refers to the error protection of the inner convolutional code. Together with the outer error-correction code (RS 204,188) and the overhead for pilot carriers a spectrum efficiency of 0.65 to 4.2 $bit/Hz_{bandwidth}$ can be achieved. For example in an 8 MHz TV channel, useful data rates from 4.98 to 31.67 Mbit/s can be transmitted.

4 PROPAGATION MEASUREMENTS

In comparison to analogue television signals, which behave like narrow-band signals because of the single video carrier, the DVB-T signal is a wide-band signal where the energy is distributed over a large number of carriers in the radio channel. The first issue for investigation was the received field strength at any reception point and the statistics of the location variation.

Some results for signals from a single transmitter are given in Table 1. The bulk of distribution functions of the received field strength for different test routes was following a log-normal law. Measurements of the CCETT showed that the standard deviation of an analogue TV signal transmitted from the same tower is 0.1 to 0.4 dB higher than the one of the digital signal [16].

Location	Terrain Class	Standard Deviation / dB		
		fast fading	slow fading	combined
TERACOM, Stockholm, Sweden	open field forest suburban urban	1.7 2.6 2.3 2.2	2.7 3.3 3.2 2.5	3.3 4.4 4.1 3.3
CCETT, Rennes, France	rural suburban urban			2.5 3.3 3.9
BBC, London, UK	rural urban			2.5 4.0
Deutsche Telekom, Berlin, D	suburban			3.3

Table 1: Location variation of field strength
for various locations and receiving conditions

Location	Terrain Class	Margin for 50 % to 99 % covered locations	
		analogue TV	digital TV
CCETT, Rennes, France	rural suburban urban	11.7 dB 16.0 dB 16.7 dB	9.7 dB 12.0 dB 11.8 dB

Table 2: Margin for the increase from
50 % to 99 % coverage

It is well known that, in contrast to analogue services, there is a very rapid degradation of a digital transmission system at the fringe of the coverage area. For DVB-T the margin in a Gaussian channel between the onset of impairment and the failure point is only about 1– 2 dB, in a Rayleigh channel it can be much more, due to fading effects. Therefore, it is not sufficient to consider the median value of the field strength for coverage considerations, but to introduce a margin from e.g. 50% to 99% of the covered locations. For analogue TV systems this margin was in the order of 16 dB. Latest results from CCETT [16] given in Table 2 show that there is a distinct lower margin necessary for the digital system than for the analogue one. This result relaxes the power requirements for DVB-T.

4.1 Single Frequency Network Gain

Conventional networks use individual radio frequencies for each transmitter (MFN: multi-frequency network) to avoid mutual interference. One programme transmitted within a network occupies therefore a set of radio frequencies. Now, the great advantage of the DVB-T transmission system is that a large area may be covered by transmitters working all on the same radio frequency, provided the relevant signals from various transmitters arrive at a reception point within the duration of the guard interval.

Such single-frequency network (SFN) has important advantages for network planning. The frequency efficiency of large SFNs can be up to 4 times higher than for MFNs. Furthermore, the power efficiency of an SFN is better, because the coverage probability at a reception location is increased owing to the signal diversity of the different propagation paths.

Measurements of the Deutsche Telekom in Berlin in a SFN with 3 transmitters showed that the standard deviation of the received power is about 2.6dB compared to 3.3 dB for the signal from a single transmitter. Especially, if the coverage probability in the middle between transmitters is considered, where the contribution of the main signal paths is usually in the same order and rather low, there is observed a high diversity gain in an SFN. For example, the SFN gain was found at such locations to be in the order of 4 – 6 dB (considering a value of 90 % for the coverage probability). Further measurements are still necessary to achieve more statistical results.

4.2 Professional gap-filler

One additional advantage of SFNs to be mentioned is, that every gap within a coverage area can be covered by using active deflectors working on the same single frequency, so-called professional gap-fillers. There will be in principal no physical, but may be a financial limitation to cover an area up to 100% with such devices.

A prototype of a professional gap-filler for application in real SFNs was developed in the framework of VALIDATE by Mier Communicaciones, Spain. First field trials were performed in Berlin in co-operation with Deutsche Telekom, where the gap-filler received the DVB-T signal from a tower at 21 km distance. The signal was then retransmitted with a power of 100 W ERP to cover the city of Potsdam, which is about 26 km away from the main transmitter and shadowed by hills. The trial was very successful. A very high antenna isolation of up to 105 dB was achieved between receiving and transmitting antenna. Further improvement is expected during the optimisation of the prototype.

4.3 Single Frequency Network Synchronisation

It is evident that the individual transmitters of a SFN have to transmit each single bit exactly in the same manner and at the same time. This is a minor problem if the broadcast signal is retransmitted directly or after frequency transformation. But in general the MPEG transport stream may be send through different digital links to each transmitter and it becomes essential to synchronise the modulation procedures of all individual transmitters.

VALIDATE investigated this problem in detail and supported the specification process for synchronising SFNs. A synchronisation device for DVB-T modems was developed by ITIS [8] and was successfully tested by RTE and ITIS in Dublin, Ireland, in November 1997 using two transmitters. It was the first SFN operation based on a real primary distribution network as described by the SFN-DS specification [17]. The synchronisation is based on a central SFN adapter inserting Mega-frame Initialisation Packets (MIP) into the MPEG2-TS with GPS time information. At each transmitter site the MPEG2-TS, e.g. from a 34 Mbps PDH link is modulated in a synchronous mega frame according to the local GPS time.

5 INDOOR PROPAGATION MEASUREMENTS

The field-strength distribution within buildings is very important for portable receivers using very small indoor antennas or poor whip antennas. To estimate the service coverage, measurements were made at a number of locations within office buildings and within a sample of domestic dwellings where set-top reception on portable receivers would typically be required (e.g. living room, kitchen, bedroom). The field strength was found to be log-normally distributed with standard deviations given in Table 3. The value of the standard deviations in rooms in direction to the transmitter was about 0.5 – 0.6 dB higher than the value for rooms at the opposite side of the house. For comparison, measurements of signals with lower bandwidth were performed, too. This was a DAB signal with 1.5MHz bandwidth and an analogue carrier with 120 KHz bandwidth.

Location	Standard Deviation
BBC, London, UK (within one room)	2.8 dB 2.4 – 3.2 dB
CCETT, TDF, Rennes, France	2 dB
TERACOM, Stockholm, Sweden	3.2 dB
IRT (1.5 MHz bandwidth)* (120 KHz bandwith)*	3.5 dB 5.5 dB

Table 3: Location variation within rooms

(* not DVB-T, for comparison only)

Investigations of the time variance of the signal due to moving people in the room showed a log-normal distribution, too. The standard deviation was about 1 dB. However it must be pointed out that very deep fades corresponding to a total shadowing of the receiving antenna are not taken into account by such a standard deviation. Such fades are usually caused by somebody coming very close to the antenna and are not to be considered as a normal condition of reception.

5.1 Building penetration loss and building loss

The indoor measurements in conjunction with outdoor measurements at the same site allow accurate values for the building penetration losses to be determined for use in service planning models for portable reception.

Two different questions can be distinguished: What is the loss between outdoor and indoor reception of DVB-T based on the same antenna height (e.g. field strength outside the window), which is here referred to as the building penetration loss, and what is the loss, compared to the traditional roof-top antenna, which is here referred to as building loss. The results given in Table 4 indicate that the height loss is a very significant part of the building loss, were the building penetration loss itself is in average lower than 10 dB.

Location	Average Building Penetration Loss
IRT, Munich, Germany	8.5 – 9.1 dB (VHF) 7.0 – 8.5 dB (UHF)
TERACOM, Stockholm, Sweden	6.4 dB (UHF) (standard deviation 3.6dB)
Location	**Building Loss (incl. height loss)**
BBC, London, UK	21 – 23 dB (1st floor, UHF) 28 – 30 dB (ground floor, UHF)
CCETT, TDF, Rennes, France	10 – 17 dB (individual house)

Table 4: Building penetration loss and building loss

for various locations and receiving conditions

5.2 Domestic gap-fillers

As portable reception is one of the chief advantages for DVB-T compared to satellite and cable transmission systems. VALIDATE investigated solutions to increase the field strength in buildings by using domestic gap-fillers, which work as on-channel repeaters inside buildings. Two different prototypes, differing in size and cost, were developed by Televés, Spain. One working as broadband device and the other amplifying three selected channels.

The first trials performed by Retevision and BBC of indoor reception of DVB-T using domestic gap-fillers validated this concept and were very encouraging. Real off-air signals received by a directional roof-top antenna or derived from a MATV system were rebroadcast in domestic houses and in a very hostile laboratory environment. An omnidirectional antenna or a small yagi antenna was used in the centre or in a corner of a house, respectively. An output of less than 250 µW from the domestic gap-filler was found to be sufficient for a set-top reception of DVB-T with 64-QAM in every room of a residential building. Detailed measurement are still going on at the BBC and have now been started at other VALIDATE test sites.

6 SERVICE COVERAGE MEASUREMENTS

Since propagation measurements merely consider the received power they do not take into account the properties of the DVB-T system. This means that the question whether one location is covered depends not only on the received power, but on the fact whether the receiver is really able to provide an error-free reception of the sound and picture or not. Therefore, the individual performance of the receiver, the chosen technical parameters like modulation and channel coding as well as the type of transmission channel have to be considered in detail.

The determination of the service coverage at any location can be based on the picture quality itself or on real bit-error ratio measurements (BER). A BER of $2 \cdot 10^{-4}$ after the Viterbi decoder (inner code) was adopted as one reference value corresponding to quasi error-free (QEF) operation after the outer Reed Solomon RS (204,188) decoder. The BER after Viterbi allows for more accuracy of the results than the BER after the Reed-Solomon error protection, which would be available on the MPEG transport-stream level. This QEF operation generally corresponds to a criterion based on an period of at least 30 seconds, where no picture or sound impairments occur. Concentrated errors usually are visible and audible if the signal-to-noise ratio *C/N* for $2 \cdot 10^{-4}$ is reduced further by about 1 dB, corresponding to a BER of more than 10^{-3} after Viterbi decoding.

In the DVB-T specification [1] there are figures available for the required *C/N* for all transmission modes to achieve a BER of $2 \cdot 10^{-4}$. These Figures are based on simulation results for three types of transmission channels, but without taking any implementation margin into account:

- Gaussian channel
  direct sight, no multipath, laboratory condition
- Rice channel (k = 10 dB)
  for stationary reception using directional antennas
- Rayleigh channel
  for portable reception using omnidirectional antennas

The transmission channel in the field is usually an intermediate type between a Gaussian and a Rayleigh channel. Therefore, the required *C/N* or the required signal power, respectively, to achieve BER $2 \cdot 10^{-4}$ will be different at different receiving locations. This fact is actually shown by the BER curves measured at different test locations in Munich [13]. Each of Figure to Figure 6 shows the BER behaviour after Viterbi decoding of a chosen transmission mode at about 15 different receiving locations versus the receiver input power. Three modulation modes were examined in the field:

- 64 QAM, code rate R= 2/3, guard interval GI = 1/8, 8k-FFT
- 16 QAM, code rate R= 3/4, guard interval GI = 1/32, 8k-FFT
- QPSK, code rate R= 1/2, guard interval GI = 1/4, 8k-FFT.

The results are given for stationary reception (directional antenna at 10m height) as well as for portable reception (omnidirectional antenna at 1.5m height). The continual curves of the BER show that the results in the field are reliable and stable, which is important for the validation of the DVB-T specification.

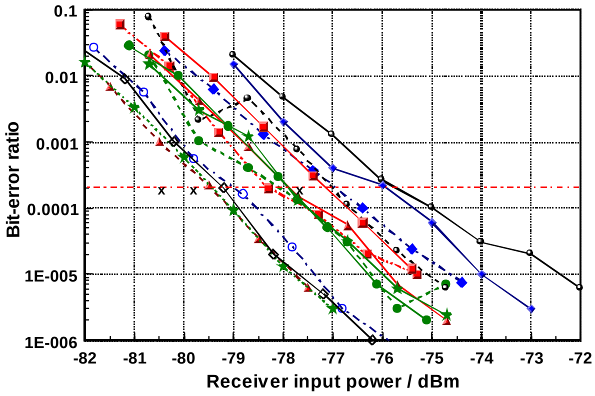

Figure 1: BER versus receiver input power modulation: 64 QAM, R 2/3, GI 1/8, 8k FFT directional antenna height 10 m above ground

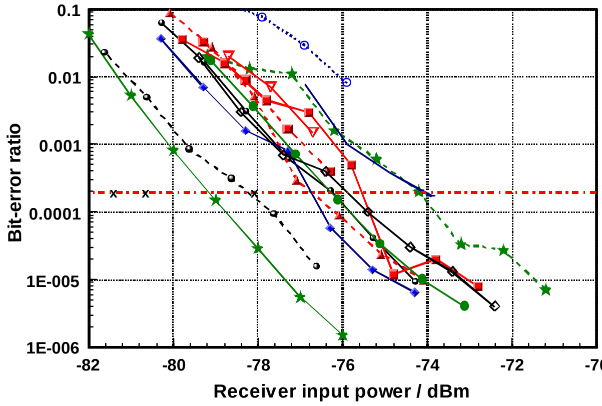

Figure 2: BER versus receiver input power modulation: 64 QAM, R 2/3, GI 1/8, 8k FFT omnidirectional antenna height 1.5 m above ground

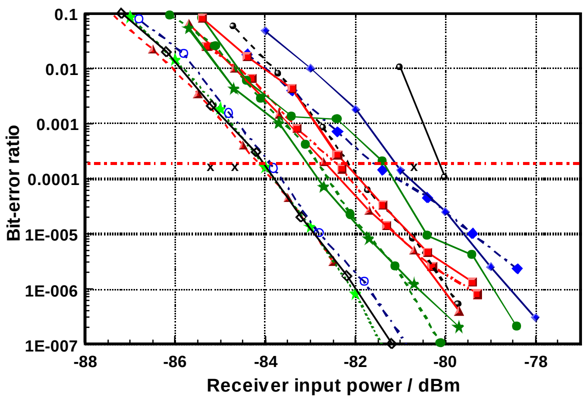

Figure 3: BER versus receiver input power modulation: 16 QAM, R 3/4, GI 1/32, 8k FFT directional antenna height 10 m above ground

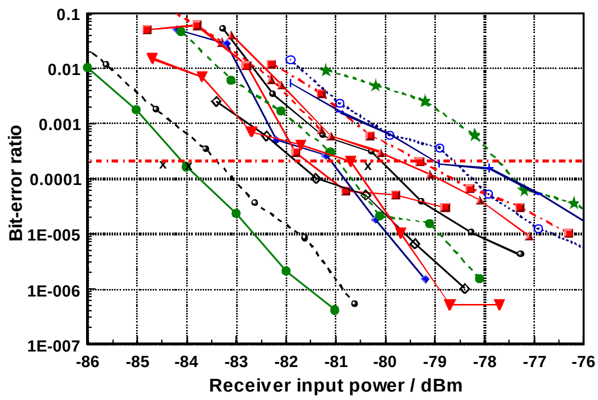

Figure 4: BER versus receiver input power modulation: 16 QAM, R 3/4, GI 1/32, 8k FFT omnidirectional antenna height 1.5 m above ground

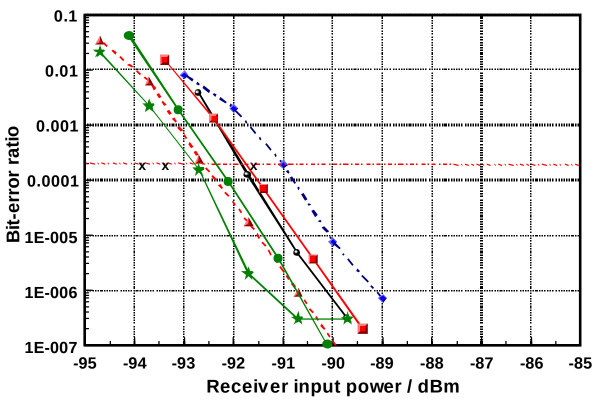

Figure 5: BER versus receiver input power modulation: QPSK, R 1/2, GI ¼, 8k FFT directional antenna height 10 m above ground

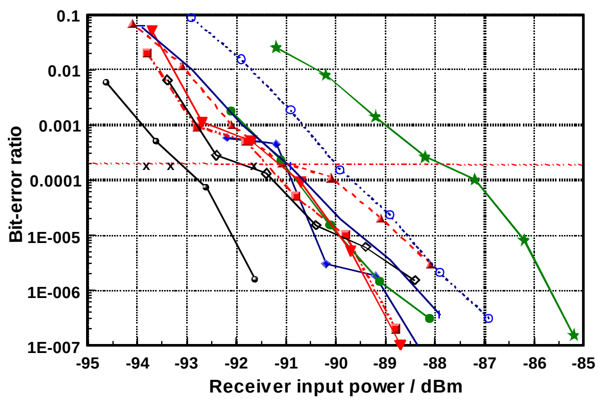

Figure 6: BER versus receiver input power modulation: QPSK, R 1/2, GI ¼, 8k FFT omnidirectional antenna height 1.5 m above ground

Figure 1 to Figure 6 can be used to determine the required receiver input power (abscissa) to achieve a quasi error-free reception, which is indicated in the figures by a horizontal broken line at BER of $2 \cdot 10^{-4}$. This value is of great interest for planning DVB-T services. But for the verification of the DVB system, the most important parameter is actually the required *C/N* value in comparison to the theoretical *C/N* values given in the DVB-T specification.

In the real transmission channel *C/N* can be determined based on of the equivalent noise figure of the receiver and the actual signal power received. The receiver noise figure in these tests was about 8 dB corresponding to a noise floor of –97 dBm with an accuracy of about ±1 dB (receivers may have noise figures as low as 5 dB). Based on this figure the actual *C/N* value can be estimated at each reception location. For comparison, the theoretical *C/N* values for the three types of transmission channel are indicated with a cross on the horizontal broken line in the figures (from left to right: Gauss, Rice and Rayleigh channel). The *C/N* evaluation, which should be considered as indicative only, allows nevertheless the conclusion that the implementation margin of the receiver in the field is rather low: 1.5 – 3 dB in addition to the theoretical value for a Gaussian or Rayleigh channel, respectively. This value was confirmed by measurements of Deutsche Telekom in Berlin.

6.1 Comparison with service prediction

The planning of digital terrestrial services is based largely on computer predictions. Consequently, it is important to determine how well these predictions compare with the coverage obtained by measurements with real DVB-T equipment.

The tests in Munich considered above showed a good accordance with the prediction, but only few results of measurements were available for a statistical analysis.

More extensive surveys have been conducted by the BBC in both the London area and in the North East of England to measure the percentage of coverage within a number of 1 km by 1 km squares. Only squares with a marginal level of coverage were considered. They were selected with respect to initial results of a coverage prediction using a computer propagation model. Measurements were made at 10 to 15 randomly chosen test points within each square to determine the percentage of these points at which reception was achieved. These results were compared with the predictions made using the methods adopted during the UK planning study. In 80% of the squares the coverage was better than predicted. Most of the areas, where the measured coverage was not as good as predicted, were known to suffer poor analogue reception. This was generally due to tall buildings which were not considered by the propagation model. Other areas which were predicted to be only marginally served were in fact completely covered. In conclusion, the measured coverage was found to be rather better than predicted.

6.2 Mobile reception of DVB-T

Even though the DVB-T standard was not developed for mobile reception there were very encouraging results of initial field trials performed by Deutsche Telekom in Cologne. The tests in UHF channel 40 (626 MHz) showed, especially if the QPSK mode, R=1/2, 2K-FFT, is chosen, no reception loss due to the movement of the receiver. The tested speed was 170 km/h. It may have been advantageous reception conditions, because any failure of the system did occur at locations where the field strength was not sufficient at all. Tests with 16-QAM at a speed of 60 km/h were successful, too, but further investigation are required.

Especially, in the follow-on project of VALIDATE, which is named MOTIVATE, more tests (not only 2K-FFT) will be performed and the receiver and the channel estimation will be optimised for mobile reception of DVB-T.

7 DEMONSTRATIONS

Most of the VALIDATE trials conducted were combined with various professional and public demonstrations of the performance of DVB-T.

Since May 1996 the BBC performed public DVB-T demonstrations in the London area and the North of England using a fully DVB-T compliant 2K-FFT modem developed by them. This modem was also used to demonstrate DVB-T at IBC'96 and at DBC'96 in the Netherlands. The first public demonstration using the 8K-FFT modem developed in the European Race project dTTb (digital Terrestrial Television broadcasting) took place in Munich in January 1997.

Further demonstrations in 1997 with either 2K-FFT or 8K-FFT modems were performed or supported by VALIDATE partners, respectively, in Berlin, Cologne and Munich (D), Madrid (E), ITVS'97 Montreux (CH), Sutton Coldfield (UK) and at IBC'97 Amsterdam (NL).

At the Internationale Funkausstellung Berlin (IFA'97) three UHF channels were used to transmit a total of 8 TV programmes and one DVB data service. Stationary reception from two different transmitters was demonstrated by Deutsche Telekom. Portable reception of one programme was demonstrated by the IRT as well as mobile reception in a bus and a car. The high reception quality of DVB-T when using a whip antenna smaller than a pencil in a very hostile environment, especially in comparison to analogue TV reception, was highly convincing.

8 CONCLUSION

The VALIDATE project has verified the very complex European specification for digital terrestrial broadcasting DVB-T. A notable amount of field trials have been conducted so far and unambiguously proved the results of laboratory tests and computer simulations.

Propagation measurements performed outdoor as well as indoor showed clear benefits of the broadband DVB-T signal. The performance for stationary and portable reception in the field was as good as expected or even better in terms of C/N. Different modulation modes and channel coding rates were tested and the results confirmed predictions from simulation.

The field trials demonstrated the performance of DVB-T, the operation of a SFN, the concept of gap-fillers and the possibility of mobile reception. Under comparable poor receiving conditions the quality of DVB-T was found to be greatly superior to the analogue reception of TV.

9 ACKNOWLEDGEMENTS

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10 VALIDATE PARTNERS

British Broadcasting Corporation (BBC)	UK
Robert Bosch GmbH (Bosch)	D
Centre Commun d'Etudes de Télédiffusion et Télécommunications (CCETT)	F
Deutsche Telekom AG (Telekom)	D
Deutsche Thomson Brandt GmbH (DTB)	D

Institut für Rundfunktechnik GmbH (IRT)	D
Innovations Télécommunications Image Son (ITIS)	F
Mier Comunicaciones (MIER)	E
Radio Telefís Éireann (RTE)	IRL
Rai Radiotelevisione Italiana (RAI)	I
Retevisión	E
Rohde & Schwarz GmbH & Co KG (R&S)	D
Télédiffusion de France (TDF)	F
Tele Danmark AS	DK
Televés SA	E
Teracom Svensk Rundradion AB (Teracom)	S
Thomcast	F
European Broadcasting Union (EBU)	
Nederlandsche Omroep Zendermaatschappij (NOZEMA)	NL

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Proceedings of NAB '98

RESULTS OF TESTS WITH DOMESTIC RECEIVER IC'S FOR DVB-T

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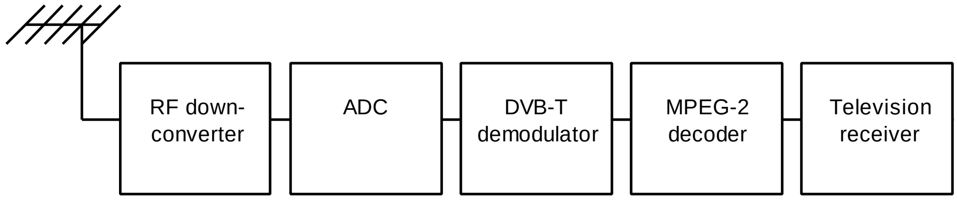
ABSTRACT

Digital terrestrial television services using the DVB-T standard will be launched later this year in the UK, followed by Sweden and perhaps other countries soon afterwards. Reception of these services will make use of domestic set-top boxes and integrated receivers using DVB-T demodulator ICs (integrated circuits). The first of these ICs are now becoming available, and it is important that their performance is carefully checked, to confirm that the behaviour is close to expectations. This in turn will confirm that the planned DVB-T services will deliver the predicted coverage.

At the time of writing this paper, BBC R&D is testing the first two receiver ICs which have become available. The results of these tests show that working silicon is available and that the ICs generally provide performance in excess of that assumed by the frequency planners. This will allow set-top box and receiver manufacturers to prepare their production for the launch of operational digital terrestrial television services later this year.



INTRODUCTION

BBC R&D reported at IBC '97 results of tests on the BBC's prototype DVB-T digital terrestrial television modem – see Nokes et al (1). During 1998, several DVB-T demodulator ICs are becoming available. These will be used in the first DVB-T set-top boxes and television receivers that will be sold for the launch of operational DVB-T services in the UK later this year, and in Sweden soon afterwards.

It is important that the performance of these first ICs is carefully checked, to confirm that the performance is close to expectations. This in turn will confirm that the planned DVB-T services will deliver the predicted coverage. At the time of writing, BBC R&D is testing the first two receiver ICs which have become available. The results of these tests will be reported in this paper. In accordance with IBC rules, the two chip-sets are identified as "IC A" and "IC B". As well as comparing the results against each other, they are compared with the results achieved with the BBC prototype demodulator, and with the assumptions made for service planning purposes – see Maddocks et al (2). It should be remembered that both the chip-sets tested are first generation chip-sets, and so the results may change for later generations.

Scope of measurements

Basic functionality of the ICs was demonstrated during interoperability tests which have been described by Oliphant and Christ (3).

In the tests described in this paper, the following quantitative measurements have been made:

- Performance with Gaussian noise
- Performance with co-channel PAL
- Multipath performance
    - Channel typical for set-top reception
    - Single echo with Doppler
- Backstop noise performance

(The tests on backstop noise performance had not been completed at the time of publication of this paper).

More details of the methods of measurement used, and the significance of each test, are given along with the results in the following sections. Unless otherwise stated, the tests used the DVB-T mode which will be used for services in the UK – 2K, 64-QAM, code rate 2/3, guard interval fraction 1/32 (7 µs).

Error! Reference source not found.1 shows a typical DVB-T receiver block diagram. The tests which have been performed have been confined to assessing the performance of the DVB-T demodulator ICs. In principle this means the ICs which process the signal from the output of the RF down-converter, to the MPEG transport stream output. However, the test arrangement for the ICs included an RF down-converter (tuner), which was a prototype domestic type, specifically designed for DVB-T receivers; so the performance recorded is typical of the performance which would be expected in a domestic receiver. The tests with the BBC prototype demodulator were conducted using a professional fixed-tuned down-converter.

The performance of the MPEG decoder ICs or other ICs necessary in a receiver has not been tested.

MEASUREMENT CRITERIA

DVB performance criteria have traditionally always been measured to a point described as Quasi-Error-Free (QEF). This is the point at which errors would occur in the decoded transport stream approximately once per hour. Given that not all errors are visible, and in a multi-programme stream errors may occur in a programme other than the one you are watching, this means a very low visible error rate.

This very low error rate cannot be measured directly. So the QEF point has been defined to be measured before the final error corrector – i.e. after the Viterbi decoder – and QEF is defined as a bit-error ratio of 2×10^{-4}.

An alternative performance criterion has been used in connection with the ATSC system, which defines the threshold of visibility (TOV) of errors in the decoded picture. Exactly how visible these errors are will depend on several factors – the

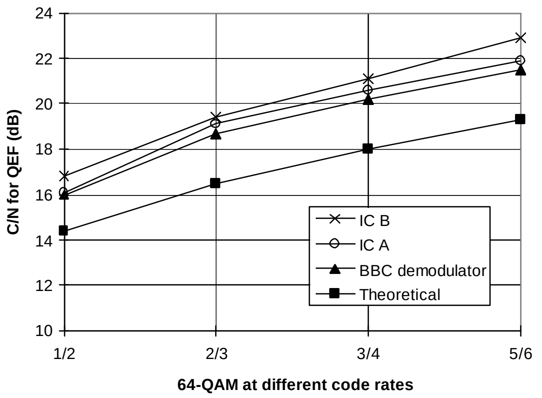


Figure 10 Performance with AWGN for a selection of DVB-T modes

complexity of the source picture material, whether there is any error concealment in the MPEG decoder, and whether the error information is passed between the demodulation stage and the MPEG decoder. TOV is defined as a bit-error ratio of 3×10^{-6}, on the decoded output. This would correspond to a bit-error ratio of about 3×10^{-3} after Viterbi decoding.

Performance measurements could be made for the DVB-T system using the TOV criterion. Clearly the results would be more relaxed for TOV compared with QEF – the exact difference will depend upon the DVB-T mode being used and the nature of the impairment. For example in 64-QAM rate 2/3 it might be 1-2 dB difference for Gaussian noise, but about 4dB for co-channel interference.

Since service planners must define coverage areas where the system is "still just working", QEF has been used as the performance criterion for all the tests reported here.

RESULTS

The results of the tests are presented and discussed in the following sections:

Additive White Gaussian Noise (AWGN)

This is the most fundamental test of the system. It confirms that the system will be able to operate with a high level of noise at the input to the demodulator. The test is conducted at a high input level, and artificially generated noise is added. This eases the problems of measurement and comparison between receivers, because it eliminates variations due to receiver noise figure. Also, it eliminates other effects which can occur with low signal levels such as self-interference – these effects tend to be more problems of the down-converter than the demodulator ICs (and would be tested with an input sensitivity test).

The test has been conducted for a few of the basic modes of the DVB-T system, and the results are shown in Figure 10. The curve for the theoretical values from the DVB-T specification (4) is also shown for comparison. Note that the theoretical curve does not include any allowance for the effect of the channel equaliser. This allowance could be negligible for an equaliser designed to have a slow temporal response. However, most demodulator designers prefer to opt for an equaliser which can track dynamically changing channels, at the expense of about 2 dB in the Gaussian noise performance. This 2 dB difference can be seen between the theoretical curves and the measured results.

The figure assumed for frequency planning in the UK was 20 dB (for code rate 2/3) – both ICs exceed this figure.

Co-channel PAL interference

This is an important test, particularly in the context of an interleaved frequency plan, such as will be used in the UK when services are launched later this year. In this plan the new services will be broadcast alongside the existing analogue services, and in some cases, digital coverage will be limited by co-channel PAL signals from nearby transmitters. It is therefore important to measure the exact amount of co-channel PAL which can be tolerated by the receiver. This is largely a function of the demodulator IC, whereas adjacent channel protection is mainly affected by the performance of the tuner.

The results are presented as a co-channel protection ratio, when the wanted signal is degraded to QEF by the interferer only. The protection ratio is the power of the wanted (digital) signal minus the power of the interfering (analogue) signal, assuming decibel (dB) values for the power of the signals. So a negative result implies that the interfering signal is stronger than the wanted signal – a more negative value implies a system more able to withstand interference. The digital signal is measured as RMS power, but the analogue signal is measured for peak-sync-power (the RMS power of the analogue signal during the line synchronisation pulses).

Co-channel protection ratios generally show a cyclic variation – see for example Figure 4 of Nokes et al (1). Typical values for the results of the measurements are given inTable , along with the figure assumed for frequency planning purposes in the UK.

From these results it can be seen that IC A performs about 4 dB better than the assumption made for frequency planning and IC B about 4 dB worse than the planning assumption. The result for the BBC demodulator was about 3dB better than the assumption.

Device	Protection ratio
IC A	0 dB
IC B	8 dB
BBC demodulator	1 dB
Frequency planning assumption	4 dB

Table 1 - Protection ratios for co-channel PAL interference

Multipath performance

Two types of multipath performance measurement have been carried out on the chip-sets – the first with conditions representative of static portable reception, and the second representative of mobile reception conditions. Neither of these conditions was specified for frequency planning purposes, although an assumption was made that 3 dB higher carrier to noise ratio would be required for roof-top reception under multipath conditions, than under Gaussian conditions. However, the exact multipath conditions were not specified. Both of the following tests are more demanding tests than this requirement for roof-top reception.

Portable set-top reception test

This test makes use of a "portable" channel with six paths – the amplitudes and delays of the paths are the six strongest paths from Annex B of the ETSI specification (4), and are given inTable 2.

Delay (µs)	Relative Attenuation (dB)
0	2.8
0.05	0
0.4	3.8
1.45	0.1
2.3	2.6
2.8	1.3

Table 2 Channel profile use to test portable reception

The results given in Table 3 are presented as loss of noise margin – i.e. the difference in carrier-to-noise (C/N) ratio required for QEF with and without the "portable" channel. It should be noted that in the case when the "portable" channel is applied, the wanted carrier power (C) is increased by 7.4 dB by the addition of the six paths.

Device	Loss of noise margin
IC A	4.7 dB
IC B	9.2 dB
BBC demodulator	10.5 dB

Table 3 - Loss of noise margin for "portable" channel

Device	Maximum frequency shift between paths
IC A	199 Hz
IC B	155 Hz
BBC demodulator	203 Hz

Table 4 Maximum frequency shift between signal paths for QEF, with an echo of 3 dB attenuation at 6.3 µs.

Single echo with Doppler

In this test, a single echo was added to the main signal. The echo was half the power of the main signal, and was shifted in frequency relative to the main path. The maximum shift in frequency of the echo which can be tolerated by the system with no added noise has been recorded. It should be noted that the receiver's AFC may make this equivalent to a shift of half the amount for each signal path. For example, if the maximum recorded frequency shift for the echo path had been 100 Hz, this is equivalent to a shift of-50 Hz for the main path and +50 Hz for the echo. This is the situation which would occur for a mobile receiver in a single frequency network, between two transmitters, with the receiver travelling towards one transmitter at a speed of just over 100 km/hr (for a transmission frequency of 500 MHz).

The results are given in**Error! Reference source not found.**. The test shows that the ICs are able to operate successfully in dynamic channels, despite that fact that it is not thought that either of the ICs has been optimised for mobile reception. Also, the DVB-T mode which will be used in the UK would not be a natural choice for either mobile reception or for single frequency networks.

Backstop noise performance

BBC R&D has developed a simplified noise model for the DVB-T transmission chain. This is shown in Figure . It consists of two stages – the first stage represents degradations which are dependent upon carrier level, such as the receiver noise figure. The stage has a gain G_1 and an equivalent noise figure F_1. The gain G_1 is inversely proportional to the input power, C, to model ideal automatic gain control. So the output to the second stage is at a constant level.

The noise in the second stage of the model represents impairments that are independent of carrier level. Examples of this would be phase noise, quantising noise, or numerical processing noise inside the demodulator ICs. Whereas the effects of the first stage noise can be overcome by increasing the signal level, the second stage noise is present at any signal level, and so is referred to as backstop noise, or noise floor.

The effects of this noise model are shown in Figure 4, which shows the C/N ratio presented to the demodulator as a function of the input signal level. It can be seen that as the input signal level is raised, so a limiting value of C/N is achieved, corresponding to the backstop noise level.

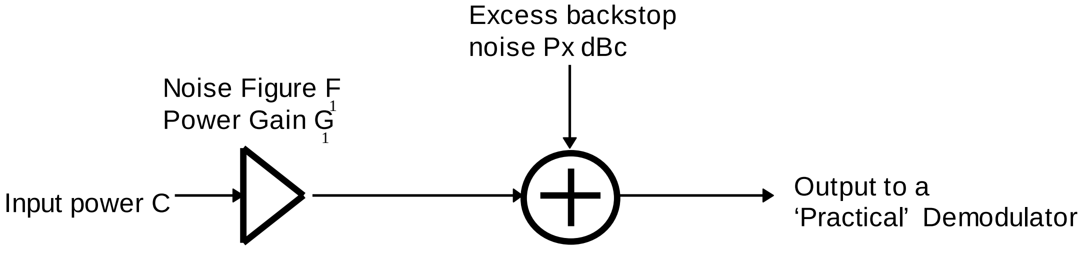


Figure 3 Simplified noise model

Values for backstop noise (noise floor) are given in units of dBc, which means dB relative to the carrier power. Therefore a noise floor of –28dBc is equivalent to a system with a C/N ratio of 28dB.

The reason for being concerned about backstop noise, is that a high level of backstop noise in the overall transmission system will make reception either very difficult or impossible under harsh receiving conditions. For example, we would normally expect a C/N requirement of about 20 dB for QEF at most reception sites. However, if a particularly difficult transmission channel requires a C/N ratio of 25 dB, and the backstop noise within the system is -25 dBc, reception will be impossible for any input signal level.

The noise components of the first stage of the model are generally associated with the down-

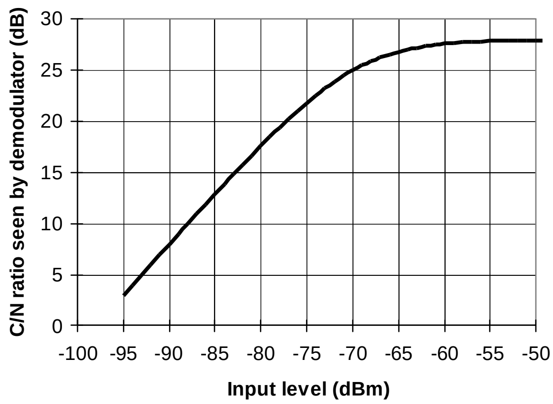


Figure 11 Theoretical C/N ratio seen by a demodulator for a system with a noise figure of 7 dB and a backstop noise of -28 dBc.

converter, and can be quantified quite easily. However the backstop noise of the system is difficult to measure. Most of the significant components contributing to the backstop noise are likely to be in the tuner (phase noise) and ADC (quantising noise). However, it is important to check that there is no significant contribution to backstop noise from the demodulator itself.

Two techniques have been developed for measuring the backstop noise within a demodulator. Both methods require that the operating conditions for the demodulator are made more difficult than for a Gaussian channel. Noise performance is then compared with a system which is known to have a very low backstop noise, in this case the BBC demodulator. This allows the excess backstop noise of the system under test to be estimated. The two methods of making the operating conditions more difficult are:

a) to use results from the most demanding of the Gaussian noise cases (i.e. 64-QAM at the highest code rates);

b) to deliberately transmit signals with errors – see Nokes (5).

Both these techniques have been used in the past to test systems with relatively high backstop noise and have been shown to be useful techniques.

These tests could not be completed in time for the publication of this paper. However, Figure 5 shows an example curve for a system with a backstop noise of approximately –30 dBc. Some allowance must be made for backstop noise within the transmitter. Therefore, it is thought that a receiver with an overall noise floor of about –33dBc, including the effects of the tuner and ADC, will provide adequate performance in difficult channels. Since most of this requirement is likely to be used up by the tuner/ADC, it is important that the contribution from the demodulator ICs should be significantly less than this.

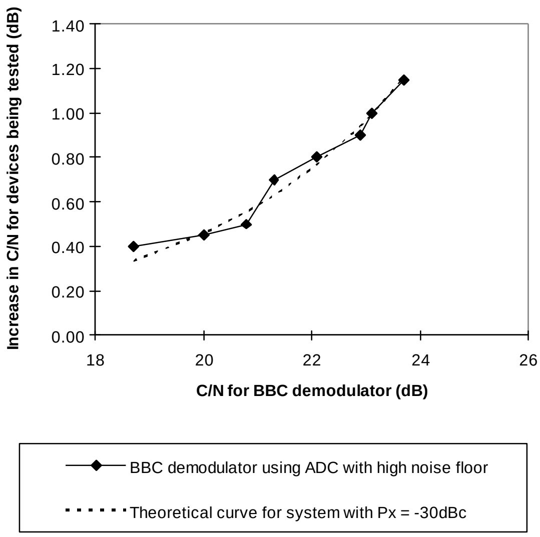


Figure 5 Increase in required C/N under difficult operating conditions

CONCLUSIONS

Some of the most important performance parameters of the first demodulator ICs for DVBT have been measured and reported. Where possible, these parameters have been compared with the performance assumed in the UK frequency planning project.

For most of the parameters tested, the ICs provide performance in excess of that assumed by the frequency planners. The only area of slight concern is the protection ratio from co-channel PAL.

Overall both ICs demonstrate that working silicon is available, which will allow set top box and receiver manufacturers to prepare their production for the launch of operational digital terrestrial television services in the UK, Sweden.

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MOBILE RECEPTION OF 2K AND 8K DVB-T SIGNALS

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ABSTRACT

The main problems associated with mobile DVB-T reception are discussed. Fundamental limits for Doppler and delay in mobile DVB-T reception are given. The concept of FFT leakage is introduced and an algorithm for its reduction by receiver processing is presented, together with simulation results. Laboratory measurement results, performed with the Teracom DVB-T demodulator, showing Doppler performance close to the fundamental limits are given. Network planning and receiver synchronisation aspects are discussed as well as a comparison between 2K and 8K.

INTRODUCTION

Digital terrestrial TV (DTTV) using the DVB-T standard [1] is gaining more and more interest in Europe and other parts of the world. In the UK and in Sweden there are concrete plans for a commercial introduction of DTTV services in late 1998, and other countries will follow soon after this.

Within the EU funded ACTS project VALIDATE 18 different organisations have together, since Nov. 1995, performed extensive work for the verification and testing of the DVB-T standard in the context of fixed roof-top and portable reception. This work has provided a solid technical foundation upon which networks and receivers are now designed for DTTV services.

During the VALIDATE field tests it was found that also mobile reception of DVB-T signals at very high speeds is in fact possible. This has triggered a wide interest in mobile DVB-T services and a new ACTS project - MOTIVATE - has been created to investigate in detail the behaviour of DVB-T in mobile channels. This paper addresses some of the main aspects of mobile DVB-T reception.

THE DVB-T STANDARD

DVB-T is a flexible standard using COFDM modulation where the terrestrial network operator can choose any combination of

- No. of carriers: 6817 (8K mode) or 1705 (2K mode)
- Guard interval Δ: $T_U/4$, $T_U/8$, $T_U/16$ or $T_U/32$, where T_U is the inverse of the carrier spacing (T_U = 896 µs in 8K and 224 µs in 2K)
- Constellation: 64-QAM, 16-QAM or QPSK
- Convolutional code rate R: 1/2, 2/3, 3/4, 5/6 or 7/8

which results in 120 non-hierarchical modes[1], suitable for a wide range of network structures and receiving conditions, and with bit rates ranging from 4.98 Mbit/s to 31.67 Mbit/s.

In addition to the coded data the DVB-T signal contains reference information, defined by the standard, which can be used by the receiver for e.g. synchronisation and channel estimation. In figure 1 below the pattern of the so called scattered pilots is shown.

PROBLEMS TO BE OVERCOME IN MOBILE DVB-T RECEPTION

To achieve successful mobile DVB-T reception there are a number of problems to be overcome:

1. The receiver channel estimation has to track the channel variations in time and frequency.
2. The receiver has to withstand the noise-like distortion called FFT leakage, created by the time variant channel during the time T_U of a symbol.
3. The received field strength, and consequent C/N, has to be sufficiently high at a sufficiently

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[1] There are also 1200 hierarchical modes in the standard

high number of locations to permit a reliable mobile service.

4. The receiver has to synchronise correctly in time and frequency in the mobile channel.

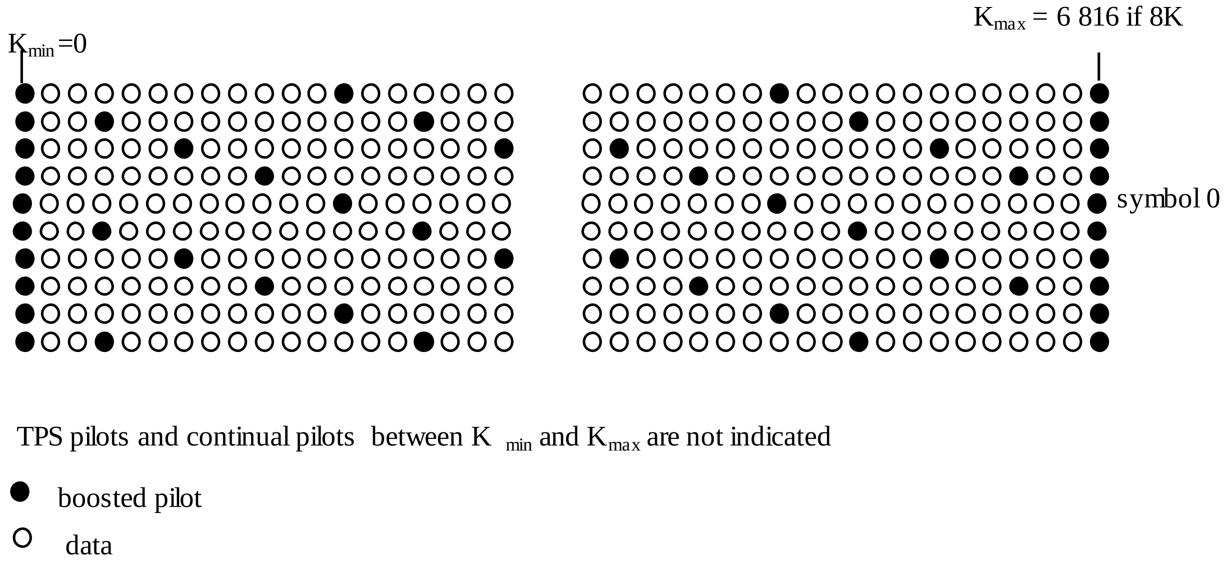

Fig. 1 Frame structure of DVB-T

Tracking of channel variations in time and frequency

As can be seen in fig.1 there are scattered pilots (hereafter only called pilots) on every symbol but only on every third carrier. In a given symbol there are pilots every 12th carrier. Since the value of each transmitted pilot is known by the receiver it can divide the received value with the transmitted value and thereby obtain an estimate, H_k, of the channel for that pilot cell[2]. However, equalisation of the data cells requires a corresponding channel estimate for each of them. These can be obtained by interpolation in time and frequency between the pilots.

One can view the pilot pattern as a 2-dimensional sampling of the channel. The 2-D spectrum is caused by the Doppler and delay spread of the channel. Since these are independent we can assume a rectangular spectrum, which makes separable time and frequency interpolation possible. As long as the echo delays of the channel are less than $T_U/3$ (299 µs in 8K) and the total bandwidth of the Doppler spectrum is less than $1/[4(T_U+\Delta)]$ (between +/-112 Hz and +/-135 Hz in 8K) there will be no aliasing due to the pilot sampling of the channel. The 2-dimensional bandwidth (including spectral repetitions) that can be spanned by the pilots is shown in fig 2 below.

The purpose of the interpolation filters is of course to calculate an interpolated pilot value for every data cell. In the spectrum domain this is equivalent to the removal of all spectral repetitions.

There is also an alternative possibility: if the echo delays are less than $T_U/12$ a Doppler spectrum as wide as $1/(T_U+\Delta)$ (between +/-446 and +/-541 Hz in 8K) can be spanned by the pilots. For a sacrifice of a factor 4 in maximum echo length a factor 4 in maximum Doppler frequency can therefore be gained. In this case time interpolation is not necessary; only interpolation within a symbol is required. In fig 2 this would correspond to a 90 degree rotation of the 2-dimensional baseband, with a correspondent rotation of all spectral repetitions. It is easy to see that there will not be any aliasing in this case either.

A reasonable question is whether there exists any intermediate step, where e.g. a factor 2 in

[2] A cell is defined to be one carrier during one symbol

maximum echo length could be sacrificed for a factor 2 gain in maximum Doppler frequency, or more generally, if there exists any other possible interpolation strategy (perhaps with a non-separable 2D filter) which is "better" than the two extreme cases indicated above.

The answer to both questions is unfortunately no, since any such attempt would lead to an overlap (aliasing) of the wanted bandwidth and its spectral repetitions, with a consequent wrong channel estimate.

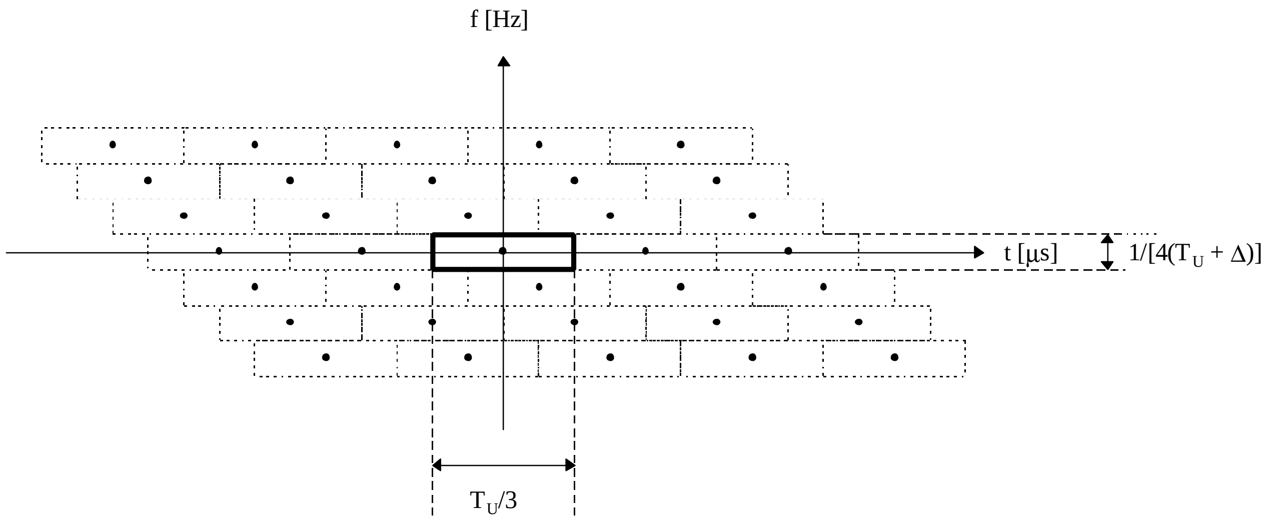

Fig. 2 2D-spectral representation of the channel

FFT leakage

If we regard an OFDM signal on a frequency selective, but time invariant, channel over the time interval T_U each received carrier is a pure sinewave with a certain amplitude and phase. Since these sinewaves are spaced $1/T_U$ along the frequency axis they are orthogonal over the time interval T_U independently of the amplitude and phase values. This orthogonality makes it possible to demodulate a specific carrier without it being interfered by the neighbouring carriers. In a time varying channel however, the carriers are no longer pure sine waves, so the orthogonality requirement is no longer fulfilled. A demodulated carrier will now be partly affected by (in principle) all the other carriers in a symbol (intrasymbol intercarrier interference) so that the demodulated amplitude and phase values are somewhat distorted. We call this effect FFT leakage. Since the amplitude and phase of the error vector is dependent upon the random amplitude and phase values of a large number of neighbouring carriers, the error vector itself has a random amplitude and phase.

If we call the transmitted signal vectors z_k Geslin [2] has shown that the received signal vectors r_k are given by

$$r_k = A_{kk}.z_k + \sum_{l \neq k} A_{kl}.z_l$$

(1)

where, for first and second order channel variations respectively,

$$A_{kk} = H_k \ and A_{kl} = \frac{\Delta H_l}{j2p(l-k)}, l \neq k$$

$$A_{kk} = H_k + \frac{\Delta^2 H_k}{24} \ and A_{kl} = \frac{\Delta H_l}{j2p(l-k)} + \frac{\Delta^2 H_l}{4p^2(l-k)^2}, l \neq k \quad (2)(3)$$

Equation (1) shows that (for first order channel variations) a received signal vector can be seen as the sum of two terms: a conventional term, which is what we would get without FFT leakage, and an error term, which is dependent both on the values z_l of the surrounding carriers and the change ΔH_l of these carriers over the symbol.

If the matrix A_{kl} is exactly known the values of z_k can in principle be found by solving the linear equation system R = A Z, where R and Z are vectors containing the received and transmitted signal vectors respectively. Both these prerequisites are of course unrealistic; the complete linear equation system is far too complex to be solved in real time and A_{kl} is not exactly known, because the received pilots, with which we calculate A_{kl}, are distorted by FFT leakage and normally also thermal noise. Instead of having to solve the linear equation system a new iterative algorithm for FFT leakage equalisation has been studied within Teracom. The iterative procedure is given below.

$$\begin{cases} \hat{z}_{k,0} = r_k / \hat{A}_{kk} \\ \hat{z}_{k,i+1} = \hat{z}_{k,0} - \sum_{l \neq k} \hat{A}_{kl} . \hat{z}_{l,i} / \hat{A}_{kk} \end{cases}$$

(4)(5)

First a conventional estimate of z_k is calculated. Then these estimated values are used, together with an estimate of A_{kl} to calculate an estimate of the total error term for each z_k, which is then subtracted from the originally estimated z_k values. The result of these operations is normally z_k values with less FFT leakage. These improved z_k values can then be input to a new iteration. With ideal (in the sense: free from FFT leakage and noise) values of H_k as a starting point the algorithm converges fast and gives a very large reduction of FFT leakage. However, when real, noisy, values are used only a small improvement is obtained. If somehow the noise on the pilots could be removed we would then also be in a position to remove the FFT leakage.

One possibility is to use a channel estimation interpolation filter with a much lower bandwidth in time and/or frequency than the maximum bandwidth.

A drawback with this approach is of course that such narrowband filtering will in itself limit the class of channels that can be tracked.

An alternative approach that has been investigated (with and without narrowband channel estimation filtering) is to let also the pilots be part of the iterative process.After one iteration not only the data carriers are a little bit improved, but also the pilots are a little bit better. These improved pilots can then be used for a new estimation of A_{kl}, and a new iteration can be performed.

This algorithm has been studied by Geslin [2]. The result is that very significant gains in maximum Doppler frequency can be obtained already with first order channel variations. Only small additional improvements were found with second order variations. Different variants of the algorithm has been evaluated for different DVB-T modes over different MFN and SFN channels.

Examples of performance with and without the algorithm is given in Table 1 below.

8K DVB-T mode	Bit rate [Mbit/s]	Channel	$f_{d,max}$ [Hz] without eq. of FFT leakage	$f_{d,max}$ [Hz] with eq. of FFT leakage	v_{max} [km/h] at 666 MHz without eq. of FFT leakage	v_{max} [[km/h] at 666 MHz with eq. of FFT leakage
16-QAM R=1/2 Δ/TU=1/4	9.95	Typical Urban	81.5	95.5	132	155
16-QAM R=1/2 Δ/TU=1/4	9.95	SFN (0,100,210)	97.5	111.5	158	181
16-QAM R=1/2 Δ/TU=1/8	11.06	SFN (0,50,100)	100.4	113.8	163	185
64-QAM R=1/2 Δ/TU=1/4	14.93	Typical Urban	49.5	70.1	80	114
64-QAM R=1/2 Δ/TU=1/4	14.93	SFN (0,100,210)	55.5	90.0	90	147
64-QAM R=2/3 Δ/TU=1/8	22.12	Rural Area	22.0	32.6	36	53
64-QAM R=2/3 Δ/TU=1/8	22.12	Hilly Terrain	24.3	39.8	39	64
64-QAM R=2/3 Δ/TU=1/8	22.12	Typical Urban	26.6	46.3	43	75
64-QAM R=2/3 Δ/TU=1/4	19.91	SFN (0,100,210)	31.2	62.9	51	102

Table 1 - Simulated performance gain by equalisation of FFT leakage

Performance has been evaluated for a BER of 2×10^{-4} after Viterbi decoding. For a stationary channel this corresponds to a Quasi Error Free (QEF) MPEG-2 TS after Reed Solomon (RS) decoding. This correspondence between BER after Viterbi and after RS no longer holds for DVB-T in a mobile channel. Another quality criterion is therefore needed. Failing this, the traditional criterion has however been used in the simulations. The channel models used are directly taken from COST 207 [3], except the SFN model which is derived from COST 207 by combining three Typical Urban (TU) models (each having independent Rayleigh fading), where the second and third models are delayed x and y relative to the first model. "SFN (0,y,z)" means a channel which consists of a sum of all paths in three COST 207 TU models, where the paths in the second and third model has been delayed y and z µs, in relation to the standard model. The speeds are given for the middle of the UHF band (ch.45 - 666 MHz).

As can be seen the gain obtained by the algorithm is higher in SFN than in MFN channels. One explanation to this is that the additional diversity introduced by the SFN makes the field strength variations from symbol to symbol more even, which is not only good from a network planning point of view, but also from an FFT leakage point of view, since the FFT leakage varies from symbol to symbol and is worst in connection with deep fades, since the change ΔH of the channel is then large.

Since deep fades occur more rarely in SFN this explains the better performance. For the same average BER after Viterbi decoding the bit errors in SFN tend to be more evenly distributed than in MFN, where they tend to come in very long bursts. After RS decoding this leads naturally to a lower BER in SFN, since the depth of the outer interleaving is rather limited.

For the soft decision decoding the quality of each received bit is traditionally weighted with $|H|^2$. This is however only optimum when the interfering power (such as e.g. Gaussian noise) is flat. This condition no longer holds in mobile channels, where the FFT-leakage interference will have a power distribution in frequency that will vary from symbol to symbol. The simulations have been done without $|H|^2$ weighting. The optimum weighting is probably to use the local $|H/I|^2$ where I is the sum of all interferencies including Gaussian noise and FFT leakage. It remains to be seen which improvements can be achieved by this.

Field strength

To have coverage at a certain point the received field strength must be higher than the minimum required field strength value. The field strength is varying from place to place due to two effects: shadow fading (slow fading) and Rayleigh fading (fast fading - the field strength in one position is independent from the field strength $\lambda/2$ away). All mobile systems have to cope with slow fading; the network simply has to be planned for this. The effects of fast fading depend strongly on the system parameters. For a COFDM system with a sufficiently deep time interleaving (in relation to the wavelength and the speed) and strong coding, associated with appropriate soft decision decoding, the fast fading does not play any important role, since what matters is that the *average power* during the interleaving depth is high enough. For DAB (at sufficiently high speeds) this condition holds and the system becomes essentially insensitive (from a field strength point of view) to fast fading. DVB-T on the other hand does not have any time interleaving, so the received field strength must be large enough for every received symbol to avoid bit errors. On the other hand, for sufficiently low speeds, where the time interleaving is non-efficient, the variations in received field strength is lower in DVB-T than in DAB thanks to the five times larger DVB-T bandwidth.

DVB-T network planning must therefore be made for a very high percentage of locations, since any received symbol with insufficient power will lead to a long burst of bit errors in the MPEG-2 TS. This will require that an additional field strength margin be added compared to the case when planning only considers slow fading. It is not yet clear how large this additional margin has to be, although field measurements performed in the summer 1997 by Teracom in Stockholm, Sweden, showed the following standard deviations for the fast fading: urban 2.2 dB, suburban 2.3 dB, open field 1.7 dB and forest 2.6 dB.

The required margin may depend on several factors such as topography, network diversity (SFN), receiver diversity and type of service (e.g. TV or data). In an SFN the received signal strength is generally increased and signal strength variations decreased, both with regard to slow fading and fast fading. With receiver space diversity using two receiving antennas, separated by a few wavelengths, and (partly) separate DVB-T front-ends, a significant diversity gain can be expected. Both network and receiver diversity will be studied in ACTS/MOTIVATE.

Receiver synchronisation

For synchronisation the receiver may use the guard interval for course timing, the scattered pilots for fine timing and the continual pilots for frequency synchronisation. With these approaches the mobile channel does not seem to be any major obstacle for the synchronisation. When the impulse response and the Doppler spectrum of the channel is quasi stationary, or changing only gradually, the receiver will normally not have any problem of maintaining synchronisation. Problems might however arise when there are sudden changes. These changes will either be permanent, in which case it would be optimum to react as quickly as possible, or they might be only temporary, so that the original situation is re-established soon again (in which case it would have been best not to change anything). Since the receiver does not know what the future will be there is a trade off between fast and slow receiver adaptation to a changing environment. In existing receivers a change of timing is normally performed via a change in sampling frequency. This change must however not be too large, since sampling frequency errors lead to some distortion of the signal, with a consequent penalty in required C/N. In principle a change of timing could be made instantly (at the border between any two symbols). Since a change of timing is equivalent to a phase shift, which is proportional to the carrier number, such an instant shift in timing should only be done if the phases of all previously received symbols, which are still in the memory, are corrected correspondingly.

LABORATORY MEASUREMENTS

Within the ACTS/VALIDATE project Teracom has developed a DVB-T demodulator[3] optimised for mobile reception. The demodulator uses channel estimation interpolation filters which are close to the theoretical limits (e.g. 111 taps for the time filter). No equalisation of FFT leakage is however performed. A first series of measurements of Doppler performance has been made using this demodulator. The measurements focused on the DVB-T mode {8K, QPSK, R=1/2, Δ/T_U=1/8} resulting in a bit rate of 5.53 Mbit/s and a guard interval of 112µs. For this mode it was believed that the limiting factor would be the pilot density and not the FFT leakage. From fig. 2 it is clear that the fundamental Doppler limit imposed by the pilot density is +/-124 Hz for all 8K modes with Δ=112 µs (assuming time interpolation is performed, which is necessary if echoes longer than T_U/12 are present).

The demodulator was tested over a two path 0 dB echo channel with different delays and frequency shifts introduced. For both a short (1.3 µs) and a long (100 µs) 0 dB echo QEF decoding was possible at a frequency shift of 238 Hz between the two paths, corresponding to a Doppler spectrum of +/- 119 Hz and a speed in the centre of the UHF band (666 MHz) of 193 km/h.

DISCUSSION

Initial studies and tests suggest that the principal obstacles for mobile DVB-T reception can be removed, although sometimes with some consequences in receiver complexity. From the Doppler performance point of view the 2K mode has an obvious advantage; in principle 2K can cope with 4 times higher Doppler frequencies and speeds than 8K. On the other hand, from a network planning point of view the use of SFNs might make coverage planning easier and reduce network costs, since SFN can provide significant network gains both in terms of the slow and fast fading. The question whether 2K or 8K is best for mobile reception is therefore not so easy to answer.

CONCLUSIONS

The fundamental theoretical limits for mobile DVB-T reception are given by the 2-dimesional pilot sampling of the channel. When FFT leakage is not the limiting factor (which at least seems to be the case for QPSK R=1/2) tests with a real DVB-T demodulator show that performance can come close to these limits. Theoretical studies and simulations also show that the FFT leakage can be significantly reduced with receiver processing, which in principle opens the possibility for 8K mobile reception also at higher order modulation.

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[3] The demodulator has been developed in co-operation with SINTEF Telecom and Informatics, Trondheim, Norway

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VALIDATE & MOTIVATE: COLLABORATIVE R&D TO SPEED UP THE LAUNCH OF DIGITAL TERRESTRIAL TV

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ABSTRACT

The VALIDATE project has verified the performance of the DVB-T specification in the laboratory and in field trials. Its successful collaboration has advanced DVB-T technology to the point where services are ready to start. Recent achievements include a multidimensional interworking demonstration, a transmitter specification, single-frequency network synchronisation and gap-filler transmitters (on-channel repeaters). Trials have shown that mobile reception of DVB-T is possible with bitrates up to 15 Mbit/s, offering a range of attractive new services. A new project, MOTIVATE, will develop mobile reception of DVB-T.

INTRODUCTION

The VALIDATE project started work in November 1995 with the aim of verifying the DVB-T specification and laying the foundations for the launch of digital terrestrial TV services. These aims have been achieved and VALIDATE completed its work in June 1998.

Mobile reception was not a main aim of the DVB-T specification. However, measurements by Deutsche Telekom AG within the VALIDATE project showed that mobile television and multimedia services are possible using some of the more rugged modes of the Specification.

Most of the VALIDATE participants were keen to extend their collaboration to investigate this new possibility. Deutsche Telekom AG took the lead in forming this new project, MOTIVATE, which started work in May 1998, just before the end of VALIDATE.

This paper reviews the work of VALIDATE, highlighting progress in the final year, and describes some of the work that will be done by MOTIVATE – starting by suggesting some possible applications of mobile DVB-T.

VALIDATE: PREPARING FOR LAUNCH OF SERVICES

Introduction

The VALIDATE project (TABLE 1) formed a Europe-wide 'virtual laboratory' to test the DVB-T system and speed up its acceptance. Members agreed the testing needed and the procedures to

TABLE 3 – Partners in VALIDATE and MOTIVATE

V*M	BBC	UK	**V M**	NOZEMA	NL
V M	Robert Bosch	D	**V**	Radio Telefís Éireann	IRL
V M	CCETT	F	**V M**	RAI	I
V M*	Deutsche Telekom Berkom	D	**V M**	Retevisión	E
V	Deutsche Thomson Brandt	D	**V M**	Rohde & Schwarz	D
V M	EBU		**V M**	TDF	F
V M	IRT	D	**V**	Tele Danmark	DK
V M	ITIS	F	**V M**	Televés	E
V M	Mier Comunicaciones	E	**V M**	Teracom	S
M	Nokia	SF	**V M**	Thomcast	F

V - VALIDATE partner ***** - Coordinator **M** - MOTIVATE partner ***** - Coordinator be followed; this allowed the work to be shared out and ensured that results of tests by different Partners could be compared within the Project and presented together to the standards authorities.

The first task of the VALIDATE project was to verify the DVB-T specification. This verification required three elements:

- checking that the specification was clear and unambiguous by demonstrating interworking between simulations and then between real hardware produced by separate laboratories,
- checking that the system performed as expected in the repeatable conditions of the laboratory,
- checking that it met broadcasters' expectations in field trials.

This vital task was completed by the end of 1996, with the result that the DVB-T specification was rapidly approved as an ETSI standard. The work was described by Nokes *et al*. (1). Since then further field trials of different network configurations have been carried out in many European countries: a compendium of the results has been given by Weck (2). These field trials have shown not only that the DVB-T specification meets broadcasters' current expectations, but have opened the possibility of mobile reception.

The laboratory tests and field trials reported by VALIDATE formed the basis of international agreements on coordination of digital TV transmitters agreed by 32 countries at Chester (UK) in July 1997(3).

VALIDATE has also carried out a wide range of other work on distribution networks, transmitters, service planning parameters, single frequency networks (SFNs), and gap-fillers both for professional and domestic use. Much of this work has been documented in Implementation Guidelines, prepared for the DVB Project and now published as an ETSI Technical Report (4).

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.

Some recent successes

Interworking tests

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

Sixty-one 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. Remotely synchronised SFN operation (see below) 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.

TRANSMITTER PARAMETERS

Transmitter manufacturers and transmission network operators must agree on the specifications for the performance of transmitters, as must the network operators and the service providers. As this is a new technology, there is no existing basis for such specifications. VALIDATE has therefore drawn up a transmitter performance specification. It suggests the parameters that need to be measured and some realistic values for them as well as defining minimum interface specifications (not all of which are mandatory).

A useful 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 – a 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.

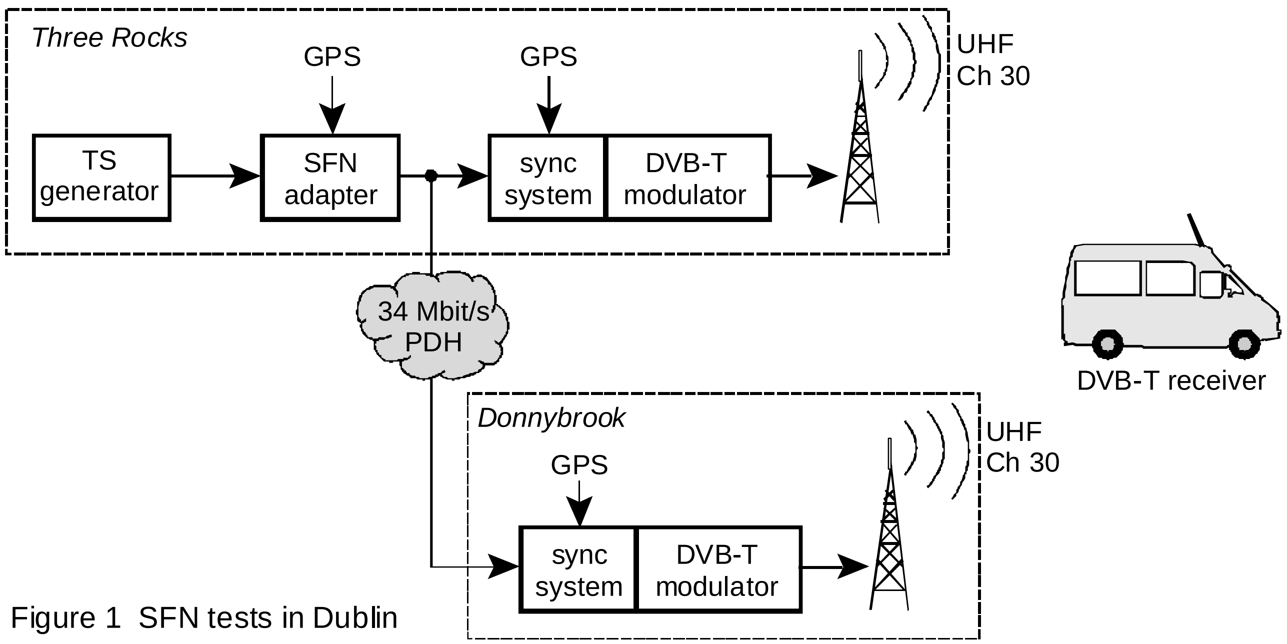

Figure 1 SFN tests in Dublin

SFN Synchronisation

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

All transmitters in an SFN must be synchronised so that their broadcasts are frequency identical and bit identical. VALIDATE partners have led the standardisation of a method of synchronising an SFN by defining a megaframe in the MPEG-2 transport stream using a megaframe identification packet (MIP) (5). The megaframe length has been chosen to contain an integral number of OFDM frames, of Reed-Solomon packets, and of the energy dispersal sequences. 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 reference at the transmitter, all signals can be time synchronised.

To test this synchronisation technique, VALIDATE partners RTÉ and ITIS set up, with the assistance of TDF, a DVB-T SFN using two transmitters in the Dublin area on UHF channel 30 (see Fig. 1). The transmission mode used for this experiment was 8K, 64-QAM, R=2/3, guard interval=1/4. An MPEG-2 Transport Stream (TS) generator, an SFN adapter, a DVB-T modulator, and a 1kW TV transmitter operating at 50 W were set up at Three Rock. A second DVB-T modulator and a 25W transmitter were set up at Donnybrook. 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 an SFN adapter (MIP inserter) and GPS receivers.

At a site near Donnybrook where the signals from the two transmitters were at similar levels, the programme 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 (5).

Gap-Filler Transmitters

SFN techniques can be used on a smaller scale to improve coverage. VALIDATE partners have been studying 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 caused by feedback of 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 (see Fig. 2). With both receiving and transmitting antennas mounted on the same concrete tower an isolation of 105dB was obtained. The ripple on the output DVB-T signal spectrum was less than 3dB 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.

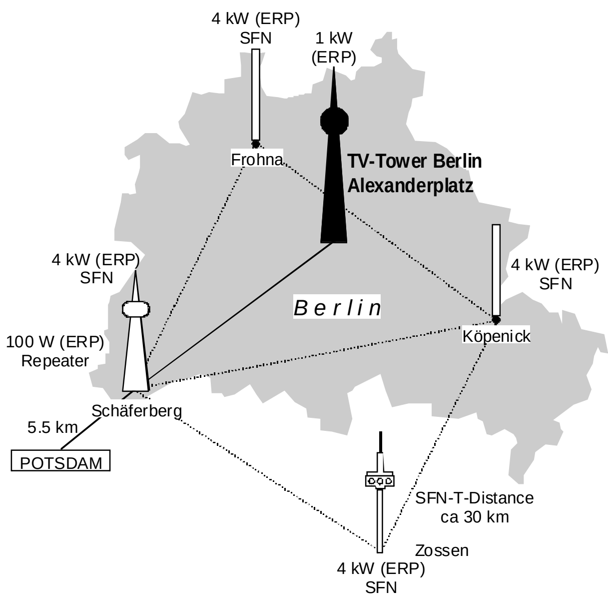

Figure 2. The experimental network of Deutsche Telekom AG in Berlin

For the domestic gap-filler, VALIDATE partner Televés carried out a feasibility study that gave encouraging conclusions, then built a prototype. As a domestic device, the safety of such a device and its cost were important considerations.

In a first test conducted by the BBC in the London area, the domestic gap-filler gave sufficient field strength to provide portable reception in all rooms of a house with an output power less than 200 µW. There were no problems of stability when it 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.

Five more houses and flats of different sizes and different methods of construction have been measured since, some of them in areas of poor reception where indoor portable reception would otherwise have been impossible; in all cases use of the gap-filler allowed portable reception in all rooms of the dwellings. Reception has been proved possible even with very poor input signals (20 dB tilt across the channel and 5 dB ripple).

VALIDATE – summing up

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 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.

MOTIVATE: DEVELOPING MOBILE SERVICES

Introduction

In some countries – such as the UK – terrestrial television is still dominant. In these countries the initial application of DVB-T will be to provide more channels to increase choice. In other countries – such as Germany – there is a much higher penetration of cable and satellite: only 6.8 M of the 36 M German households rely on terrestrial broadcasting. DVB-T could overcome some of the limitations of analogue terrestrial TV but this alone would not guarantee a successful introduction of DVB-T services in such countries: added value services are needed to attract more users and increase revenues for broadcasters and network providers.

Mobile reception of video, Internet and multimedia data could be an attractive feature to help the launch of DVB-T in countries such as Germany. Only terrestrial broadcasting could bring mobility to the end user. A data rate up to 15 Mbit/s using one 8 MHz UHF channel seems to be possible with the 64-QAM mode. Mobility is one of the advantages of the European DVB-T solution against competing standards.

Mobile Services

Mobile reception of DVB-T could bring new features to broadcast networks, making applications and services accessible and usable by anyone, anywhere, anytime, for business or individual use. A narrowband return channel could be integrated using GSM. Here are some examples of mobile services, some of which will be tested in the MOTIVATE project.

Digital television for cars, buses and trains

Digital television in cars, buses and trains could become the first service for mobile users. It would use some of the existing programmes with additional traffic and navigation information. An audio description service would be needed to make programmes safely accessible to drivers and front-seat passengers

Mobile contribution links

RTÉ and Deutsche Telekom Berkom have tested mobile transmission of DVB-T signals for contribution links. A low power transmitter can be installed in a vehicle to transmit MPEG-2 signals from a vehicle – even while in motion – to a studio. Tests have been made at UHF and in the L-Band. This service might be used at sports events, such as the Tour de France or the London Marathon, for interviews with busy politicians, or for the reporter in the field.

Mobile Webcasting

Today, solutions for Webcasting have been developed for stationary reception, mainly using satellite and cable based services. Webcasting is based on an Integrated Receiver Decoder (IRD) which could combine broadcast and telephony. The return channel and interactivity is limited to the bandwidth of the telephony network. Mobile DVB-T together with GSM would allow users to receive Internet in cars, buses, on 'watchmen', laptops, on-the-move. GSM as a return channel for DVB-T was standardised by the DVB project.

Mobile reception of DVB-T

The analysis of mobile reception using DVB-T started in early 1997. Since then, Deutsche Telekom has carried out an extensive series of measurements with a DVB-T compliant modem to investigate the performance of the DVB-T specifications in a mobile environment (6).

Doppler shift, deep fading, and shadowing are the dominant factors that decrease the system performance in mobile environments. The behaviour and limits of the DVB-T specifications were analysed through theoretical investigations, computer simulations, and laboratory tests. Field trials were performed in the area of Cologne in a variety of conditions, in the 2k mode only.

For the first time, measurements and field trials of mobile reception were carried out with higher orders of modulation, (16-QAM and 64-QAM) as well as QPSK. Results using channel 43 with an echo of 25µs showed that QPSK and 16-QAM need a carrier-to-noise ratio (C/N) about 6-7dB greater than in a Gaussian channel for a speed of 200 km/h; 64-QAM at 150 km/h needs C/N 10 dB greater. In all cases code rate 1/2 must be used.

It seems that the Doppler shift, especially for the QPSK or 16-QAM rate 1/2 modes, is not the fundamental limitation of the DVB-T specifications, although it does reduce the noise margin. Other limitations might be the lack of time interleaving (in the case of certain simulated channel profiles) and long echoes, particularly in the 2k mode; the 8k mode offers longer guard intervals to avoid inter-symbol interference effects. However, both laboratory measurements and field trials have shown that transmission of 15Mbit/s is possible at 64-QAM. In this case the required C/N is about 27 dB up to a speed of 100 km/h.

Nevertheless further investigations, especially field trials, have to be made to get a clear impression of this problem and the necessary transmitted power to overcome the problem of signal blocking.

The MOTIVATE project

The MOTIVATE project started work in May 1998 as a successor to VALIDATE. It will investigate the mobile reception of digital terrestrial TV in single-frequency and multi-frequency networks with data rates up to 15 Mbit/s. It is led by Deutsche Telekom Berkom GmbH and builds on the strong consortium shown in TABLE 1. The project has the backing of a number of sponsoring partners (Tele Danmark, RTÉ, DVB promotional module) which could make MOTIVATE the spearhead for the implementation of mobile DVB-T services. MOTIVATE is open for cooperation with broadcasters and network operators interested in DVB-T services.

The main objective of MOTIVATE is to provide practically-based implementation guidelines for mobile DVB-T reception. To ensure that these guidelines are soundly based, MOTIVATE will carry out theoretical and practical work on network structures, service planning and receivers.

Network structures

The MOTIVATE project will investigate coverage aspects of different network configurations (MFN, SFN, gap fillers) for portable and mobile reception to evaluate SFN network gain. Laboratory measurements and field trials will be carried out to optimise the network topology by selection of the antenna polarisation, the combination of MFNs and SFNs, the use of gap-fillers, and the choice of suitable DVB-T modes (modulation, code rate, and guard interval).

Service planning

The planning of different configurations of DVB-T networks needs parameters describing the receiver performance for mobile reception. MOTIVATE will specify a reference receiver and a minimal set of performance parameters needed to obtain a certain service quality with a certain type of receiver.

Receivers

MOTIVATE will study, implement, test and optimise efficient receiver algorithms for synchronisation, channel estimation and channel correction appropriate to the mobile environment. Prototypes of mobile receivers will be tested in MFNs and SFNs, in order to evaluate the real gain of the network. MOTIVATE will also contribute to the development of new and intuitive user interfaces.

Importance of MOTIVATE

MOTIVATE could have an impact on political decisions on a national and European level. The successful implementation of DVB-T for stationary reception in the UK and Sweden will help to make political decisions in other European countries; the successful verification of mobile DVB-T will help to overcome political constraints in other countries.

THE IMPORTANCE OF COLLABORATIVE R&D

Collaborative R&D is needed in selected areas where no one player can act alone, and where common European specifications and standards are necessary. This objective of the ACTS programme is true for the introduction of DVB-T. No single player, – network operator, broadcaster, programme provider or manufacturer – could start DVB-T in Europe in the narrow window of time available: new technologies are overtaken or will wither away if they are not quickly implemented.

One of the outstanding results of the ACTS programme was the verification by VALIDATE of the DVB-T specification and the implementation guidelines derived from it. A collaborative project of this kind involving broadcasters, network operators, and manufacturers is an excellent vehicle for verifying standards and ensuring a common basis for the early start of services.

CONCLUSIONS

The work of the VALIDATE project has verified the very flexible DVB-T specification, technically proving the excellent behaviour of DVB-T in critical broadcasting situations. VALIDATE has studied all technical aspects of the implementation of DVB-T networks and services. It has made its experience available to other broadcasters in the form of Implementation Guidelines. In particular it has developed the concept of the 'gap-filler' transmitter for DVB-T and has pioneered the mobile reception of DVB-T signals.

Though DVB-T was not specified for mobile reception, it appears to work also in mobile environments. Mobile reception could open up new possibilities for digital terrestrial broadcasting, offering value-added services that could make terrestrial broadcasting an attractive proposition even in countries where there is substantial penetration of cable and satellite.

The new project MOTIVATE will carry on the work of VALIDATE with a special emphasis on mobile reception. It will study the network topologies, service planning constraints, and receiver features needed for mobile reception,

Collaborative research and technological development is needed to bring together the resources needed to launch a new technology and to ensure interoperability on a European scale.

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DTT COVERAGE – PREDICTIONS AND MEASUREMENT

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INTRODUCTION

Digital terrestrial television services began in the UK in November 1998. Unlike previous analogue services, the planning of digital television is based largely on computer coverage predictions. Although this reduces the need for extensive coverage measurements, some field work is required to validate the predictions for both rooftop and indoor reception. It is also important to investigate situations that may give rise to reception difficulties. This paper discusses the first phase of field work recently undertaken for this purpose by the BBC.

COVERAGE VS. PREDICTION

Initial checks

A helicopter measurement system was developed to measure the measure the horizontal and vertical radiation patterns of the DTT transmitting antennas. Field strength measuring equipment was installed in a helicopter, which was flown around the antenna. During the flight, field strength was recorded on a computer along with positional information from a differential GPS system. Subsequent analysis of the data allowed the Horizontal Radiation Pattern (HRP) to be plotted. Also, signals were measured as the helicopter ascended vertically in order to determine the Vertical Radiation Pattern (VRP). Having used this equipment to check that the antennas were performing as intended, valid ground-based measurements could be made to check that the actual coverage was as predicted. It is important to note that the intention is to perform these measurements only in selected areas. It is not intended to survey all DTT transmitters

Coverage measurements

Having verified the transmitting antenna characteristics, coverage measurements were made using the BBC survey vehicle. Figure 1 shows the configuration of test and measurement equipment in the vehicle. Signals were received using a wideband log-periodic antenna mounted on a ten metre pneumatic mast. The antenna had a forward gain of 8 dB. The signals were fed via a tuneable band-pass filter to a distribution amplifier, which produced feeds to a measuring receiver, a spectrum analyser and a DVB-T receiver. The DVB-T receiver was the BBC prototype receiver with a professional front end.

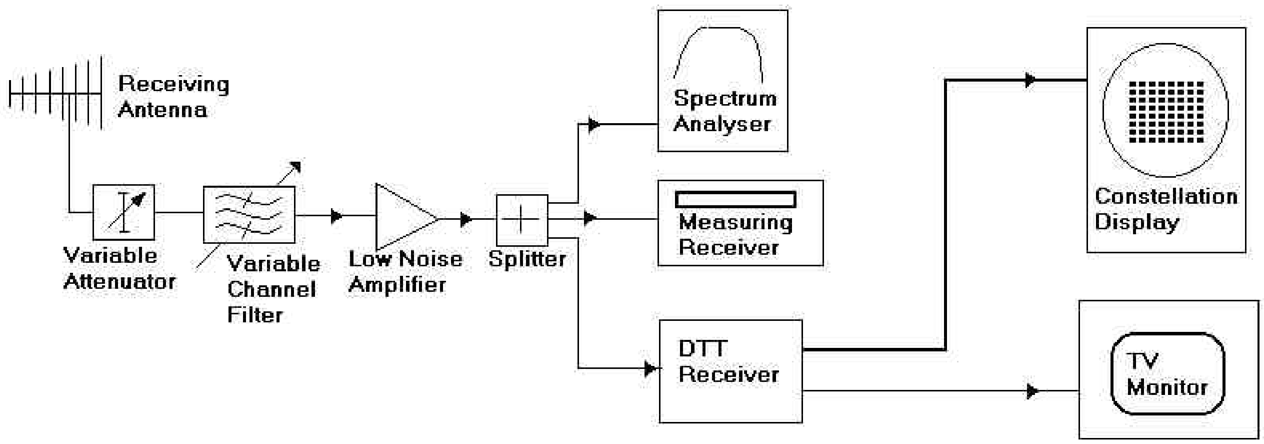


Figure 1. Experimental equipment in survey vehicle

In order to measure the coverage; a square sampling technique was used. The purpose of this work was to measure the percentage of coverage for a number of 1km squares and compare it with the computer prediction. This was achieved by selecting a number of points evenly distributed throughout each square. The survey vehicle was then positioned at each of these points in order to determine whether or not pictures and sound could be received. The percentage of measured points for which reception was possible was then judged to be the measured percentage of coverage for that square.

The squares were mainly chosen in residential town areas, because, these are the areas where most potential viewers live. Rural areas are not suited to this type of survey, since there are generally insufficient roads for a satisfactory sampling of the square to be achieved. Town centre commercial areas, on the other hand, have a dense road network, but it is not usually possible to stop the vehicle.

As far as possible within the constraints of the road network, the survey points within a square were selected so as to sample the square evenly. In most cases there were about 10 points in a square. This was judged to be a good compromise between time and measurement accuracy. To provide a more accurate coverage figure it would have been necessary to use more points, perhaps up to 100. However, this would have limited the number of squares that could be measured within the time available.

So far detailed surveys have been carried out in six squares, associated with the Crystal Palace transmitting station, since the operational transmitters came on air. The measured and predicted coverage figures are given in Table 4. Reception was achieved at all test points visited, even where coverage was predicted to be less than 100%. This suggests that coverage is at least as good as predicted. However, these are very early results. Furthermore, it is important to remember that the predictions are based on levels of interference that only occur for a small percentage of time. In cases where measured coverage exceeds predictions, this may not be the case for 100 percent of time. More useful information will be gained when more marginal areas are surveyed.

OS Square	*Location*	*DTT Channel*	*Measured coverage %*	*Predicted coverage %*
TQ3058	Coulsdon	22	100	95
		28	100	98
TQ3157	Old Coulsdon	22	100	98
		28	100	99
TQ3558	Warlingham	22	100	96

		28	100	94
TQ3562	Selsdon	22	100	98
		28	100	98
TQ3965	West Wickam	22	100	100
		25	100	100
		28	100	100
		29	100	98
		32	100	100
		34	100	98
TQ3966	West Wickam	22	100	100
		25	100	100
		28	100	100
		29	100	98
		32	100	100
		34	100	100

Table 4. Measured vs. predicted coverage

RECEPTION ANOMALIES

In some areas, although the field strengths of the DTT signals were significantly greater than the reception threshold, reception was difficult. Possible causes of such anomalies have been investigated. These include adjacent channel interference from analogue services, multipath propagation and man-made interference.

Adjacent Channel interference from analogue services

In order to avoid causing interference to other analogue and digital transmissions, many digital stations have been planned so that the radiated power is restricted in some directions. Generally, the analogue services from the same station will not be subject to these restrictions. Consequently, in these directions the ratio of analogue to digital field strengths will be significantly higher that the ratio of the nominal maximum transmitter ERPs. In cases where the analogue and digital signals are on adjacent channels this may result in reception difficulties due to adjacent channel interference from the analogue signal.

In order to investigate this situation, surveys were carried out in the coverage areas of the Hannington and Crystal Palace DTT transmitters.

At Hannington the DTT transmissions are subject to an ERP restriction to the East. It was expected that this would result in reception difficulties in the town of Basingstoke, to the South East of the transmitter. Three of the six multiplexes are at risk, since they have adjacent channel analogue services. Figure shows the results obtained at a sample of test points in the Basingstoke area. This diagram shows the relative locations of the test points and the transmitter site. The approximate HRP of the transmitting antenna is also indicated. For each test point, figures are given for the analogue to digital power ratios for the received digital signals.

The village of Overton receives virtually the full ERP of the digital transmitter. Thus the power ratios are in agreement with the ratio of the nominal transmitter ERPs (17 dB). Consequently the digital signal can be decoded easily as denoted by the ‘tick’ indicators in the diagram. In Basingstoke, however, the effect of the ERP restriction can be seen. In the south of the town, the ratio is significantly higher than at Overton, but still not too high for the signals to be decoded. The further north the test point, the closer it is to the centre of the HRP null. Consequently, the more extreme are the analogue to digital power ratios. In the suburb of Chineham, in the extreme north, the analogue signal levels are all at least 40 dB greater than the digital signals, and in one case the figure is 54 dB. The digital signal levels are sufficient to achieve reception, but the receiver will not operate with these high levels of adjacent channel interference. This is denoted by the 'cross' indicators. The protection ratio assumed for planning is 35 dB. When the ratio just exceeds this, the receiver used in these tests could be made to work by careful adjustment of signal levels. However, reception could not be guaranteed. This is denoted at one of the test points by intermediate 'question mark' indicators.

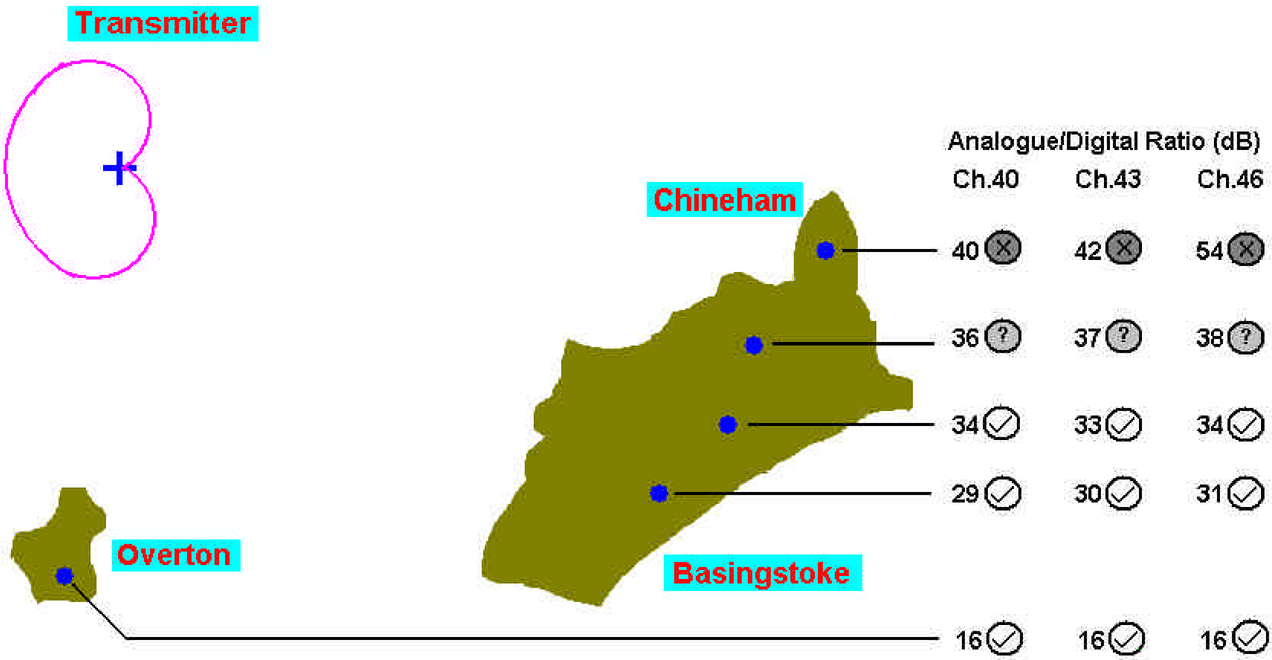


Figure 2. Reception results and analogue/digital ratios for test points in the Basingstoke area

A similar effect was noted in the coverage area of Crystal Palace. In order to avoid causing interference south of the transmitter, the transmitting antenna for the four highest power multiplexes is arranged so that in some directions the maximum power is directed about 3 degrees below the horizon. Therefore the ERP radiated towards points close to the transmitter is greater than that radiated towards points further away. The two lower power multiplexes are transmitted from the same antenna as the analogue services, which has an omni-directional pattern.

Figure shows the average of the received analogue to digital power ratios for the four highest power multiplexes measured at points along a radial line centred on the transmitter site. The radial route was chosen to lie in a direction corresponding to one of the ERP restrictions. Also shown is the average analogue to digital power ratio for the two lower power omni-directional multiplexes.

At 5 km from the transmitter, the analogue signals are reduced owing to the VRP of their antenna, whereas the high power digital multiplexes are not. Thus the analogue to digital ratio for the high power multiplexes is considerably smaller than the ratio of the nominal maximum ERPs (20 dB). As distance increases, however, the situation reverses and the ratio becomes greater than the ratio of the nominal maximum ERPs. In the case of the low power multiplexes the ratio remains relatively constant. It can be seen that, beyond 10 km, the ratio for the higher power multiplexes becomes greater than that for the lower power multiplexes. The 18 km point corresponds to the town of Swanley. Detailed surveys around this area revealed some locations where the ratio for the high power multiplexes was great enough to prevent reception. Ironically, the lower power multiplexes, which were not subject to the ERP restriction continued to be received.

Although these interference effects result in reception difficulties in high signal strength areas, the transmitting antenna characteristics that cause them are incorporated into the computer prediction algorithms, and the effects are generally well predicted.

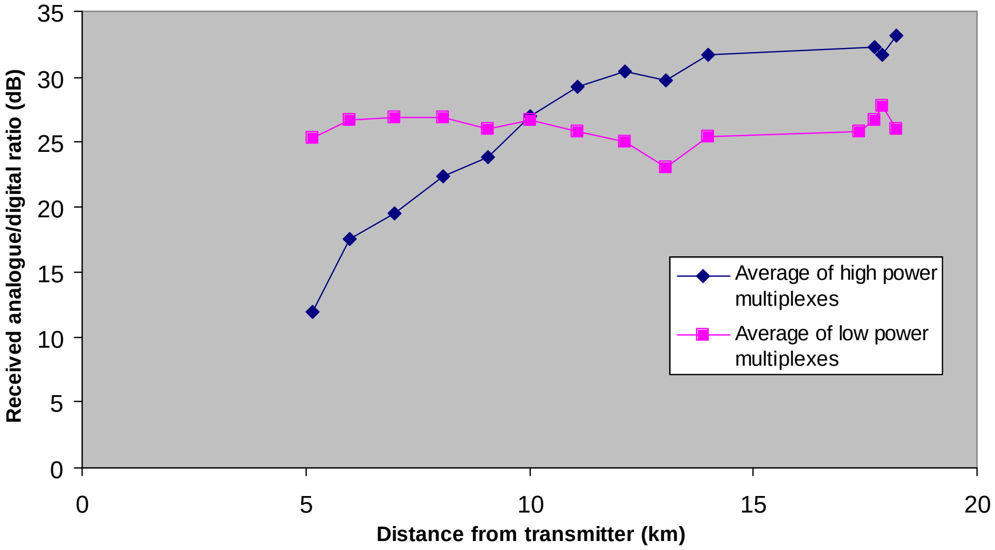


Figure 3. Analogue/digital ratio vs. distance from transmitter in ERP restriction

Multipath propagation (the capture system)

Reception is sometimes impaired by multipath propagation with relative delays in excess of the guard interval. The effect of this is generally to increase the required Carrier to Noise Ratio (C/N), and hence the field-strength threshold, for the receiver to operate. In extreme cases the receiver will not operate at any signal levels. As with adjacent channel analogue interference, there is an increased likelihood of multipath problems in areas where there is a restriction in the radiation pattern of the transmitting antenna. However, they are not easy to predict.

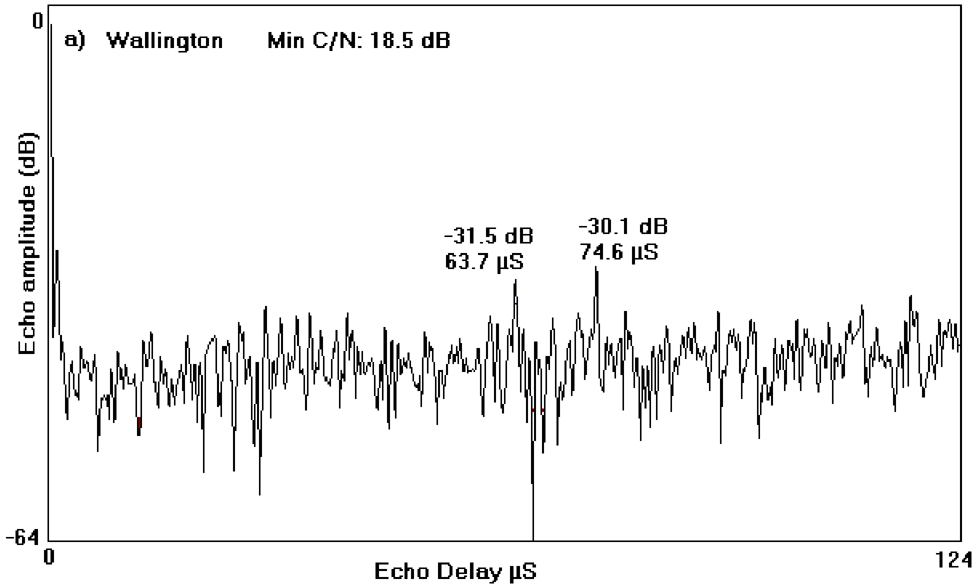
In order to investigate multipath effects, a powerful PC-based analysis tool was developed in association with Pioneer Digital Design Centre Ltd. The system consists of a fast Analogue to Digital Converter to digitise the received COFDM signal and a digital memory to store a sample of the waveform. Associated software analyses the captured sample to determine the amplitude and delay of any multipath echoes.

This technique was used extensively during field trials between 1996 and 1998 using an experimental pilot DTT transmitter at Crystal Palace. The transmissions had a very directional HRP such that the power radiated to the North was 20 dB higher in level than that radiated to the South. This was found to result in severe multipath in many areas to the South of the transmitter. Figure shows three multipath profiles derived from the capture system during this work, along with the associated minimum required C/N. The diagrams show the amplitudes of delayed signals in dB relative to the direct signal, plotted against their delay times. At the Wallington test point, the echoes were relatively low in level. Consequently reception was possible with a C/N of 18.5 dB (about the lowest vale normally encountered). At Nork, there was a higher level echo, resulting in an increased C/N requirement of 25.3 dB. At Epsom Downs the multipath was even more severe and reception was not possible at all.

This measuring technique has continued to be used since the beginning of the service for DTT in the UK. However, although areas of multipath propagation have been found, due to less directional HRPs, no areas have yet been found where reception is prevented by multipath propagation.

Man-made Noise

In town centres, man-made noise can be a problem if the field strength does not exceed the reception threshold by a sufficient margin. So far this problem has been identified at one location in Basingstoke. This location was near to the commercial centre of the town and suffered from low field strengths because of the transmitter HRP.



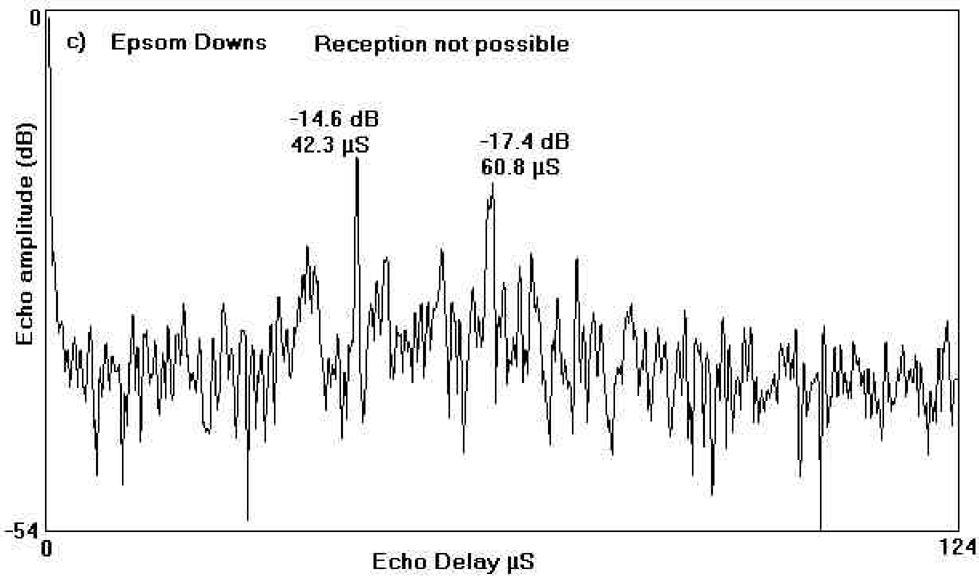


Figure 4. Delay/amplitude plots for multipath echoes

INDOOR RECEPTION

An important aspect of terrestrial transmission is indoor portable reception. Work has been carried out to determine the limit of coverage to indoor antennas and how it might be improved.

Measurements were made in a total of 33 residential buildings in the coverage area of the pre-operational experimental DTT transmissions from Crystal Palace. At each building, measurements were made of the loss of field strength associated with various rooms on different floors of the building. To do this a small indoor antenna was moved around the room at a typical 'set-top' height of about one metre above floor level. The signals from the antenna were fed to a measuring receiver interfaced to a computer, which recorded the measurements as the antenna was moved around the room. Analysis of the resulting data produced values for the median and standard deviation of the field strength within the room. A reference field strength was also measured outside the building at a height of 10 metres using the survey vehicle. The building loss of a room was defined as the ratio in dB of the outdoor field strength to the median value inside the room. Further tests were carried out to determine the minimum field strength required inside the rooms for the digital signals to be decoded. By adding the building loss, it was possible to calculate the minimum outdoor field-strength required at 10 metres to provide indoor coverage.

In practice, there was a considerable spread of values of building loss. A statistical approach was therefore adopted with measured rooms grouped according to floor level – ground, first and second. The results are summarised in Table 5. The first column gives the median value of the minimum outdoor 10 metre field strength corresponding to each floor level. However, since the building loss values themselves relate to the median field strength in a room, this value would only provide coverage to 50% of locations within the worst rooms. This level of coverage is considered to be just acceptable. Good coverage, with 90% of locations within a room served, requires an additional field strength equal to 1.3 times the standard deviation of the field strength variation within the rooms (see Column 2).

Columns 3 and 4 of Table 5 give the maximum values of the 50% and 90% field strengths for each floor level. These represent the field strength values required to cover *all* measured rooms. When compared to the minimum field strength required for outdoor reception at 10 metres (45 dB µV/m for the channel used in the tests), it becomes clear that blanket coverage to all buildings can only be achieved in high field strength areas close to the transmitter. However, an acceptable level of indoor reception, particularly in upstairs rooms, may be expected in a relatively large proportion of the coverage area of a transmitter.

Room category	50% of rooms		All rooms	
	50% of locations within room	90% of locations within room	50% of locations within room	90% of locations within room
Ground Floor	74	79	86	91
First Floor	69	74	81	86
Second Floor	68	74	79	84

Table 5. Minimum field strength required at 10 metres to achieve various levels of indoor coverage

Clearly, there will be many areas where the field strength is too low for any useful level of indoor reception. In order to provide the flexibility of indoor reception in such areas, work was carried out within the ACTS VALIDATE project to determine the viability of a small domestic 'gap-filler'. Such a device would amplify the DTT signals from an outdoor antenna and re-radiate them within the building. A prototype was developed by Televes, one of the partners within the VALIDATE project. Although there are still a number of issues to be resolved, initial trials were promising. An output power of less than 1 mW was found to provide good coverage in all houses tested.

CONCLUSIONS AND FUTURE PLANS

The roll-out of the DTT network in the UK is progressing well. Measurements in a few areas have confirmed that the coverage is generally in line with expectations. In some areas, coverage is limited by HRP restrictions in the transmitting antennas. This can give rise to difficulties such as multipath propagation and adjacent channel interference from analogue transmissions. In addition, at some locations the digital signals have been found to suffer from man-made interference. Some preliminary work has been directed at quantifying these issues. As the transmitter rollout proceeds, more measurements will be required and, if necessary, solutions to any problems will be developed. However, it is not the intention of the BBC to survey the coverage areas of all DTT transmitters. Indoor set-top reception of DTT services has been demonstrated. Although perfect indoor reception can only be expected very close to the transmitter, a useful level of such reception can be expected in many more areas. Even if reception is only possible with an outdoor antenna, set-top reception could, in principle, be achieved using a domestic gap-filler device. Future work will be directed at the issue of reception with commercial receivers using both outdoor and indoor antennas.

IEE Colloquium 'Digital Television - where is it and where is it going? 16 March 1999

POTENTIAL BENEFITS OF HIERARCHICAL MODES OF THE DVB-T SPECIFICATION

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1 INTRODUCTION

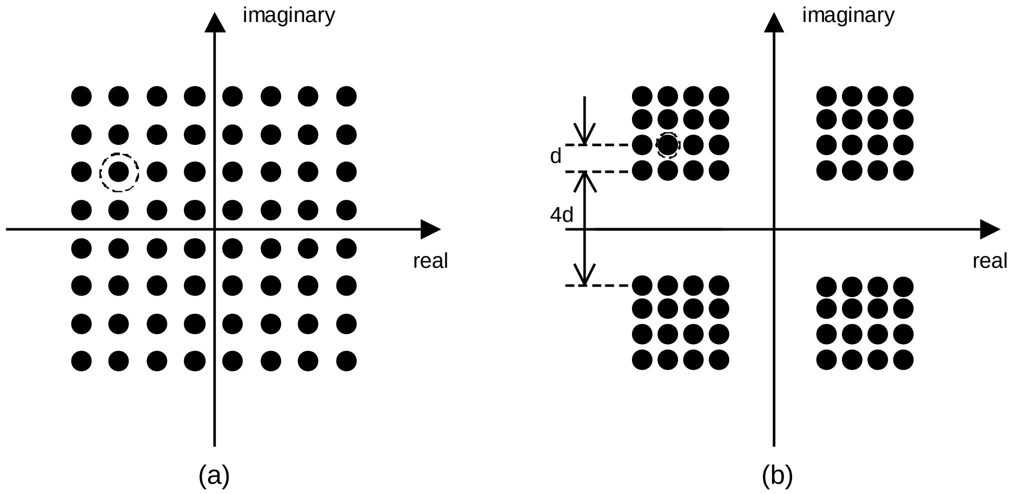
Most people attending this IEE colloquium will be very familiar with the concept of digital terrestrial television (DTT), and hopefully will all have seen live reception of the signals at some time. However many of those people will not have encountered the idea of hierarchical modulation, which is a part of the ETSI standard [1] – the definition of the RF transmission standard for DVB-T signals.

This paper will introduce the ideas behind the hierarchical modes, and show one of the ways in which they could be used at some time in the future, or perhaps by countries still in the process of planning their DTT services at the moment. This paper is not intended to suggest that the existing UK DTT services should be replaced by hierarchical services, but instead it points out a potential way in which the DTT system could be used, if additional frequencies become available in the future.

2 WHAT IS HIERARCHICAL MODULATION?

The hierarchical modes of the DVB-T specification provide a means by which the MPEG-2 bit-stream can be divided into two parts. One stream, the high priority (HP) stream, is heavily protected against noise and interference, whereas the second, low priority (LP), stream is much less well protected. The HP stream often carries data at a lower bit-rate than the LP stream.

The hierarchical modulation options are most easily illustrated by reference to constellation diagrams. Figure a shows the constellation of the data carriers of the DVB-T signal in the standard mode as used in the UK (this mode is 2K, 64-QAM, code rate 2/3, guard interval fraction 1/32). The pilot carriers have been omitted for clarity. Figure b shows the constellation for one of the hierarchical



modes.

Figure 1Constellations of 64-QAM DVB-T signals (see text for description of circled points) a) non-hierarchical; b) hierarchical with α=4

In Figure1a it can be seen that each of the real and imaginary axes carries three bits of data, leading to eight modulation levels on each axes, and 64 constellation points. All of the 64 constellation points are equally spaced, and are treated equally. There is one data stream and the entire set of constellation points is used to transmit it. So for example the data sequence ‘100111’ would cause the indicated constellation point to be used.

In Figure 1b the constellation points have been grouped. The data that modulates the HP stream is used to select the quadrant of the transmitted point. For example if the HP bit sequence ‘10’ is to be transmitted, the top left quadrant will be used. The LP stream, which operates at a higher bit-rate, is used to determine the exact constellation point within the quadrant. For example the LP sequence ‘0111’ would select the indicated constellation point. In the hierarchical case a receiver with a low signal level and hence a high level of thermal noise would only be able to detect the quadrant and not the individual constellation points, and so only the HP stream could be decoded. A receiver with a lower level of noise could decode all of the points, and so would be able to reproduce both HP and LP streams.

It should be noted that the hierarchical modulation options do not make any constraint on the data streams that are transmitted, (other than that they should be MPEG-2 transport streams). There have been suggestions in the past for systems where hierarchical modulation was linked to hierarchical source coding. Although hierarchical source coding is not catered for in the DVB-T specification, it is possible to use a simulcast system, to provide a standard definition picture in the HP stream and a high definition (HDTV) picture in the LP stream.

2.1 Specification Options

The constellation ratio α is used to determine the spacing between the groups of constellation points. α is the ratio of the spacing between the groups to the spacing between individual points within a group. So for the example above, the ratio is 4. The permitted values of α are 1, 2 and 4. In the case of α =1, the constellation is indistinguishable from that of Figure . The description above applies to the set of cases where the constellation is of 64-QAM form. An alternative set of options allows for a constellation of 16-QAM form.

3 WHAT CAN WE USE THE HIERARCHICAL MODES FOR?

The flexibility provided by hierarchical modulation could be used in a number of ways, and these are described in the following sections.

3.1 More rugged main services

As we have seen from the previous description, hierarchical modulation provides one bit-stream that is more strongly protected against noise and interference. This stream could be used to carry one service in a multiplex that was considered more important than the other services. There have been some discussions in Australia about operating some of their DTT services in this way, for simulcasting HDTV. This could provide a standard definition service for portable receivers and an HDTV service for fixed receivers (HDTV receivers are unlikely to be portable in any case!).

An alternative way of looking at this option would be to say that the service area coverage that is achieved for the HP stream is higher than the coverage for the equivalent non-hierarchical mode. This point will be illustrated further shortly. Whilst this sounds as though something is being achieved for nothing, in practice the penalty is that there is a small loss of coverage for the LP stream compared with the non-hierarchical mode.

3.2 More bit-rate for similar coverage

If a different approach is adopted, the coverage achieved with an existing non-hierarchical mode could be roughly matched when using the hierarchical mode, but whilst carrying data at a higher overall bit-rate. This would be achieved by for example converting non-hierarchical 64-QAM with a code rate of 2/3 into a hierarchical system with an HP code rate of 3/4, and an LP code rate of 2/3. This would still have broadly similar coverage for the HP bit-stream, and again a slightly reduced coverage for the LP bit-stream, but an overall increase of the data-rate of 1 Mbit/s if the shortest guard interval is being used. However, as will be seen in section 4, although the Gaussian channel performance of the HP stream with code rate 3/4 is slightly better than the non-hierarchical system, the performance with co-channel PAL is no better. In a channel with severe multipath, the performance will be worse than the non-hierarchical system, and so the overall coverage pattern will be changed slightly from the non-hierarchical case.

3.3 Combined mobile and fixed services

Perhaps the most exciting possibility for hierarchical modulation would be for planning a combined mobile and fixed service. Mobile services require higher field strength than for fixed services, so if service planning was carried out on the basis of operation to mobile receivers of the HP stream, very good coverage could be achieved to fixed receivers of the LP stream.

4 TECHNICAL PERFORMANCE OF HIERARCHICAL MODES

To illustrate the points made about the use of the hierarchical modes in the preceding section, some laboratory measurements of the DVB-T system were carried out. The measurements made use of a domestic tuner and chip-set and so are representative of the performance that could be expected in a set-top box. However, the tuner used was the best available domestic tuner in terms of adjacent channel performance, so overall performance is better than has been assumed for the frequency planning that was done for the UK DTT services. Table gives the performance measurements for some of the 64-QAM DVB-T modes. The first line gives the values used for the UK frequency plan, for reference. The second line shows the actual values measured for the same mode. The three rows shown in bold correspond to the figures that were used for the coverage comparisons in section 5.

Stream	Code rate	Max. bit rate Mbit/s	?	Gaussian noise (C/N)	Protection ratio of digital signal in channel N from analogue PAL in channel:		
					N-1	N	N+1
UK plan	*2/3*	*24.1*	-	*20 dB*	*–35 dB*	*+4 dB*	*–35 dB*
Non-hierarchical	**2/3**	**24.1**	**-**	**19 dB**	**–44 dB**	**–1 dB**	**–40 dB**
HP	**2/3**	**8.0**	**1**	**14 dB**	**–46 dB**	**–5 dB**	**–44 dB**
LP	**2/3**	**16.1**	**1**	**20 dB**	**–42 dB**	**+1 dB**	**–38 dB**
HP	2/3	8.0	2	11 dB	–48 dB	–6 dB	–47 dB
LP	2/3	16.1	2	21 dB	–41 dB	+2 dB	–37 dB
HP	3/4	9.1	1	17 dB	–45 dB	–1 dB	–41 dB
HP	3/4	9.1	2	13 dB	–47 dB	–3 dB	–44 dB

Table 1 Some basic planning parameters for a selection of the 64-QAM modes

5 ILLUSTRATIVE COVERAGE PREDICTIONS

To gain some understanding of the potential advantage of using a hierarchical mode, some example coverage predictions have been carried out. For this it has been assumed that the extra ruggedness of the HP stream will be used to enhance the coverage for the services carried by that stream.

A single frequency from a single transmitter has been chosen (channel 25 from the Crystal Palace transmitter in south London, using the current DTT transmitter power and radiation pattern. Coverage predictions were carried out on the basis of the measured performance figures given in section 4. Note that the non-hierarchical 64-QAM (which is the same mode as is used for the UK DTT service) has different performance parameters from the values used for the UK frequency planning. The values used for frequency planning are the values agreed following a number of measurements on a range of receivers. The figures used for this example are the results from a single very good tuner. Hence the coverage predictions in the maps do not directly correspond to the actual coverage of today's DTT service. Furthermore, since the coverage of only a single transmitter has been calculated, the coverage cannot be taken as exactly representative of the coverage that would be obtained throughout the whole country. It does however give some indication of the likely benefits.

Figure 2 shows the coverage that might be achieved using a non-hierarchical modulation with the performance parameters of section 4. Figure 3 shows the coverage of the HP stream of a hierarchical transmission with $\alpha=1$ and figure 4 shows the coverage of the LP stream. The actual population coverage figures are shown in Table 2. It can be seen from this that the coverage for the HP stream is increased by 8.4% compared to the non-hierarchical transmission, whereas the coverage of the LP stream is only reduced by 2.7%.

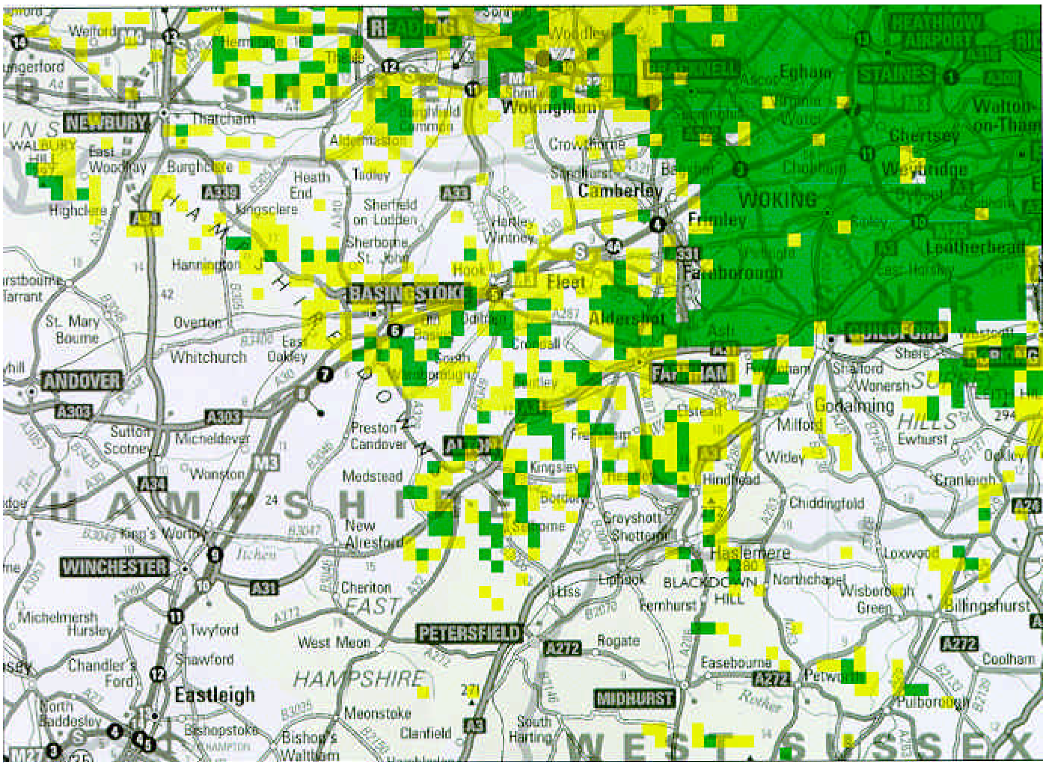


Figure 2 Coverage for non-hierarchical system

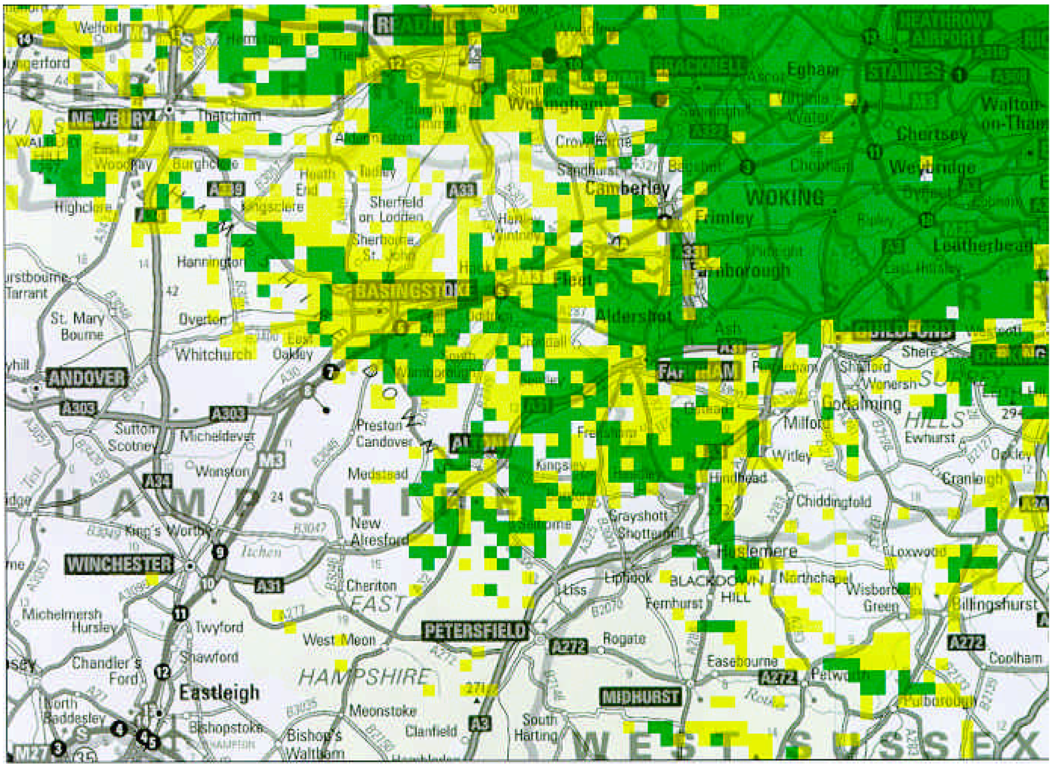


Figure 3 Coverage for HP stream

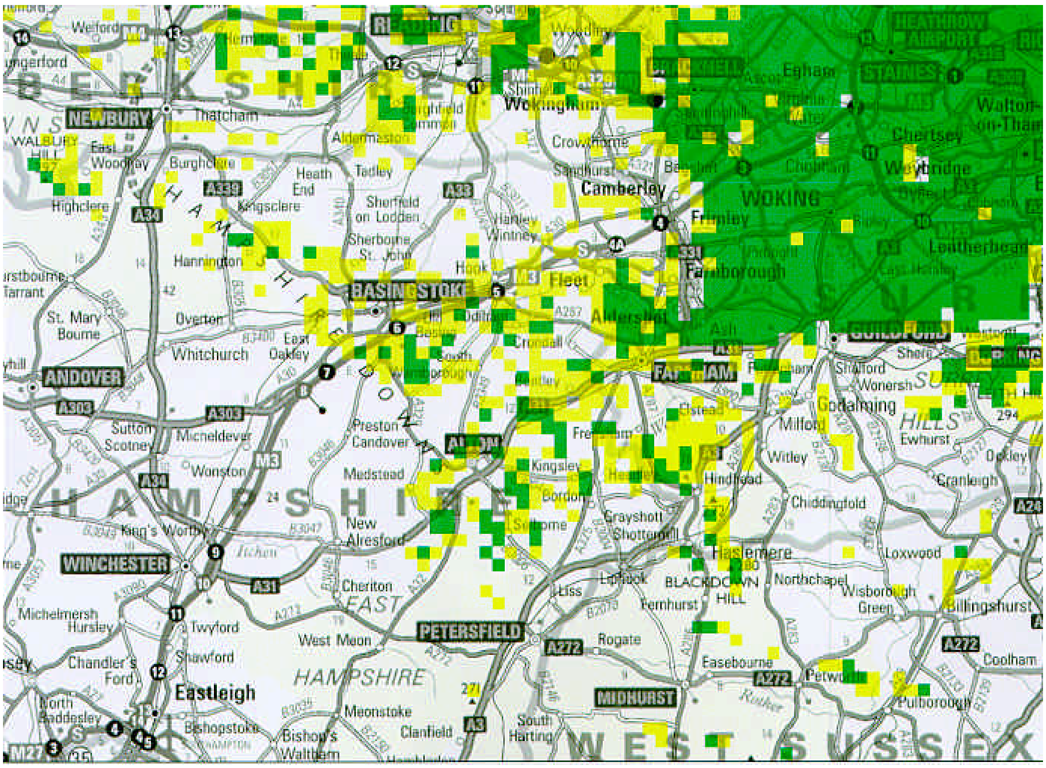


Figure 4 Coverage for LP stream

Stream	Code rate	α	Coverage	
			Population (million)	% change
Non-hierarchical	2/3	-	9.3	–
HP	2/3	1	10.1	+8.4%
LP	2/3	1	9.0	–2.7%

Table 2 Coverage predictions from Crystal Palace on channel 25 for the selected modulation options

6 CONCLUSIONS

An introduction to the use of the hierarchical modulation options of the DVB-T specification has been given, explaining what they are and how they could be used. Some performance parameters for a selection of the hierarchical modes have been measured.

The performance parameters have been used to predict the coverage that could be achieved using hierarchical modulation from the Crystal Palace transmitter. These predictions have shown that the HP stream could achieve a coverage increase of 8.4% compared to the non-hierarchical case, whilst the coverage of the LP stream is reduced by 2.7%.

7 ACKNOWLEDGEMENTS

The authors would like to sincerely thank their colleagues without whose contributions this paper would not have been possible: Adrian Robinson who carried out all the performance measurements, and Phil Marsden who performed the coverage predictions. The work was carried out within the ACTS MOTIVATE project which is supported by the Commission of the European Union through the fourth Framework programme.

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INTRODUCING MOBILE MULTIMEDIA BROADCASTING SERVICES

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ABSTRACT

This paper presents the MOTIVATE project funded by the European Commission and will give first results of laboratory measurements, field trials and simulations of an optimised receiver in the framework of the MOTIVATE (Mobile Television and Innovative Receivers) project funded by the European Commission. These two major streams of innovation are expected from this project:

- Specification for an optimised DVB-T receiver for mobile reception,
- Implementation guidelines for planning of mobile DVB-T networks.

Finally, this paper should give an outlook on first mobile services that will exploit results of the MOTIVATE project. Applications designed for the specific needs of the car environment will be introduced with an outlook IFA'99.

INTRODUCTION

In the UK terrestrial television will stay the prevalent distribution media. The initial application of DVB-T is to provide more channels to increase choice. In other countries – such as Germany – there is a much higher penetration of cable and satellite: only 6.8 M of the 36 M German households rely on terrestrial broadcasting. DVB-T could overcome some of the limitations of analogue terrestrial TV but this alone would not guarantee a successful introduction of DVB-T services: added value services are needed to attract more users and increase revenues for broadcasters and network providers.

Mobile reception of video, Internet and multimedia data could be an attractive feature to help the launch of DVB-T in Germany. Only terrestrial broadcasting could bring mobility to the end user. A data rate up to 15 Mbit/s using one 8 MHz UHF channel seems to be possible with the 64QAM mode. Mobility is one of the advantages of the European DVB-T solution against competing standards.

THE MOTIVATE PROJECT

In May 1998, after two years of feasibility tests of mobile reception by Deutsche Telekom, a consortium of 17 broadcasters, network operators, manufacturers of professional and domestic equipment and research centres launched the MOTIVATE project. It is funded by the European Commission in the ACTS (Advanced Communications Technologies and Services) Programme. MOTIVATE investigates the practical and theoretical performance limits of DVB-T for mobile reception. The optimisation of receiver algorithms for channel estimation, channel correction and time synchronisation will lead to the next generation of DVB-T receivers designed for the mobile environment. MOTIVATE will prepare guidelines for broadcasters and network operators on how to implement DVB-T networks for mobile receivers. The promotion of mobile television will be an essential part of the MOTIVATE project. Major Demonstrations are planned for IFA'99 and IBC'99. MOTIVATE builds on the strong consortium shown at the bottom of this page and has the backing of a number of sponsoring partners (TeleDanmark, RTÉ, DVB promotional module, TU-Munich, BMW and TU-Braunschweig). The collaboration with all broadcasters interested in mobility makes MOTIVATE the spearhead in promotion of mobile DVB-T services.

Mobile channel

The mobile channel is characterised by multipath propagation and Doppler effect. The multipath propagation causes different strong attenuation in the receiving signal depending on elapse time, amplitude and phasing of the echo paths. The Doppler effect causes a frequency shift depending on transmission frequency *f* and speed of the receiver *v* . The Doppler frequency is determined by $f_D = v/c \; f \cos \alpha$ (*c* speed of light, α angle between receiving path and direction of movement).

OFDM is an effective method to combat the distorsions of the transmitting signal caused by the multipath propagation. The received signal can tolerate echoes by insertion of a guard interval if the longest echoes are within this interval. In the case of Doppler frequency an efficient channel estimation can remarkably improve the performance of the receiver.

Mobile lab and field tests of Deutsche Telekom

Deutsche Telekom Berkom carried out extensive measurement series in the laboratory and in the field to investigate the performance of DVB-T receivers in a mobile environment. For all measurements a 2K-FFT signal was used.

We used for laboratory measurements a failure criteria determined by the subjective assessment of picture quality. A sufficient picture quality is achieved if no errors are visible in a picture sequence of 20 seconds. This method is called the subjective failure point (SFP) method.

The artificial two paths model with Doppler shift was generated in a channel simulator for the laboratory measurements. The critical case of 0 dB echo in all measurements was used.

Figure 1 shows the results of laboratory measurements. The C/N behaviour for different DVB-T modulation schemes (QPSK, 16-QAM, 64-QAM with code rate 1/2 and QSPK and 16-QAM with code rate 2/3) versus speed at an echo delay of 20 µs is shown. QPSK (CR=1/2 and 2/3) and 16-QAM (CR =1/2) show no noticeable increase of C/N values at higher speeds. However, the C/N values of 16-QAM with CR=2/3 and 64-QAM with CR=1/2 are increasing from a speed of 100 km/h.

Three suitable modes could be identified for mobile reception of DVB-T, QPSK, 16-QAM and 64-QAM with code rate 1/2 for each.

Thresholds of the minimum receiver input voltage for the AWGN and the mobile channel can be given as a result of the laboratory measurements. These thresholds are contained in Table 1 for the investigated modes QPSK, 16-QAM and 64-QAM with code rate 1/2 each. Levels higher than these thresholds guarantee error free pictures at the receiver.

Threshold	QPSK	16-QAM	64-QAM
AWGN	16 dBµV	22 dBµV	30 dBµV
Mobile	22 dBµV	29 dBµV	38 dBµV

Table 1: AWGN and Mobile thresholds

Deutsche Telekom Berkom made field trial measurements to study the performance of a DVB-T receiver in real mobile environments in the area of Cologne. The ERP of the transmitter was 1 kW. The transmission of DVB-T signals performed in the UHF channel 40 (626 MHz). The same modes were investigated as in the laboratory tests.

The main objective of the field tests was to check the identified mobile thresholds in Table 1 in a real mobile environment. If the thresholds are correct then a prediction of the expected Video Error Rate for the route can be given on the basis of a field strength prediction.

The field tests have confirmed the results obtained from the laboratory tests of the DVB-T modes with the simple 0 dB artificial echo model. The thresholds for the examined receiver (corresponding to the constellation order) guarantee a faultless mobile video transmission. The identified mobile thresholds correspond to a coverage probability of 99 %. These thresholds can be seen as a first basis for the planning of services. Further investigations are still needed.

"Mobile MOTIVATE DVB-T Lab Tests"

The "Mobile DVB-T lab tests" were organised in November 1998 to compare the behaviour of state-of-the-art receivers and to study the performance in a mobile environment. Three different channel profiles were defined (easy, regular and difficult profile) to perform these tests with a channel simulator.

9 receivers have been tested which constitute a large panel of equipment for different purposes (professional, consumer and experimental demodulators). The measurement results made clear that mobile DVB-T reception is possible even with currently available receivers. Six suitable modes (three for the 2k mode and three for the 8k mode) could be identified for mobile reception. All of them have the code rate 1/2. Table 2 contains the reachable speed on average of all receivers and the necessary C/N ratio at a speed of 100 km/h of the 2k and 8k mode for the case of easy profile.

Modulation	Data rate [Mbit/s]	Average speed	C/N [dB] at 100 km/h
2k QPSK ½	4.98	400	9
2k 16QAM ½	9.95	250	15
2k 64QAM ½	14.92	190	21
8k QPSK ½	4.98	100	10*
8k 16-QAM ½	9.95	70	17*
8k 64QAM ½	14.92	50	-

Table 2: Measurement results of mobile reception in the 2k mode (based on UHF channel 43), (* C/N at 50 km/h)

The speed limit is approximately reduced by the factor of four in the 8k mode case. One receiver was already optimised slightly towards mobile reception and achieved much better results in difficult reception conditions and 8k mode.

Next Generation Mobile Receiver

From this reference MOTIVATE started to optimise the algorithms for mobile reception.

The mobile reception of DVB-T results in two additional components the system has to cope with. On the one hand the Doppler frequency has to be taken into account, on the other hand the channel transfer function is no longer a static channel, but a fast time variant channel. For stationary or even portable reception it is not necessary to provide a channel estimation which is able to follow fast variations of the channel transfer function.

The optimisation of channel estimation using Wiener filter algorithms and FFT leakage equalisation, the optimisation of antenna diversity in a mobile receiver provided first encouraging results.

Further simulation work is needed in 1999 before a specification for the next generation mobile DVB-T receiver could be given and implementations on a hardware platform could be realised. Prototypes receivers will be tested in MFNs and SFNs, in order to evaluate the real gain of the network for coverage in a mobile environment. Hierarchical modulation offers a real possibility to combine the robustness of QPSK modulation for mobile reception and much higher data rates of 64 QAM modulation for stationary reception.

Network structures

The MOTIVATE project investigates coverage aspects for DVB-T services by using simulation and prediction tools and by measuring the performance of DVB-T in both laboratory tests and field trials. The network topology is being optimised by the selection of the antenna polarisation, the combination of MFNs and SFNs, the use of gap-fillers, microcell/macrocell and the choice of suitable DVB-T modes (modulation, code rate, guard interval).

Partners in MOTIVATE adapted existing planning software for DVB-T urban networks and first mobile DVB-T measurements were performed and compared with prediction models. One main outcome of the project will be the implementation guidelines for mobile DVB-T reception to set up transmitter networks. To ensure that these guidelines are soundly based, MOTIVATE carries out laboratory measurements and field trials.

Hierarchical Modulation

Enhanced mobile and portable reception was experienced by applying the hierarchical transmission scheme as specified for DVB-T. One high priority data stream (HP) and one low priority stream (LP) were transmitted independently using a QPSK modulation within a 16- or 64-QAM modulation. This means, two bits of the encoded HP stream are used to select the quadrant of one complex carrier and 2 or 4 bits of the encoded LP stream are used to form the constellation point within the selected quadrant. Therefore, a subset of broadcast services transmitted in one TV channel is routed to the HP stream and the other part of programmes are routed to the LP stream.

With hierarchical modulation different service coverage areas for the HP and the LP data stream will exist. The main questions investigated in MOTIVATE concerning hierarchical modulation were:

Does hierarchical modulation allow mobile or portable reception of the HP stream even if there is no reception of the LP stream ?

What is the loss in performance for the reception of the LP stream using hierarchical modulation compared to the reception performance of a conventional, non-hierarchical 16- or 64-QAM ?

What is the difference in C/N performance and in the size of the service coverage area between mobile or portable reception of the HP stream compared to the stationary reception of the LP stream ?

What is the difference in C/N performance and in the size of the service coverage area between mobile reception of the HP stream compared to portable reception of the LP stream ?

The results of the field trials performed in MOTIVATE showed that there is a high robustness for mobile or portable reception of the HP stream. Even if the constellation is totally noisy an excellent reception of the audio and video is possible. The loss in performance for the reception of the LP stream using hierarchical modulation compared to the reception performance of a conventional, non-hierarchical modulation in average is 1.4 db for the receiver tested.

Mobile Services

Mobile reception of DVB-T could bring new features to broadcast networks, making applications and services accessible and usable by anyone, anywhere, anytime, for business or individual use. A narrowband return channel could be integrated using GSM. Here are some examples of mobile services, some of them will be demonstrated by the MOTIVATE project at IFA'99 and IBC'99.

Digital television for cars, buses and trains

Digital television in luxury cars, buses and trains could become the first service for mobile users. It would use some of the existing programmes with additional traffic and navigation information. An audio description service would be needed to make programmes safely accessible to drivers and front-seat passengers.

At IFA'99 the MOTIVATE project will develop and implement Mobile Multimedia Services into the car environment taking into account the specific requirements given by the resolution, position and size of the navigation display already implemented in cars, the peripherals such as the in-car network, antenna and other communication systems such as GSM. MOTIVATE will customise mobile services for the driver and co-pilot which are mainly interested in traffic, business, travel and other information. In addition the storage capacity of the receiver would allow to download and update a significant amount of data on-the-move.

Mobile contribution links

RTÉ and Deutsche Telekom Berkom have tested mobile transmission of DVB-T signals for contribution links. A low power transmitter can be installed in a vehicle to transmit MPEG-2 signals from a vehicle – even while in motion– to a studio. Tests have been made at the UHF and in the L-Band. This service might be used at sports events, such as the Tour de France or the London Marathon, for interviews with busy politicians, or for the reporters in the field.

Mobile Internet Broadcast

Today, solutions for Internet Broadcast have been developed for stationary reception, mainly using satellite and cable based services. Internet Broadcast is based on an Integrated Receiver Decoder (IRD) which could combine broadcast and telephony. The return channel and interactivity is limited to the bandwidth of the telephony network. Mobile DVB-T together with GSM would allow users to receive Internet in cars, buses, on 'watchmen', laptops, on-the-move. GSM as a return channel for DVB-T was standardised by the DVB project.

IFA'99

At IFA'99 Deutsche Telekom Berkom will set up the full demonstration chain to present mobile DVB-T programmes and services.

The sponsoring partners BMW and TU-Munich will handle all aspects related to the integration of the mobile receiver into the car environment.

Special requirements from car manufacturers are

an easy to use enter button,

the size of the display and with it the size of types and information.

the integration of the mobile DVB-T receiver into the communication network already available including peripherals such as antennas, position of receiver.

the PC with DVB-T card will be installed in the back of the car.

First applications will contain traffic, business and travel information to meet the requirements of a busy politician or businessman on the way from the airport to the city centre. The content will be broadcasted within two multiplexes available for IFA. The applications designed for the MOTIVATE demonstration will allow a maximum data rate of 2Mbps.

Further mobile data services will be shown at IFA'99. The MOTIVATE demonstration should promote DVB-T as a mobile system.

CONCLUSIONS

MOTIVATE could have an impact on political and business decisions on a national and European level. The successful implementation of DVB-T for stationary reception in the UK and Sweden will help to accelerate political decisions in other European countries; the successful verification and demonstration of mobile DVB-T could open up new possibilities for digital terrestrial broadcasting, offering value-added services that could make terrestrial broadcasting an attractive proposition even in countries where there is substantial penetration of cable and satellite.

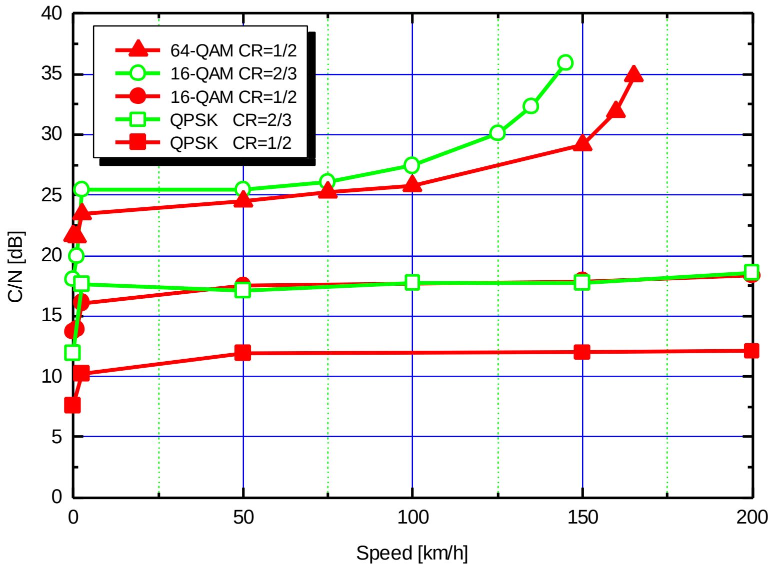

Figure 1: C/N of different DVB-T modes at different speeds (UHF channel 43)

Partners in MOTIVATE

BBC	UK	NOZEMA	NL
Robert Bosch	D	Radio Telefís Éireann	IRL
CCETT	F	RAI	I
Deutsche Telekom Berkom	D	Retevisión	E
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SINGLE FREQUENCY NETWORKS FOR DIGITAL VIDEO BROADCASTING

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ABSTRACT.

This paper introduces the Terrestrial Digital Video Broadcasting DVB-T, stating its innovative aspects and its major advantages for data broadcasting, particularly TV broadcasting. It also presents the experimental DVB-T network built up by Retevisión in the framework of the Spanish VIDITER project (Terrestrial Digital Video) and the European ACTS VALIDATE (Verification and launch of Integrated Digital Advanced Television in Europe) and ACTS MOTIVATE projects (Mobile Television and Innovative Receivers). The experience and some of the results of the different tests carried out by Retevisión are afterwards discussed.

WHY DIGITAL TV BROADCASTING?

Generally, the digital technology presents some major advantages in baseband efficiency, flexibility and RF performance that make its use very attractive to broadcasters.

Effectively, when addressing to TV broadcasting, the digital signals are more robust and the spectrum use is more efficient; more than one program may be broadcasted using the same bandwidth and having even better picture quality. Moreover those digital signals are easier to process and more computer friendly.

The only issue is how long will it take to completely change the technology considering the large number of analogue TV receivers worldwide. Some transition period will probably be started in which both technologies coexist (broadcasting the same TV contents in analogue and digital, often called SIMULCASTING, and some additional only-digital contents).

WHAT IS DVB?

The Digital Video Broadcasting Project (DVB) is a marked-led initiative to standardise digital broadcasting worldwide. It is formed of 240 members from more than 35 countries, in which there are representatives of broadcasters, manufacturers, network operators and regulatory bodies.

The DVB was formed in September 1993 and along these years has been producing several system specifications that have become standard in organisms as the ETSI (European Telecommunication Standard Institute) or CENELEC (European Committee for Electrotechnical Standardisation).

The DVB family of standards

The DVB has been producing different system specifications including satellite: DVB-S [EN 300421], cable: DVB-C [EN 300429], terrestrial: DVB-T [EN 300744], microwave: DVB-MVDS [EN 30048] and DVB-MMDS [EN 300749], community antenna: DVB-SMATV [EN 300743] and others.

The key word of the DVB standards is *interoperability*, all of them are part of a family of systems that make use of maximum commonality in order to enable the design of “synergetic” hard- and software.

The DVB transmission systems offer a “pipe” for data containers. They are transparent for SDTV (Standard Definition TV), EDTV (Enhanced Definition TV) and HDTV (High Definition TV), for audio at all quality levels and for all kinds of general data (multimedia data broadcasting).

All the specifications are based on the selection of the MPEG-2 (Moving Pictures Experts Group) for coding audio and video and for the system level.

DVB-T – TERRESTRIAL DIGITAL VIDEO BROADCASTING

The DVB-T system for terrestrial broadcasting is probably the most complex DVB delivery system.

The key feature of the system is the use of COFDM (Coded Orthogonal Frequency Division Multiplexing). This is a very flexible wide-band multicarrier modulation system that uses different levels of forward error correction, time and frequency interleaving and two level hierarchical channel coding.

Basically, the information to be transmitted is split into a given number (“2k” 1705 or “8k” 6817) of modulated carriers with individual low bit rate, so that the corresponding symbol time becomes larger than the delay spread of the channel. A guard interval (1/4, 1/8, 1/16, 1/32 of the symbol time) is inserted between successive symbols to avoid intersymbol interference and to protect against echoes.

Depending on the channel characteristics, different parameters (sub carrier modulation – QPSK, 16QAM, 64QAM –, number of carriers – 2k, 8k –, code rate of inner protection, guard interval and modulation parameter - a) can be selected obtaining different *operation modes*. Every mode offers a trade-off between net bit rate and protection of the signal (against fading, echoes, etc.). Depending on the selected operation mode, 60 different net bit rates could be obtained ranging from 5 to 32 Mbps.

The selection of the COFDM modulation system presents two major advantages that make its use very interesting to terrestrial digital video broadcasting:

- COFDM improves the ruggedness of the system in the presence of artificial (long distance transmitters) or natural (multiple propagation) echoes. Actually, the echoes may benefit instead of interfere the signal if they fall inside the guard interval.
- On the one hand, COFDM provides a considerable degree of immunity to narrow-band interferers as maybe considered the analogue TV signals; and on the other hand it is seen by those analogue signals as white noise, therefore not interfering or having little effect upon them.

All these characteristics enable a more efficient use of the spectrum (possible use of the so-called *taboo* channels, which usually are the only available ones to start new DVB transmissions); and the introduction of Single Frequency Networks (SFN).

Moreover, portable and mobile reception of DVB-T signals is possible. One efficient way to achieve that is by using hierarchical transmissions, in which one of the modulated streams (so-called HP – High Priority stream), having higher protection against errors but reducing its net bit rate, is used for portable and mobile reception; while the other one (so-called LP – Low Priority stream), having lower protection and higher bit rate, is used for fixed reception.

The ACTS MOTIVATE project, in which Retevisión participates, is currently addressing such issues, demonstrating and assessing the mobile and portable reception of DVB-T and developing algorithms and models for new enhanced receivers optimised for such reception conditions.

MULTIMEDIA AND INTERACTIVITY

Nowadays the importance for the broadcasters of offering new added value services, especially multimedia and interactivity, is out of question.

The number of applications is continuously growing and evolving. Among them: pay per view, NVoD, video on demand, home shopping, home banking, Internet access, etc.

Most of those interactive services are asymmetric; the user expects a great amount of information (several Kbps or even Mbps) but request this information through a low speed return channel (few Kbps).

DVB provides network independent protocols together with a full set of network dependent return channels (e.g. PSTN – ISDN, DECT, GSM, etc.).

The advantage of DVB transmissions is that they do not distinguish between data, video or audio (it may even be used to broadcast data which itself incorporates audio and video as some Internet pages do).

Besides, DVB-T provides the extra advantage of joining portable and mobile reception to the previously mentioned characteristics.

DVB data profiles

DVB foresees four ways of data broadcasting depending on the necessities:

- *Data piping*: asynchronous, non-synchronised, end to end data delivery.
- *Data streaming*: streaming oriented, end to end delivery of asynchronous, synchronous or synchronised data.
- *Multiprotocol encapsulation*: data services that require the transmissions of datagrams (as the ones of TCP-IP).
- *Data carousels*: data services that require periodic transmissions of data modules.

SINGLE FREQUENCY NETWORKS

Traditionally, the analogue TV broadcasting had to face the problem of co-channel interferences by prohibiting the re-use of the same channel over considerable distances. This results in an extremely inefficient use of the spectrum. As shown in Figure 1, in conventional 9-frequency layouts, each channel is prohibited over approximately 89% of the land area.

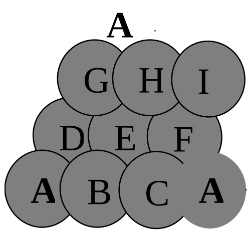

Fig. 1. MFN frequency planing for Conventional Analogue TV

An alternative to those Multi Frequency Networks (MFN) is to use a set of transmitters spread throughout a given territory (a city, a region or even a country) temporally synchronised and transmitting at the same frequency. Such configuration is called Single Frequency Network (SFN).

The advantages are enormous in terms of spectrum efficiency. Whereas in analogue MFN a single SDTV program was transmitted over 9 RF channels, now more than one program could be broadcasted using a single RF channel. 9 Times less spectrum is used than in MFN! Or, 45 times more programs (assuming 5 SDTV programs per channel) can be broadcasted using the same spectrum!

Moreover, taking advantage of the beneficial effect of the echoes inside the guard interval, less power would be needed in locations on the verge of the coverage area of two neighbouring transmitters, signals coming from both would contribute to improve the overall carrier to noise ratio.

Shadowed areas can also be served by direct reamplification using a co-channel retransmitter often called “gap filler”.

A drawback of SFNs is that the flexibility of dynamically replacing the contents of a program is lost. Effectively, all the transmitters of a SFN must broadcast the same contents in the same moment in time.

SFN Constraints

Following the main constraints that the SFN operation introduces into the network will be briefly assessed:

Synchronisation constraints

All the signals broadcasted by the transmitters of a SFN must be synchronised in terms of frequency, time and bit.

The *frequency synchronisation* requires that a common reference oscillator shall drive all cascaded oscillators within each transmitter.

The *time synchronisation* requires that each transmitter shall broadcast the *nth* symbol at *Tn* $\pm 1\mu s$ (where *Tn* denotes the ideal instant for the *nth* symbol to be transmitted).

The *bit synchronisation* requires that the same symbol shall be transmitted at the same time. Therefore all carriers shall be identically modulated. Hence the same bits should modulate the same *kth* carrier.

In order to fulfil those requirements, DVB-T provides the MIP specification [TR101191]. By means of a *SFN adapter*, located at the output of the Transport Stream (TS) generation process, Megaframe Identification Packets (MIP) are inserted periodically into the TS. Modulators use those additional packets for the time and bit synchronisation.

The synchronisation mechanisms are based on the existence of two global external references: a frequency reference of 10 MHz and a time reference of 1 pps (pulse per second); and example of a global system providing such references is the GPS (Global Positioning System).

Transmitter requirements

A complete set of specific requirements for transmitters have been identified within the framework of the ACTS VALIDATE project.

- *Frequency stability*. Each carrier should be transmitted in a frequency within the interval $f_k \pm (\Delta f/100)$. The transmitter needs the external frequency reference for synchronisation in SFN (10 MHz).
- *Oscillators phase noise*. One of the most limiting factors found during the tests of transmitters and transposers was the phase noise of the oscillators. In some cases transmitters which are perfectly suitable for PAL transmissions appear to be of no use in the case of DVB-T because of phase noise.
- *Output back-off*. The maximum power that can be obtained by a given transmitter is limited by the non-linearity effect of the amplifiers, consequently affecting to the quality of the reception. For each kind of transmitter used for DVB-T broadcasting there is a fixed output power value that maximises the coverage area. Transmitting below this value, the capabilities of the equipment are not fully used, and transmitting above, we obtain added system implementation losses, which are greater than the expected coverage gain. Typical back-off values are in the order of 6 dB or even more.

Professional Gap fillers requirements

Similar kinds of requirements stated for the transmitters are also applicable to professional gap-fillers or transposers. Though, in this case, the economic point of view should be taken into account. A transposer should be much cheaper than a transmitter, and consequently the overall requirements should not be so restrictive as for transmitters.

An additional requirement for the gap fillers is the maximum allowable gain in a given site. This gain is limited by the feedback loop gain, which is basically determined by the input/output antenna isolation. It has been proven in field tests that isolations above 100 dB, although difficult, can be feasible. The maximum gain of the transposer is then limited to the isolation value minus a security margin needed to avoid instability problems that cause strong additional implementation losses and can even produce the unavailability of the system in the area covered by the gap-filler. A typical security margin value can be around 20 dB.

Primary distribution network aspects

The primary distribution network addresses the transport of the TV signal in whatever format to the transmitter sites for its broadcasting.

The TV signal may be transported in digital format (i.e. using the MPEG-2 Transport Stream) or in analogue format (i.e. modulated according the DVB-T specification).

✓ *Decentralised generation of the DVB-T signal*

Addresses the transportation of the digital MPEG-2 Transport Stream through the primary distribution network and then modulating the signal inside each transmitter site.

The primary network may use fixed terrestrial (e.g. optical fibre, radio links) or satellite links. Various technologies or combination of them can be applied for such purpose (e.g. ATM, PDH, SDH, DVB-S, etc.).

Two major advantages arise from the use of this method:

- Flexibility: further levels of MPEG-2 multiplexing may be included, for example to provide regional programme variations, although in SFN this feature is not applicable.
- Signal quality: after the primary distribution the carrier to noise ratio is roughly preserved.

As drawbacks several DVB-T modulators are needed (one in each transmitter site) which increase the overall cost of the network and imply the need to synchronise them (see SFN Constraints). Another problem could be the jitter introduced by the multiplexing and remultiplexing processes.

✓ *Centralised generation of the DVB-T signal*

Addresses the modulation of the TV signal according the DVB-T specification at a central point and transporting through the primary distribution network the *analogue* COFDM signal.

The primary network may use fixed terrestrial (e.g. radio links) or satellite links.

The major advantage of using this method is that the number of DVB-T modulators in the network is reduced, being even possible one single modulator for the entire network. Most of the synchronisation problems of the SFN disappear, especially when using a satellite link in which not even static delays (as the ones introduced by terrestrial radio links) are introduced by the network.

Notwithstanding this method looses flexibility with respect to dynamically replace programs at the remultiplexer sites. Anyway this is not affecting in the case of SFN where no remultiplexing is allowed.

Another very important problem is that generally the final signal looses quality (i.e. the C/N is degraded in the primary distribution and this degradation can not be recovered) which translates into less coverage area.

Secondary distribution network aspects

The secondary distribution network addresses the broadcasting of the TV signal from the transmitter sites to the final user receiver.

As previously mentioned, the DVB-T provides several operation modes to adapt the signal to the radio channel characteristics. Every operation mode offers a trade-off between net bit rate that may be allocated to the TV programmes and protection of the signal against echoes, noise, fadings, etc.

Mode (FFT – GI)	Distance between neighbour transmitters
2k–1/32	2 Km
2k–1/4	17 Km
8k–1/32	9 Km
8k–1/4	68 Km

Table 6. Maximum transmitter site's separation depending on the operation mode for SFN (8 MHz channel)

An important issue for SFN is the use of *8k* modes (i.e. 6817 sub carriers), especially for wide area SFN (see Table 1), since this mode allow longer echoes (they have longer guard intervals) than the *2k* modes.

SPANISH REGULATION

Following the Spanish Technical Regulation (issued the 16th of October 1998) on Digital Terrestrial Television will be briefly described:

Channel allocation

The following frequency bands are reserved for the DVB-T service:

a) 470 to 758 MHz (ch.: 21 to 56)

b) 758 to 830 MHz (ch.: 57 to 65) – Completely available from 31 October 1999.

c) 830 to 862 MHz (ch.: 66 to 69) – Completely available from 30 June 1999.

Service planning

Four SFN national coverage channels, carrying at least four services in each channel, will be set up in the 830-862 MHz band.

One channel with national coverage and regional re-multiplexing (regional SFN), carrying at least four services, will be set up in the 758-830 MHz band. Simulcast with the analogue TV.

One SFN regional coverage channel, carrying at least four services, will be set up in the 758-830 MHz band. Simulcast with the regional analogue TV.

N channels with local coverage will be set up in the 758-830 MHz band.

The 470-758 MHz band will be used for analogue TV transmissions, MFN and local broadcasting until the *analogue switch off*, the 1st of January 2013.

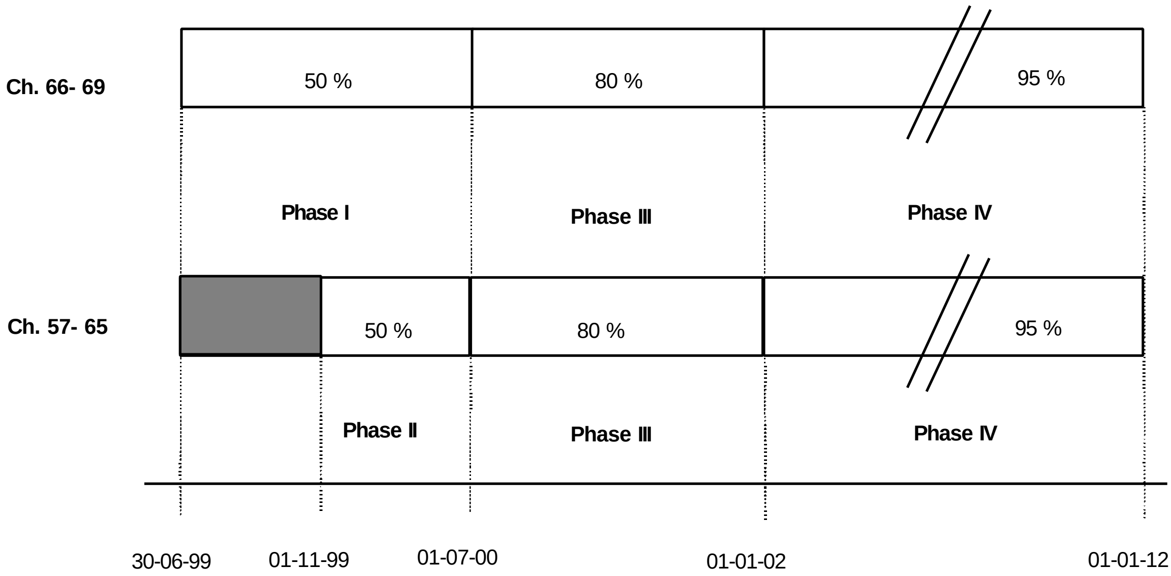

Fig. 2. Phases of the establishment of Terrestrial Digital TV in Spain

Time scale

The Figure 2 shows the four phases of the coverage plan.

The coverage is thought in terms of population, not territory.

- Phase I: SFN national channels, 50% coverage, 12 months duration from the 30th of June 1999.
- Phase II: National with regional re-multiplexing channel, 50%, 8 months duration from the 31st of October 1999.
- Phase III: all channels, 80% coverage, 18 months duration from the 30th of June 2000.
- Phase IV: all channels, 95% coverage, 10 years duration from the 31st December 2001.

Operational modes of DVB-T

The technical specifications of the Digital TV transmitters will follow the 8 MHz, 8k mode of the European Telecommunication standard EN 300 744.

THE RETEVISIÓN EXPERIMENTAL NETWORK

The experimental DVB-T network of Retevisión was built in the framework of the Spanish VIDITER project and the European ACTS VALIDATE project. It consists of two transmitters; one is located in Torrespaña (Madrid) and the other in Navacerrada (separated around 50 Km). The DVB-T emitted power is 900 W and 200 W respectively. The network also includes a professional gap filler (emitting 10 W) located 5 Km away from the Torrespaña transmitter.

Preliminary assessment of the network was carried out from February 1996 until November of the same year. Afterwards the network, configured as a Multi Frequency Network (MFN), was tested until March 1997. The objective was to gather data to establish comparisons with future SFN measurements. In parallel, several laboratory tests have been performed to verify the main parameters of the DVB-T specification.

The current SFN configuration, in channel 26, was set up in March 1998. Field tests are being done since then obtaining very encouraging results for the near future establishment of terrestrial digital broadcasting services in Spain.

The main DVB-T characteristics for SFN, always applied to the Spanish case (in terms of legislation, environment and reuse of existing broadcasting sites), were assessed in urban, suburban and rural areas.

In the framework of ACTS MOTIVATE project, the follow up of ACTS VALIDATE, more tests are foreseen during 1999 to assess portable and mobile reception.

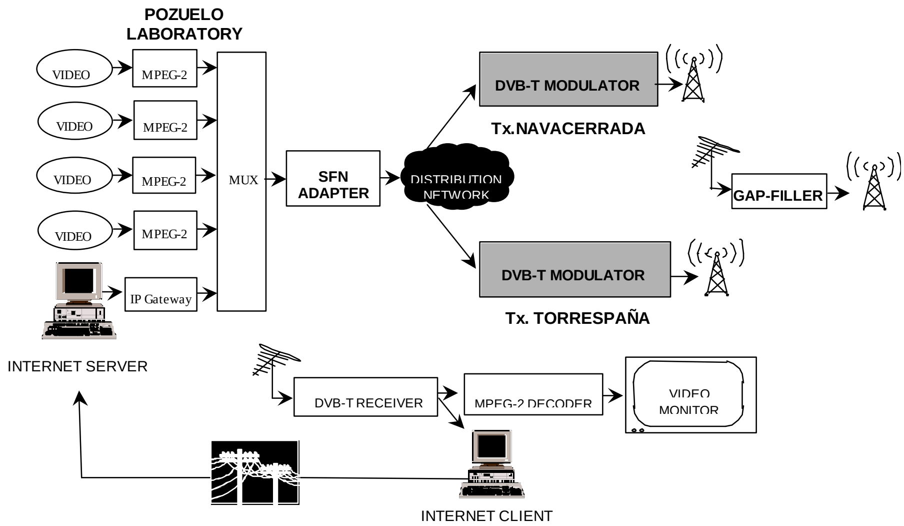

Fig. 3.Retevisión Experimental Digital Terrestrial TV network

NETWORK TOPOLOGY

Retevisión has installed a complete digital terrestrial TV chain, compliant with DVB-T, and made up of four parts:

- Production TV studio and master control room.
- Source coding, data insertion and programme multiplex.
- Primary distribution network (so-called gathering/transport network).
- Secondary distribution network (so-called broadcast network).

The production TV studio and the master control room are both located at the Retevisión's Laboratory premises, in Pozuelo de Alarcón (Madrid), and their role is to feed the experimental network with a programme bouquet (four programmes) embedded in a Transport Stream (TS). An additional data channel is also inserted into the TS in order to test data broadcasting services, like *Internet* access.

Primary distribution network

The primary distribution network has been designed to transport the signal from the Retevisión's Lab in Pozuelo up to the two transmitter sites: Torrespaña and Navacerrada.

The transport network was carrying the MPEG-2 TS from the Retevision's Lab to Torrespaña via an optical fibre link. From this point to the second transmitter site (Navacerrada), a digital radio link was used.

An important issue of the trials was related to the primary distribution of the signal, for that purpose, besides the previously mentioned methods, SDH and PDH transport of the MPEG-2 TS were both assessed.

Moreover, analogue primary distribution of the signal (decentralised generation of the DVB-T signal) was also addressed during the trials; a transponder of the Hispasat satellite was used to provide the transmitter sites with the DVB-T signal already OFDM modulated. Although the results were satisfactory this option presented a worse performance in terms of carrier to noise ratio than the digital distribution one.

Secondary distribution network

The secondary distribution network has been designed to work either as a MFN (dual frequency) or as a SFN in channel 26. As previously mentioned, the network is made out of two transmitters and a professional gap filler (or transposer).

With the current configuration, the generation of the DVB-T signal is not centralised, therefore at each transmitter site there is a modulator equipped with a GPS for the frequency, time and bit synchronisation.

The DVB-T modulators are able to reconfigure themselves using specific data sent within the MPEG-2 Transport Stream, following what has been established in the MIP specification for SFN (TR 101191).

SUPPORTING LABORATORY TESTS

Hereafter some selected results of the most relevant laboratory tests carried out up to date are presented.

Reception in AWGN

Figure 4 represents the theoretical and measured *implementation losses* with the presence of Additive White Gaussian Noise (AWGN) for 8K, 64 QAM modes. It can be observed that the actual values are always lower than 3 dB respecting the theoretical ones.

Nevertheless the measured *noise factor* value for the professional equipment is greater than the expected value, this value (9 dB) has been taken as reference for the specific coverage studies, as recommended by the results obtained in the ACTS VALIDATE project.

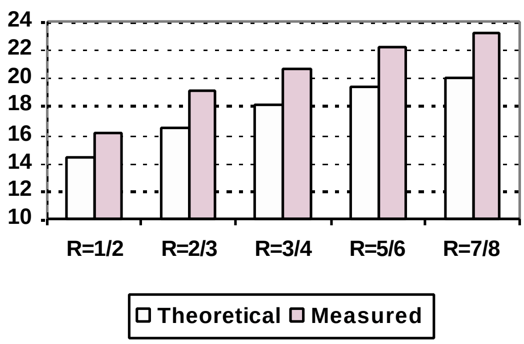

Fig. 4. C/N_{min} in AWGN

Protection ratios

The DVB-T signal presents ruggedness in front of high power PAL signals in both co-channel and adjacent channels.

The measured co-channel protection ratios (PR) against PAL signal for the mode 8K, sub-carrier modulation 64 QAM, code rate 2/3, guard interval 1/4 is about -2 dB. This means that the DVB-T signal could cope in the limit with co-channel PAL interferences if the peak sync power of the PAL signal is not more than 2 dB above the power of the DVB-T signal.

The PR measured values for adjacent channels (in the order of -24 dB) are more than 10 dB worst than the foreseen for commercial equipment.

With regard to interference from other DVB-T signals, the co-channel PR values are approximately the same ones as the C/N_{min} measured values for AWGN channel.

Multipath propagation

The performance of DVB-T against echoes has been broadly assessed and reported previously by different sources in the ACTS VALIDATE and MOTIVATE projects.

The implementation losses added ($\Delta C/N$) for 0 dB echoes within the guard interval were not greater than 8 dB in the operation mode previously mentioned (i.e. 8k, 64QAM, 2/3, 1/4).

The feasibility of receiving DVB-T signals in typical Rayleigh channels has been also tested. This issue is especially important in the case of portable and mobile reception.

Non-linearity effects

The behaviour of the system implementation losses due to non-linearity effects in transmitters and professional gap fillers has been measured in different equipment and DVB-T operation modes. Figure 5 shows the typical behaviour for 2/3, 3/4 and 5/6 code rates (8k, 64QAM, 1/4 of guard interval).

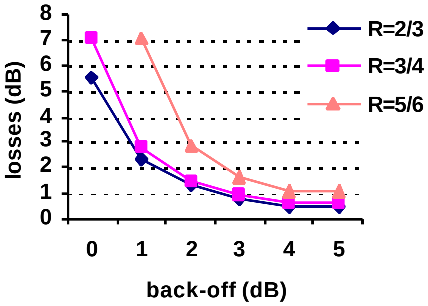

Fig. 5. Non-linearity effects in DVB-T

Feedback in SFN

When using professional gap fillers in a SFN (transposers) to cover shadowed areas, it is up to the network designer to select the gain of the different transposers in order to increase the coverage but avoiding the negative effect of a high gain due to the feedback limitations.

Figure 6 shows the behaviour of the implementation losses due to positive feedback measured in a typical transposer.

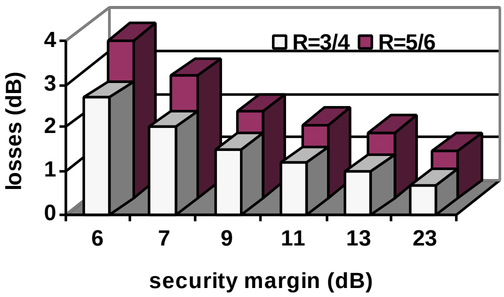

Fig. 6. Use of transposers in SFN

Effect of Phase Noise in Local Oscillators

Figure 7 shows the phase noise measured in the transposer local oscillator. It can be observed that the curve (the upper one in the figure) follows what was foreseen (the lower curve in the figure that has been issued by a signal generator). Therefore the spectral mask proposed by the ACTS VALIDATE project in ref. 9 has been verified.

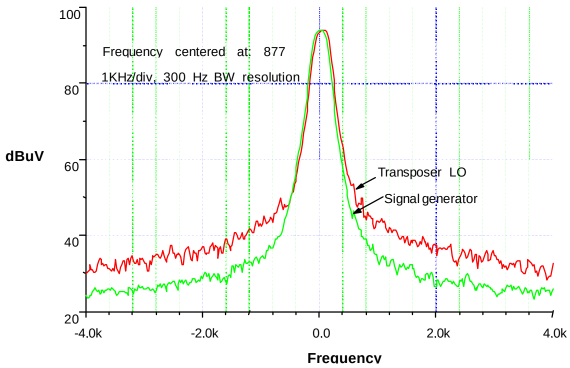

Fig. 7. Phase noise in Local Oscillators (LO)

Other measurements

Other laboratory measurements have been performed to assess the DVB-T specification in a real environment, some interesting aspects treated were: feasibility of distributing DVB-T signals through MATV installations (Master Antenna Television), technical feasibility of using *domestic gap-fillers* in SFN networks and an evaluation of the behaviour of the demodulators in presence of impulsive noise.

Laboratory tests of hierarchical modulation for portable and mobile reception have been recently started and will continue during 1999.

FIELD TESTS

Hereafter some selected results of the most relevant field tests carried out up to date are presented.

The field trials were performed in the Retevisión DVB-T network settle in the area of Madrid. The network was configured as MFN and as SFN transmitting in channel 26 (514 MHz).

A mobile unit to obtain measurements in different areas (urban, suburban and rural) was equipped with the following elements:

- A telescopic directional antenna (10 m)
- An omnidirectional antenna (1,5 m)
- A GPS receiver
- DVB-T demodulator
- MPEG-2 decoder
- TV set
- BER meter
- Field strength meter
- Spectrum analyser
- Laptop PC

The following operation modes were mainly considered during the trials:

- 8k FFT, 64 QAM, 2/3 FEC, 1/4 GI
- 8k FFT, 64 QAM, 3/4 FEC, 1/4 GI

Received spectrum

The frequency spectrum of the received DVB-T signal was measured using an ESVB and scanning it with a resolution bandwidth of 120 KHz and a step of 50 KHz.

The standard deviation (σ) of the sampled values of the spectrum within the nominal bandwidth gives an indication of the type of transmission channel. Table 2 shows the assumed classification of channels according to its σ.

Sigma	Type of channel
$\sigma \leq 1$	Gaussian
$1 < \sigma < 3$	Ricean
$\sigma \geq 3$	Rayleigh

Table 2. Types of channel

Figures 8 and 9 show the spectrum received in Ricean (typical in rural and sub-urban environments) and Rayleigh channels (typical in urban areas).

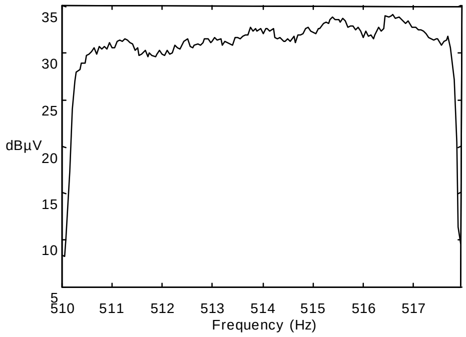

Fig. 8. DVB-T Frequency spectrum in Ricean channel (σ =2.04 dB)

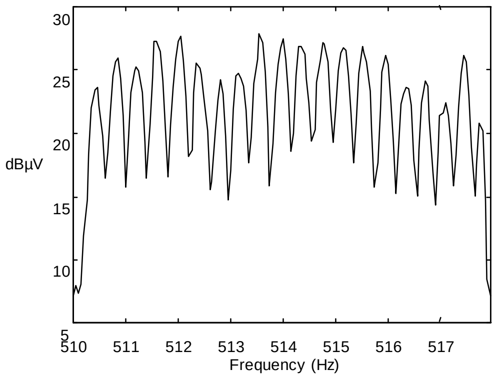

Fig. 9. DVB-T Frequency spectrum in Rayleigh channel (σ=3.48 dB)

Some areas of Madrid were presenting a strong PAL co-channel interference, however in some cases the DVB-T equipment was still able to decode and present the transmitted TV images. The received spectrum in those points looks as shown in figure 10.

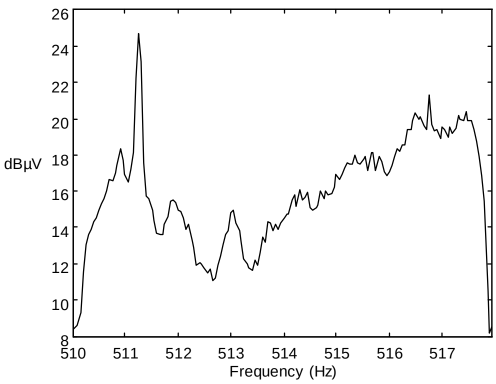

Fig. 10. PAL co-channel interference in the DVB-T spectrum

Correction factors for 70 %, 90 %, 95 % and 99 % of locations

In order to calculate the minimum field strength for planning purposes (fixed reception), the following field measurements related with the correction factors for locations in a small area (typically 100 m x 100 m) were done. It should be noted that these correction factors include effects that are not considered by propagation models (e.g. multipath).

Test procedure

Having the Yagi antenna placed at the top of a 10 meters mast, the mobile unit was following (at 5 Km/h uniform speed) a linear 100 m path. Meanwhile the measurement equipment was taking more than 1000 samples (one each 9.5 cm). The DVB-T modes examined in this test are shown in Table 3:

	Mode 1	**Mode 2**
Network type	SFN	MFN
UHF Channel	26 (514 MHz)	
FFT mode	8k (6817 carriers)	
Modulation	64 QAM	
FEC	2/3	
Guard Interval	1/4	

Table 3. DVB-T modes tested

Results

Figure 11 shows a field strength profile corresponding with a real data file. The X-axis represents the different points tested along the 100 m path and the Y-axis shows the measured voltage in dBµV. From this profile, it is possible to compute the median value ($V_{50\%}$) and additional signal levels ($V_{70\%}$ and $V_{95\%}$) where $V_{x\%}$ is defined according the following expression:

$$P(V > V_{x\%}) = \int_{V_{x\%}}^{\infty} f(v)\,dv = x\%$$

where *f*(*v*) is the probability density function

The correction factors ($C_{x\%}$) are defined as the difference between the signal level at $V_{50\%}$ and the signal level at $V_{x\%}$.

The standard deviation is computed for each set of measurements (~1000 samples).

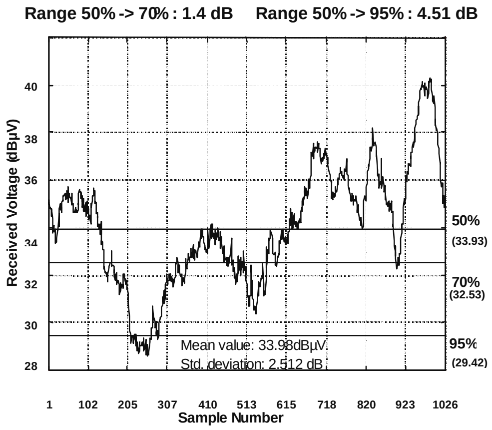

Fig. 11**.** 50%, 70% and 95% coverage levels

In MFN the estimation by means of the theoretical value (see ref. 10), i.e. assuming a log-normal distribution of the field strength for planning purposes, is on the measured values.

Figure 12 shows the field strength distribution of the values measured by the mobile unit in *suburban areas* subtracting the mean value corresponding to each route so as to emphasise the field strength dispersion.

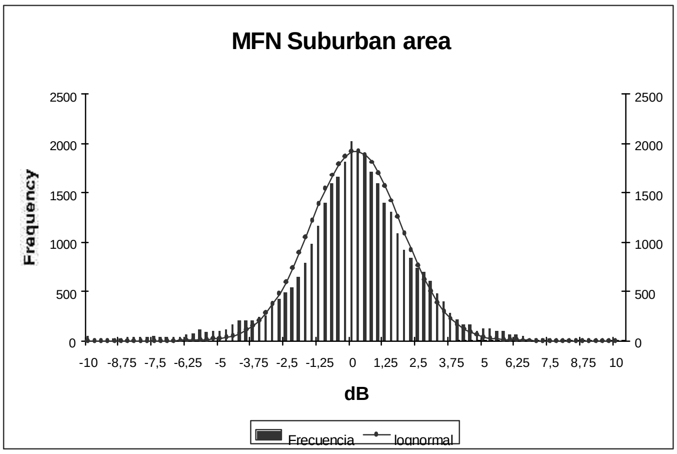

Fig. 12. Field strength distribution in suburban areas (MFN)

However in SFN the field strength can not be assumed to follow a log-normal distribution. For low coverage factors the estimation is already quite good but as coverage increases the difference between the measured and computed values enlarges, though, in principle, it depends on the network structure and the considered reception location.

Figure 13 shows the frequency distribution of the measured and computed values concerning to *suburban areas* in SFN. It should be noticed that the plotted values have been obtained subtracting to the field strength the mean value corresponding to the particular route.

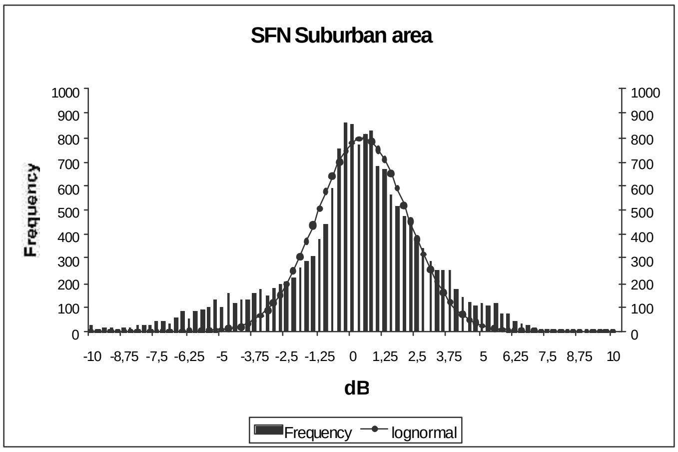

Fig. 13. Field strength distribution in suburban areas (SFN)

Analogue satellite transmissions

This test was carried out to verify the feasibility of using an analogue satellite link as primary distribution network for DVB-T signals.

The *centralised generation* of DVB-T signals and its following analogue distribution via satellite could imply certain advantages for SFN, among them:

- Possibility of using a single DVB-T modulation system for the entire network.
- Minimisation of the requirements associated with the synchronisation of the modulation process.
- Faster deployment of the broadcasting network. All transmitter sites straightforwardly covered.

But also certain important disadvantages, among them:

- Local remultiplexing not allowed. Although this is not required for SFN.
- Loss of C/N, which translates into a lower coverage area than in the digital case.

Test procedure

The transmission of the DVB-T signal was performed by means of the FM modulated system used in the analogue television and through the Fixed Satellite Services (FSS) of Hispasat.

The DVB-T signal FM modulated by a 70 MHz IF carrier was conveyed through a 36 MHz band-pass filter in order to bind the range frequency to the transponder's bandwidth.

Next, this signal was shifted to the transmission frequency by means of an up-converter so as to be boosted by a travelling wave amplification system (TWT).

The signal received from the satellite was then amplified using a low noise amplifier (LNA). Afterwards it was converted to an intermediate frequency (IF = 70 MHz) by a down-converter whose output was connected to a noise generator in order to change the C/N ratio at the FM demodulator input. In this way it was possible to check the noise margin reduction that the link was introducing.

To assess the effect of the satellite, two different tests were done; the first one, called s*atellite loop,* was as explained above, the second, called *FM loop*, consisted in modulating and demodulating in FM the DVB-T signal without the transmission to the satellite.

The DVB-T modes tested were the following ones: 8k, 64 QAM, 1/4 GI and FEC 2/3 and 5/6.

Results

Figure 14 shows the behaviour of the link (BER vs. C/N) in the cases of FM loop and satellite loop.

It should be noticed that the satellite loop not only implies a degradation of the C/N ratio but also a change in the slope of the behaviour in comparisons with the FM loop.

Other characteristics stated were:

- The 25 MHz frequency deviation was admitted as the optimum value to achieve the best C/N ratio independently of the operating mode.
- The reduction of the noise margin due to the link was approximately 3 dB for the R=2/3 mode and 8 dB for the R=5/6 mode.

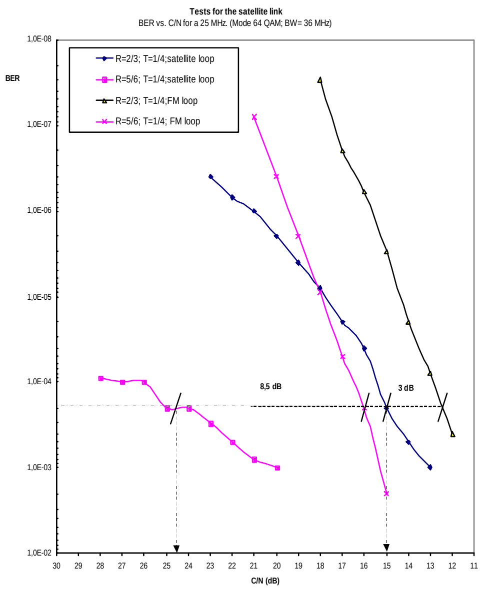

Fig. 14. BER vs. C/N

Minimum Carrier to Noise for reception

The minimum C/N for reception was also assessed during the field tests. For that more than 300 measurements were performed in portable and fixed reception with the help of the *mobile unit* previously described and using specially developed software. Figure 15 shows the fixed reception main screen, in which it is possible to visualise all the network parameters and the measurement results.

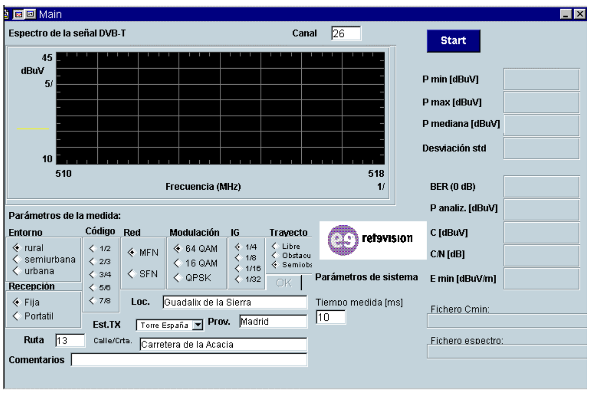

Fig. 15. Fixed reception measurement SW main screen

Hereafter the results obtained in a suburban environment, using the 8k, 64 QAM, 1/4 GI, 2/3 FEC DVB-T operational mode are represented.

All figures represent the obtained C/N_{min} in the different test points and compares those values with the theoretical ones (Ricean and Rayleigh channels). Two considerations should be taken into account:

1. 3 dB Implementation losses due to the receiver are included.
2. Theoretical values concerning SFN are under assessment. Therefore, the same estimated values are used for MFN and SFN indistinctly.

Figures 16 and 17 presents the results corresponding to the case of MFN and SFN.

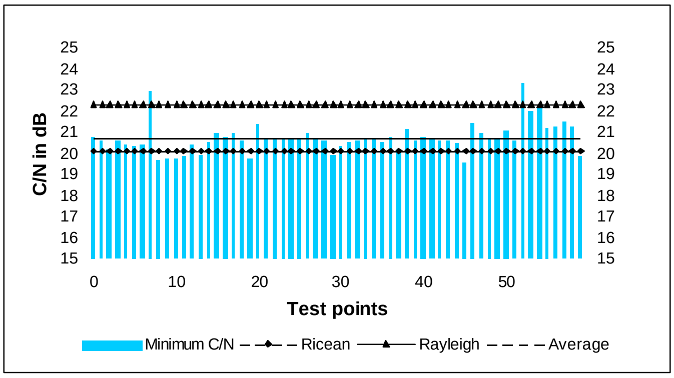

Fig. 16. MFN Fixed reception C/N_{min} measurements

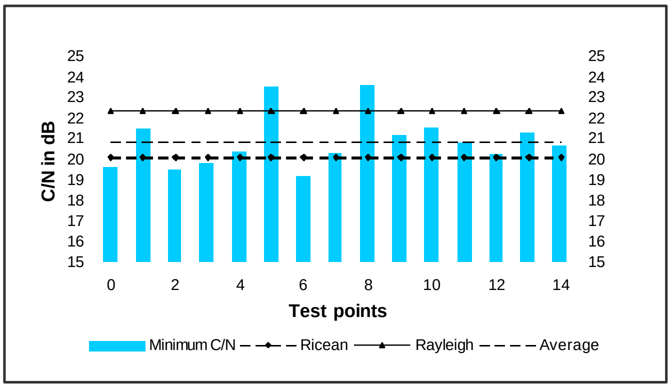

Fig. 17. SFN Fixed reception C/N_{min} measurements

In general, the received minimum carrier to noise ratio was as expected, the average value is well positioned between the theoretical Ricean and Rayleigh ones. The standard deviation is similar for MFN and SFN.

Future tests

Other field tests will be performed during 1999 to assess the DVB-T specification.

- **Multimedia and Interactivity**: Retevisión plans to start a new test campaign following the first experiences in which the feasibility of such features were demonstrated in the laboratory and experimental network, particularly with a FTP and Internet access applications.
- **Mobile Reception and Hierarchical Modulation:** *Mobile* TV reception is an important feature of the DVB-T specification that Retevisión intends to assess in depth, for that in the framework of the ACTS MOTIVATE project, a campaign of measurements will be started in short term period. The hierarchical

modulation tests are going to follow the laboratory tests carried out recently to assess the usefulness for portable and mobile reception of such modulation scheme in a real environment.

CONCLUSIONS

The most important issues related to the DVB-T specification and Digital Terrestrial TV service planning have been assessed and demonstrated in a practical case.

The Retevision experimental network has been of great importance for evaluating different aspects such as initial coverage studies, multipath channel distortions, robustness against interferences (both of digital and analogue signals), transmitter non-linear distortions, oscillator phase noise, etc.

Moreover, an important feature of DVB-T networks, the SFN configuration, has been successfully implemented, providing very encouraging results for the future Digital Terrestrial TV regular service, foreseen in Spain in the summer of 1999.

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LAB & FIELD TESTS OF MOBILE APPLICATIONS OF DVB-T

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ABSTRACT

This paper gives an overview of the performance of DVB-T in a mobile environment. Conditions and results of laboratory measurements and field trials are presented. The limits of mobile DVB-T reception are explained. Conclusions are made for the choice of suitable modes for mobile applications, both for mobile reception by consumers and for mobile transmission by broadcasters for contribution links.

INTRODUCTION

The European standard for digital terrestrial transmission (DVB-T) has been launched in the UK and Sweden and launches are planned in many other countries worldwide.

To meet the different needs foreseen by the many potential users, the DVB-T specification has several sets of closely related modes with different levels of ruggedness and different bitrates. The close relationship between the different modes means that it is easy to make one receiver that can receive all the modes of the specification with little added complexity. Any of the receiver chips on the market can be programmed to receive a wide range of modes of the DVB-T specification.

Broadcasters can trade ruggedness against bitrate. The more rugged, lower bitrate modes will be suitable for widespread portable reception, whereas the less rugged, higher bitrate modes will be suitable for transmission of a multiplex of many programmes (as currently used in the UK and Sweden), or even HDTV, to receivers using rooftop aerials.

When the DVB-T specification was being prepared in 1995, mobile applications were not seen as very important. But since then in Germany, where there is already a high penetration of cable and satellite reception, mobile reception has been identified as a unique selling point for digital terrestrial TV. Work by Deutsche Telekom reported in the VALIDATE project showed that mobile applications of DVB-T are feasible using the more rugged modes of the specification.

A lot of work has been performed since then to evaluate the mobile applications of the DVB-T standard. This paper gives an overview of the major results obtained.

The MOTIVATE project

The ACTS project MOTIVATE (**Mo**bile **T**elevision and **I**nno**vat**ive R**e**ceivers) started in May 1998 to investigate the mobile and portable reception of DVB-T. MOTIVATE builds on the work of VALIDATE [1], which successfully verified the DVB specification for terrestrial broadcasting.

MOTIVATE investigates the practical and theoretical performance limits of DVB-T for mobile reception. It builds on the strong consortium shown in Table 1. The project has the backing of a number of sponsoring partners (TeleDanmark, RTÉ, DVB promotional module, TU-Munich and BMW, TU Braunschweig, NDS) making MOTIVATE the spearhead for the implementation of mobile DVB-T services.

The MOTIVATE project investigates coverage aspects for DVB-T services by using simulation and prediction tools and by measuring the performance of DVB-T in both laboratory tests and field trials. The network topology is being optimised by the selection of the antenna polarisation, the combination of MFNs and SFNs, the use of gap-fillers, microcell/macrocell and the choice of suitable DVB-T modes (modulation, code rate, guard interval). Partners in MOTIVATE adapted existing planning software for DVB-T urban networks and first mobile DVB-T measurements were performed and compared with prediction models. One main outcome of the project will be implementation guidelines for mobile DVB-T reception to set up transmitter networks.

LABORATORY TESTS

In 1997 Deutsche Telekom carried out laboratory tests to investigate the performance of an early commercial DVB-T receiver in a mobile environment in the 2K mode. Using a two path model with Doppler shift they identified three suitable DVB-T modes: QPSK, 16-QAM and 64-QAM each with code rate 1/2.

The following thresholds of the minimum receiver input voltage for the AWGN and the mobile channel were measured:

Threshold	QPSK	16-QAM	64-QAM
AWGN	16 dBµV	22 dBµV	30 dBµV
Mobile	22 dBµV	29 dBµV	38 dBµV

Table 2. AWGN and Mobile thresholds

In November 1998, Deutsche Telekom Berkom and ITIS organised a series of laboratory tests to evaluate the behaviour of state-of-the-art receivers and to study the performance limits of the DVB-T standard in a mobile environment. An additional objective was to provide a test-bed that would allow ‘Laboratory Mobile tests’ to be done in a controlled environment.

The test methodology was based on the observation of a Subjective Failure Point (SFP). The SFP aims to estimate the ‘limit of good reception’, where impairments become visible on the recovered video signal. Twelve different DVB-T modes were used. The test evaluated first, for each receiver in each tested mode that it was capable of receiving, the level of Gaussian noise to give the SFP. Then a channel simulator programmed with one of the three COST207 channel profiles described below was added, adjusted for a specific profile and a given speed (i.e. : a given Doppler characteristic), and the noise level adjusted to give the SFP. The difference between the two noise levels characterises the loss of noise margin for the receiver at a given speed.

Another measurement performed was to increase the Doppler component in a given profile (without added noise), to evaluate the maximum speed allowed by the receiver under test. This arrangement was particularly useful for comparing

Table 7. Partners in MOTIVATE

BBC	UK	NOZEMA	NL
Robert Bosch	D	RAI	I
CCETT	F	Retevisión	E
Deutsche Telekom Berkom *	D	Rohde & Schwarz	D
EBU		TDF	F
IRT	D	Televés	E
ITIS	F	Teracom	S
Mier Comunicaciones	E	Thomcast	F
Nokia	SF	***** -Coordinator	

the effects of the different modulation parameters on the mobile capability of the DVB-T standard. The results of this test are shown in the figures on the following page.

Channel Profiles

The tests used a channel simulator programmed with three COST207 channel profiles selected to reproduce the different environments in which mobile reception may be envisaged. In order of increasing difficulty for the receiver they were:

SFN like : two paths coming from transmitters located in opposite directions,

Typical Urban : six paths, having short delays and high amplitude and phase variations,

Typical Rural : six paths, having long delays and variable amplitude and phase variations.

DVB-T receivers

The nine receivers evaluated during the tests are listed in Table 2. They were designed for different purposes (prototype, professional product, consumer receiver, experimental demodulator). Except for the experimental demodulator, none of them had been especially optimised for mobile reception.

Laboratory tests conclusions

The measurement results made clear that mobile DVB-T reception is viable, even with receivers not especially designed to cope with the difficult characteristics of a terrestrial mobile channel.

Globally, the results obtained from the set of receivers are comparable. Only the experimental demodulator, which implements some original demodulation solutions intended for mobile reception, gives better results in certain circumstances.

'MOTIVATing' results were obtained for at least six DVB-T modes (three R=1/2 modes for the 2K and 8K modes) which seem to be suitable for mobile reception – confirming the earlier test results of Deutsche Telekom.

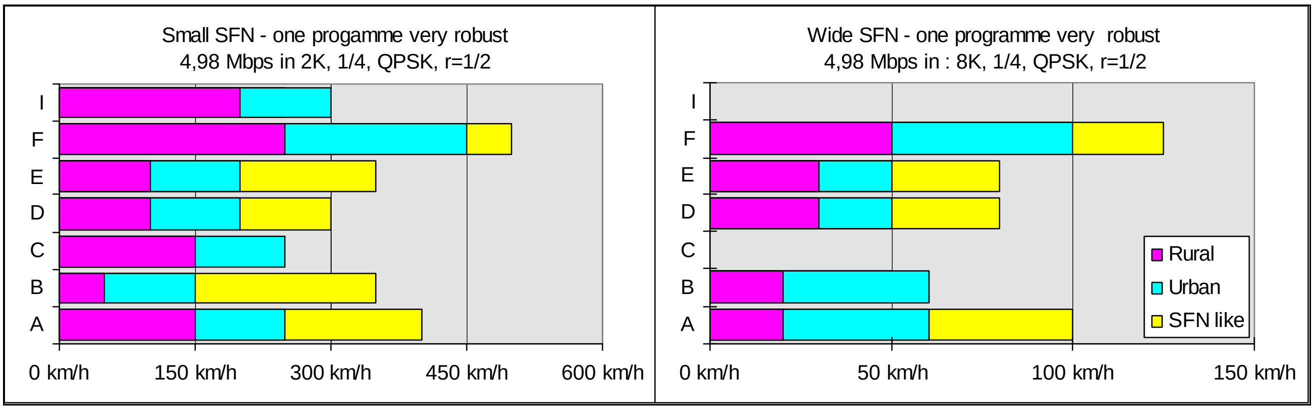
Table 3 Some details of the receivers used in laboratory tests

ID	Type	Capability	Chip-Set
I	consumer receiver	2K	Integrated chipset, same as C
H	prototype	2K/8K	Discrete components
G	consumer receiver	2K	Integrated chipset
F	experimental demodulator	2K/8K	Discrete components
E	professional receiver	2K/8K	Discrete components
D	consumer receiver	2K/8K	Integrated chipset, same as B
C	professional receiver	2K/8K	Integrated chipset, same as I
B	professional receiver	2K/8K	Integrated chipset, same as D
A	professional receiver	2K/8K	Integrated chipset

LABORATORY TESTS RESULTS

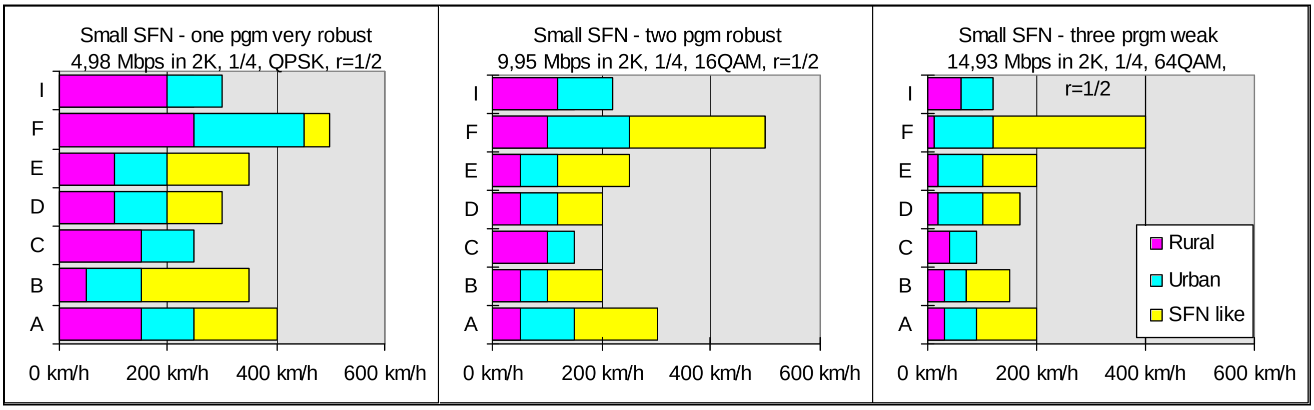
The following graphics show, for different DVB-T transmission modes and the three channel profiles, the 'maximum speed acceptance' of the receivers.

- ***Mobility vs. FFT size***



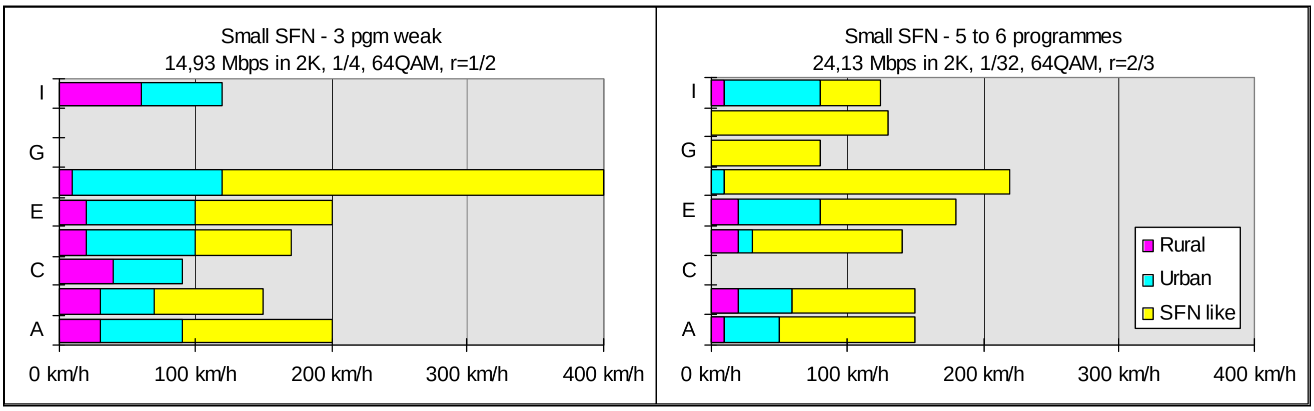
The FFT size reduces the maximum speed, roughly in proportion to the inter-carrier spacing or in proportion to the total symbol duration (including the guard interval).

- ***Mobility vs. Constellation***



Although the effects of the channel profiles show wide variations between the different receivers, the performance degradation is closely related to the density of the constellation used.

Mobility vs. Coding Rate



Although the guard intervals selected in the two modes shown are not identical, it is clear that the receiver performance in a mobile environment is heavily dependent on the coding rate, or the protection given to the useful data.

FIELD TRIALS

Field trials in Cologne

In 1997 Deutsche Telekom conducted field trials to study the performance of a DVB-T receiver in real mobile environments in the area of Cologne. The ERP of the transmitter was 1 kW in UHF channel 40 (626 MHz). The three DVB-T modes with code rate ½ were used as indicated by the laboratory tests mentioned above.

Three different routes were chosen for the field tests, one on the Cologne motorway and two in the city. The received input power and a subjective parameter for the video quality condition (go, no-go) were stored during the trips. The measurements were performed several times by varying the additional power attenuation (0 dB, 6 dB, 12 dB) of the received DVB-T signal for each route. Figure 1 shows an example of a measured curve (field strength versus distance) of the QPSK case with 6 dB attenuation. The two vertical lines indicate errors in the received video sequence.

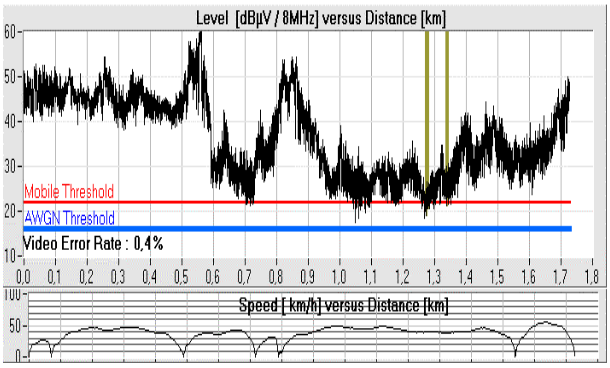


Figure 1. QPSK CR=1/2 with 6 dB attenuation

The main objective of the field tests was to check the mobile thresholds identified in Table 2 in a real mobile environment. If the thresholds are correct then a prediction of the expected video error rate for the route can be given on the basis of a field strength prediction.

The field tests confirmed the results obtained from the laboratory tests of the DVB-T modes with the simple 0 dB artificial echo model. For the receiver used, the thresholds in Table 2 guarantee faultless mobile video reception. The identified mobile thresholds correspond to a coverage probability of 99%. These thresholds can be seen as a first basis for the planning of services.

More details of the field trials in Cologne and the preparatory laboratory tests are given in [2].

Field trials and demonstration in Amsterdam

In 1998 MOTIVATE carried out a field trial in Amsterdam in preparation for a demonstration at the International Broadcasting Convention.

The PTT tower (65 m above ground level) near the RAI exhibition centre was used for broadcasting a test signal for mobile reception on channel 34 (578 MHz). The ERP of the transmitter was 880 W. The test mode was 2K 16QAM code rate=1/2 and guard interval=1/32. The useful bit rate in this mode is 12.06 Mbit/s, enough to transmit up to three TV programmes. The choice of guard interval 1/32 was possible because the surrounding country is very flat, so long-spaced echoes were unlikely – an illustration of how the flexibility of the DVB-T specification can be exploited to maximise the transmitted bitrate.

The coverage prediction was confirmed in the investigated area in most cases. Two parameters were stored simultaneously as the measuring van passed along the streets. The first one was the received input power and the other one was a subjective assessment parameter for the video quality condition (go, no-go). The reception area was up to approximately 3.5 km from the PTT tower inside the 60 degree beam of the transmitter. Nevertheless, there were many areas of error free reception outside the 60 degree beam.

As a result of measurements a main road circular route of 8 km with changing reception conditions was identified for the demonstration. Figure 2 shows the field strength along this route. There are very high dynamics in the field strength behaviour. The values are between 50 and 105 dBµV/m. DVB-T reception was possible all the way round, although it was marginal at some points.

The identified minimum receiver input voltage of 29 dBµV (see Table 2) for mobile reception in the 16-QAM mode used was confirmed by the tests in Amsterdam. With the configuration used in the van, this threshold corresponds to a necessary field strength of about 47 dBµV/m. The speed of the van did not give any restrictions of mobile reception in the DVB-T mode used. Field strength was the only critical factor to have good mobile reception. No effects of impulsive interference, which could be generated by vehicle engines or trams, were noticed.

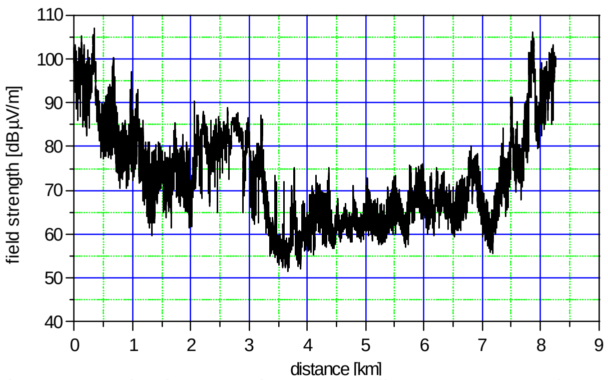


Figure 2. Field strength versus distance along the selected route in Amsterdam

During the pre-IBC field trial it was possible to carry out a mobile experiment with hierarchical modulation using the following mode: 2K QPSK-in-64QAM α=2 HP-rate=1/2, LP-rate=2/3 GI=1/32. This gives a bitrate of 6.03 Mbit/s for the HP stream and 16.09 Mbit/s for the LP stream. Both streams were decoded simultaneously, using two MPEG decoders and two monitors. While the van was on the road the system behaved exactly as one might expect: the HP stream was decodable for almost all the time and the LP stream was decodable for only some of the time (e.g. while stationary at traffic lights). Hierarchical modulation offers the possibility of broadcasting services for portable or mobile reception in the same channel as services for fixed rooftop reception; this possibility is discussed in more detail in [3].

Mobile reception was demonstrated throughout IBC. About 250 people from 30 different countries saw the demonstration. Several of them singled it out for mention during and after the Convention.

At a session on choosing a digital terrestrial system Phil Laven, Technical Director of the EBU, said "You must see the IBC '98 demonstration of mobile reception of DVB-T at 12 Mbit/s put on by the ACTS MOTIVATE project". In a final session summing up the show, Norman Green, a respected figure in broadcast engineering in the UK, said the mobile TV demonstration was the most significant demonstration of the show.

In a Conference Panel Session on Sunday afternoon, Barry Fox, the leading technical journalist on broadcasting and IT matters in the UK, spoke of "this incredibly impressive demonstration that Deutsche Telekom are running." In his column 'Set top Fox' in the last issue of IBC Daily News, Barry Fox wrote "Most exciting demo of the show? The Deutsche Telekom mini-van with two TV sets on board that has been driving delegates around town. ... The PAL picture is unwatchable .... The digital set is rock-steady with only an occasional mute." After IBC Barry Fox published an account of the demonstration in the UK weekly science and technology magazine *New Scientist*[4].

Field trials in Dublin

The tests described above concentrated on mobile reception of DVB-T. If mobile reception is possible, it follows that mobile transmission and fixed reception is also a possibility. This application could provide broadcasters with a mobile contribution link. In 1998 RTÉ demonstrated mobile transmission of DVB-T during field trials in Dublin.

In these tests an MPEG-2 test sequence was transmitted from a vehicle in Dublin and received at the Three Rock transmitter site. The vehicle had a 10 W transmitter operating on UHF channel 30 (542 MHz) and a log periodic antenna on a mast for stationary transmission or an omnidirectional whip antenna for mobile transmission. The DVB-T mode was QPSK code rate = ½. Reliable reception of a 6 Mbit/s MPEG-2 transport stream was achieved from 24 sites ranging in distance up to 18 km (two stationary with the mast extended, five stationary with the whip antenna, the rest at speeds up to

65 km/hr). Three additional sites gave usable sound but errored vision signals.

THE RATIONALE FOR MOBILE APPLICATIONS

The laboratory tests and field trials described above have shown that mobile applications of DVB-T are feasible. But how will they be introduced in practice?

Mobile transmission

A vehicle equipped with an interview position, camera, and DVB-T equipment could be used as a mobile TV studio. It could also be used as a base station for one or more radio cameras. With the vehicle stationary and a directional transmitting aerial on a pneumatic mast, a DVB-T mode could be used with a high enough bitrate to allow post-processing (say about 9 Mbit/s). With the mast down and the vehicle in motion, a more rugged lower bitrate mode of the DVB-T specification could be used to give sufficient quality for news inserts – for instance to interview a busy politician on the way to the airport.

Such professional applications can be used by broadcasters in any country, irrespective of the standards used for broadcasting to the public.

Mobile reception

Services for mobile reception will be only one potential application for broadcasting spectrum. Since the available bitrate is lower for mobile services, and the transmitted power has to be higher, a business case has to be made out for this application. The availability of spectrum and the broadcasting business situation are different in different countries, so it is likely that the balance of services for fixed and mobile reception will also differ.

In the UK, for example, terrestrial television may remain the prevalent distribution medium. The initial application of DVB-T is to provide more channels to increase the choice; mobile reception is seen as an interesting possibility for the future as analogue services are switched over to digital. In other countries – such as Germany – there is a much higher penetration of cable and satellite: only 6.8 M of the 36 M German households rely on terrestrial broadcasting. DVB-T could overcome some of the limitations of analogue terrestrial TV but this alone would not guarantee a successful introduction of DVB-T services: added value services are needed to attract more users and increase revenues for broadcasters and network providers. Mobile reception of video, internet and multimedia data could be an attractive feature to help the launch of DVB-T in Germany. Only terrestrial broadcasting could bring mobility to the end user.

CONCLUSIONS

Laboratory tests and field trials have shown that mobile applications of DVB-T are feasible using the code rate = ½ modes of the specification. A data rate up to 15 Mbit/s using one 8 MHz UHF channel is possible with the 64-QAM mode.

Mobility is one of the advantages of the European DVB-T solution against competing standards. The other is its flexibility, allowing different applications to suit the differing circumstances of different countries – or the business needs of different operators within a country – using common receiver technology.

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Proceedings of ITS '99 Montreux

AUSTRALIAN ASSESSMENT OF DTTB

Richard M Barton Facts - Australia

BACKGROUND

Australian experts have been involved throughout the development of HDTV and digital television options, from the debates on HDTV standards in the mid 1980's through to the present. Particular attention has been paid to the International Telecommunications Union (ITU-R) forums where Australian experts have consistently pressed for a common international standard. The ITU was seen to be the main forum in which to argue for convergence of television standards for the new technology choices, so as to avoid the need for continuing standards conversion and consequent operational and quality difficulties.

Early work on the use of OFDM published by the IBA in the UK and in other European studies showed similar promise to parallel work on a system to develop HDTV terrestrial broadcasting in the USA. The Australian broadcasting experts identified a need for the ITU to provide a common forum where these disparate studies could be drawn together in an attempt to evolve, for the first time, a world- wide common system of television broadcasting. As a result of an Australian proposal to ITU-R Study Group 11, Task Group 11/3 was established with the objective of preparing a common set of digital terrestrial television broadcasting (DTTB) standards.

The success of Task Group 11/3 has been well documented elsewhere. It was very successful in fostering a high level of convergence between the North American and European DTTB systems. In one essential area, it was not successful. Two systems for modulation emerged, and could not be reconciled. In the US, a single carrier 8VSB modulation system was formally adopted. European countries confirmed their adoption of a multiple carrier Coded Orthogonal Frequency Division Multiplex modulation system (COFDM). In part, these differences reflected the different market environments into which the digital technology would be implemented. In the US, there is a highly competitive localised broadcasting industry. In Europe, national broadcasters still predominate, and there is a tightly interference-limited international plan for all of Europe. Towards the end of the studies of Task Group 11/3, Japan announced that it was working on a third modulation variant which would offer segmentation of the RF channel but, like DVB, basing its system on the use of OFDM modulation.

AUSTRALIAN BROADCASTING ENVIRONMENT

The Australian television industry closely parallels the US industry in its structure. Commercial networks with affiliated stations are a dominant force, whilst the two Government-funded national networks (ABC and SBS) also draw significant audiences. On the other hand, the technology base of the industry is essentially of European origin, being built on 50 Hz PAL analogue.

Australia has a very diverse range of requirements that needed to be addressed in assessing the most suitable technology for the introduction of DTTB.

- Approximately half the population is concentrated in the two largest cities, Sydney and Melbourne. These cities have extensive urban and suburban characteristics;
- There are several other cities that have significant concentrations of urban and suburban characteristics;
- The remaining population is spread over a very large proportion of the country with many concentrations of small to medium towns having suburban characteristics.

- For a very large part of the country, the population levels are relatively low but have economic importance to the country from rural and mining activities;

In order to ensure that the Australian needs could be technically assessed for the conversion to digital television industry committees actively studied the potential of DTTB through the years from 1990. The studies lead to the production of progressive reports addressing the issues to be examined and the findings recommending the direction the Government should consider in legislating for the implementation of DTTB. These reports are identified in the references.

As part of those studies, the commercial television industry body, the Federation of Australian Commercial Television Stations (FACTS), together with the Government's Australian Broadcasting Authority and Communications Laboratory, conducted extensive testing of the two available complete DTTB systems – the European DVB-T (COFDM) and the USA ATSC (8 VSB). These comparative tests, both laboratory and field, were the first direct comparison of the two systems and have attracted wide interest. Detailed reports on the Australian tests can be found in the references

In 1997, the Australian Government legislated for the introduction of digital television. In the legislation is defined a number of key requirements.

- Digital broadcasting to commence in the main capital cities by January 1, 2001
- Existing broadcasters would be "lent" an additional full TV channel for DTTB
- Commercial broadcasters must provide HDTV but may not multi-channel
- Broadcasters must provide the same program on digital and analogue
- Coverage must match the analogue coverage as soon as practical
- Broadcasters may use spare capacity for datacasting
- Datacasting services to be licensed in the broadcasting bands

CHOOSING A SYSTEM.

The Australian terrestrial broadcasting industry appointed a panel with representatives from of the main network and regional broadcasting interests. Representation of Government was also included with participants from the Department of Communications and the Arts and from the Australian Broadcasting Authority. The group was established for convenience by FACTS who provided the secretariat for the panel. The group was titled the FACTS DTTB Selection Panel and its basic terms of reference were to examine all the available information and recommend a DTTB system for Australia.

In preparation for the first meeting, members submitted suggestions for the criteria that should be used in assessing the choice. The consequent list was refined and used as a guide for the final recommendation. The Panel met four times with its final meeting taking place on June 18, 1998.

The Panel was unanimous in its view that all free-to-air television broadcasters should use a common standard to ensure commonality of equipment and minimum cost to viewers. The evaluation process that was used assisted in clarifying the merits of each system in the context of the Australian broadcasting environment, and the process of planning for the transition to digital television.

The evaluation of the technical comparative tests played an important part in the considerations of the Panel. While the tests showed some relative strengths and weaknesses of the two options the Panel felt that there was insufficient information for technical assessment of some relevant criteria. In particular, this applied to translator performance, indoor antenna performance and carriage through Master Antenna Television systems. It was considered that each of these matters would require further testing and evaluation. Preliminary arrangements were made to obtain equipment to address each of these issues but were not progressed for comparative testing following the decision to recommend DVB.

ESTABLISHING THE SELECTION CRITERIA

Starting from an initial list of some 50 possible criteria, the Panel researched, analysed and refined the list to those criteria that were considered to have relevance for the selection. Individual elements were grouped into sets of related criteria that were then further refined by full discussion.

Elements not included in the selection

As a first step, those criteria that did not show a material differential in performance between the systems were identified as not being significant in making the choice. It was thought, however, that those elements still needed to be thoroughly considered in designing the overall system. For the purpose of the Australian choice, they were assessed as providing basically the same performance for either of the systems considered. Criteria considered to be in this category included:

- Need for co-siting
- Availability of transmission, modulation and multiplex equipment
- Compatibility with digital studio-to-transmitter links and satellite program services
- System operating costs
- Multi program/multi-channel support
- Arrangements for program associated data
- Arrangements for non-program associated data
- Stability and reliability of the technology
- System upgrade and further development capability
- Consideration of set-top boxes
- Interoperability with VCR's
- Receiver operating system
- Electronic program guides
- Conditional access

Receiver and set-top box MP@HL capability

Interlace vs progressive scanning (receivers)

Baseband input (receivers)

Other elements which might have affected the choice but were not able to be quantified were:

Technology royalty costs

Location of receiver manufacturing.

Elements included in the selection

The following elements were identified for including in the assessment with the associated explanatory notes.

1 COVERAGE

In general, the coverage would be expected to match that achieved by PAL. It is clear that the nature of DTTB, which suffers from the "cliff effect", will mean that the coverage will not be identical. There will be some levels of lesser performance arising from the power limits imposed by non-interference to PAL because of the expected extensive use of channels adjacent to the existing PAL services for DTTB. The main city allocations are expected to use the single channel gaps in Band III. On the other hand, for some aspects such as ghosting limitations there will be areas of improved reception performance. With different characteristics between 8VSB and COFDM, the different elements need to be judged on the relative coverage potential, weighted to the affected proportion of the audience. Eventually it can be assumed that, after cessation of PAL, coverage can be improved by raising power levels to that needed to match the existing PAL coverage. Coverage was assessed in different categories; each weighted in accordance with the Panel's assessment of importance.

- **Percentage of primary coverage area population served**
- **Percentage of secondary coverage population served**
- **Set-top antennas performance**
- **Mobile reception capability**
- **Co-channel performance**
- **Adjacent channel performance (d-a, a-d & d-d)**
- **Multi-path performance**
- **Immunity to electrical interference**
- **Ability to be conveyed in MATV and cabled systems**

Although as indicated above detailed comparative tests of indoor antenna performance were not able to be carried out in the time available, the relatively high proportion of viewers in urban and suburban environments (up to 30 %) meant this was an important element.

Mobile reception was seen as a future extension service rather than a prime criterion.

2 SYSTEM DESIGN ELEMENTS

This group of criteria mainly addressed the relative cost elements to broadcasters in implementing the DTTB system with respect to the transmission infrastructure and associated program service distribution systems.

- **Combining to use common transmit antennas (PAL & DTTB)**
- **Ease of use and cost of implementing translators**
- **Common Channel Translator (CCT) capability**
- **Ability to use existing transmitters**

Initial planning had indicated the expected use of adjacent channel PAL/DTTB operation with preference for using a common antenna.

3 OPERATIONAL MODES SUPPORTED

This group of criteria addressed the flexibility of the systems to offer service modes that may be needed. In this regard the Australian Government policy decision for HDTV and possibly multi-channel for national broadcasters, as well as the provision for datacasting, needed to be taken into account.

- **HDTV support**
- **Support for closed captions**
- **Support for multi-language audio**
- **Audio System**

The requirements for closed captions and for HDTV were essential to meet the legislated requirements. The other elements related to meeting perceived audience expectations.

4. OVERALL SYSTEM

- **Adoption of an accepted rather than unique system for HDTV**
- **Performance within a 7 MHz channel**
- **Number of useful MBPS per 7 MHz channel**
- **Overall encode/decode delay**
- **System upgrade and further development capability**

5. RECEIVER ELEMENTS

This group of criteria addresses the important aspect of availability of receivers suitable to meet the broadcast service objectives for Australian digital television broadcasting. Australia's relatively small market for major consumer products implies some need for commonality with a larger market base if costs are to be minimized.

- **Receiver availability features and cost**
- **Receiver and set-top boxMP@HL capability**
- **Receivers with both PAL and DTTB capability**

- **Receivers not specifically designed for Australia**
- **Receiver applications software upgrades and tools**
- **Receiver lock-up time**
- **Ability to provide automatic channel selection for Australian channeling**

ASSESSMENT

In conducting its assessment the Australian DDTB Selection Panel used the results of the laboratory and field trials, the available data on the characteristics of the Australian terrestrial television market and the accumulated theoretical knowledge built up over several years involvement in the study and development of digital television. It was necessary to take into account the government legislation requirements, particularly the need to provide for HDTV, the simulcasting of programs and the need to provide equivalent coverage to that provided by current PAL broadcasting.

The Panel agreed not to disclose the final values derived from their numerical assessment. It considered these to be specifically relevant to Australian broadcasting, and possibly open to misinterpretation if used out of full context. Instead, it was decided that a summary of the Panel's deliberations should be reported in order to explain the reasons behind the final recommendation.

It was noted that the process being used was to provide guidance to the Panel for its determination of the recommendation. As such the scoring was similar to that used to score a boxing match, but it varied by applying the importance weighting to the final points allocated.

COVERAGE

It had been hoped that the data available from the Australian tests, supported by the field test and theoretical performance data from overseas tests, would allow detailed assessment of the coverage potential of the two systems. In the time available, this proved not to be feasible. While ATSC had specific advantages in simple carrier to noise performance and impulse noise, DVB had shown advantages in environments with significant or complex multipath.

It was considered that thorough analysis would require detailed quantification of such elements, with the variations applied to detailed coverage analysis. Given the time constraints applicable, this level of analysis was not possible. The significant reliance on indoor antennas (up to 30% of households in some Australian markets, according to survey figures provided to FACTS) was an important factor for the Panel's assessment.

The Panel's assessment also had regard to the Australian approach to achievement of television coverage areas. This is based on moderate power main transmitters supported by networks of translators in the significant outlying areas. There is an average of 10 translators for each main transmitter.

Percentage of primary coverage area population served

The Panel noted the differences between ATSC and DVB with respect to C/N. It also considered the effect of ghosting on each system. It considered that ATSC may have an advantage for the outer service area with roof top antennas, but that the modifying effect of ghosting reduces the margin, particularly in obstructed reception areas. For severely obstructed areas, typified by dense urban developments, the multiple ghosting may give the advantage to COFDM.

Percentage of B coverage population served

The performance of the two systems beyond the nominal "primary" coverage area is less certain from the data available. In the areas where the angle of arrival is low there are more areas with partially or fully obstructed reception. In Australia the use of masthead amplifiers is common in the outer service areas.

Given the policy direction of the Australian Government to ensure DTTB availability to all current PAL viewers, the Panel needed to address the coverage question from two aspects. The first related to the transition period, when non-interference to PAL would set a power limit on DTTB. The second related to the period after termination of the PAL service, when power levels could be increased to provide full coverage.

Finding 1

On balance, the Panel considered the differences with respect to coverage to fixed roof top antennas to be marginal rather than significant and did not indicate a preference for either system.

Set-top antennas

The Panel considered this issue could be set aside during the initial assessment. It remained a substantial issue, given the high proportion of Australian viewers using set-top antennas, but further testing and analysis was needed before any objective differential assessment could be made. While there was satisfaction that the DVB-T system performed adequately, the ATSC system was yet to be fully tested. Although the Panel considered that on all available information COFDM would perform better it was decided that if this factor were potentially decisive in determining the choice the need for further testing would be addressed, even if that required a delay in the decision. However, in finalizing the assessment, it was evident that the decision would not be affected by the results of further testing.

Finding 2

While the Panel was satisfied that COFDM would provide adequate set top antenna performance and there was doubt if the ATSC system would perform as well, this was not demonstrable from the comparative test carried out. The relative in door performance was not considered in the final decision although it remained an important factor. There was no expectation that the ATSC system would perform better than COFDM.

Mobile reception

Mobile reception is not expected to be a major consideration for Australian television broadcasters. However, it was recognised that mobile broadcasting may have application for narrowcast (specific targeted audiences) and for datacasting. The latter is specifically addressed in Australian legislation for the introduction of DTTB. Although the mobile mode had not been tested, the Panel had participated in demonstrations of QPSK mobile mode for DVB. Although ATSC advised the potential for a 2VSB mode there was no indication of the potential being realised by practical development and marketing.

Finding 3

Only DVB offered a realistic mobile option.

Co-channel performance

The testing had demonstrated that DVB showed advantages in relation to interference between analogue and digital, while ATSC had an advantage in relation to non-coherent (i.e. unrelated program material) digital to digital interference.

Interference between analogue and digital will be important during the transition, while interference from digital to digital may be important both during and after transition.

On balance, the Panel decided not to allocate a preference.

Finding 4

The panel considered that the co-channel performance differences of the two systems largely balanced and did not provide a significant deciding factor.

Adjacent channel performance

The Panel considered that both systems provided adequate performance to meet the Australian planning requirements.

Finding 5

Both systems have adequate performance

Multipath Performance

The Panel considered that the tests showed this element was more adequately covered by the DVB system than ATSC, particularly for dynamic ghosts and complex ghosting in low signal strength areas.

Finding 6

DVB provides a better all round performance for multipath.

Immunity to electrical interference

The test established that the ATSC system had a significantly better immunity to impulse noise than the DVB system. This will be a useful improvement in the VHF band and in urban environments.

Finding 7

The ATSC system is significantly more resistant to impulse noise.

Ability to be conveyed in MATV and cabled systems

The Panel considered this issue was dependent on the way MATV systems were implemented. Many MATV systems use IF translation, while some more complex systems may use full demodulation and remodulation. The main domestic systems are either direct amplification or IF translation.

The Panel considered this issue could be left out of the current assessment because it was still an issue that had not been clearly resolved. Further investigation and testing would have been needed to provide any basis for realistic assessment.

No finding was recorded.

SYSTEM DESIGN ELEMENTS

The elements in this group mainly affect the practicality and cost of providing the infrastructure for broadcasting DTTB. For Australia, it is considered important that broadcasters are able to make maximum use of the existing transmission sites. Broadcasters also expect to rely heavily on the use of adjacent channels, for the dual advantage of reusing broadcaster and viewer antenna systems.

Additionally, the extensive reliance on the use of translators contributed to the weighting factors agreed by the Panel.

Combining to use common transmit antennas

The ATSC single carrier system is considered to be less tolerant to group delay errors within the channel than the DVB COFDM system. To some extent, this can be mitigated by using the full 7 MHz Australian channels to accommodate a 6 MHz ATSC signal. In a normal situation, a carefully positioned dynamic feedback sensor is required to drive the ATSC pre-correction system. In a typical Australian environment with multiple combined adjacent channels, appropriate positioning of the output sensing is made much more complex.

The Panel considered that this difficulty might be able to be compensated by fixed pre-correction of the combining and common antenna equipment. However, the large temperature variations that occur in many antenna systems with consequential changes to impedance were seen as posing a difficulty for fixed pre-correction.

It was accepted that the sensitivity of the ATSC system to group delay errors required feedback correction, and that this would be difficult in many cases. Because of the extensive use of common infrastructure and the proposed adjacent channel working in Australia, DVB was considered to have an advantage.

Finding 8

It was considered that combining an adjacent channel DVB signal with a PAL signal would be less complex than similarly combining an ATSC signal.

Ease of use and cost of implementing translators

From the limited testing related to translation and from theoretical assessment it was assessed that for the many simple if translation examples common to the Australian environment DVB was expected to be satisfactory. It was considered that ATSC would need to use a remodulation processing for many translator situations. While it was suggested that consumer grade 8VSB modulators would be developed and could be used for low cost remodulating translators this was yet to be demonstrated.

It was agreed that DVB would have advantages on the basis of currently available technology.

Finding 9

The DVB system offered acceptable simple translation options while ATSC would require development of adequately priced remodulation equipment. For this aspect DVB was preferred.

Common channel translator capability

The use of translators in Australia will generally involve reuse of translator frequencies within a single main service area. In many cases the transmission content will be identical. Where there are content differences, the separation is generally sufficient to provide adequate co-channel isolation. The co-channel advantage for ATSC is removed in such cases, and the coherent same channel capacity of DVB (SFN) becomes a useful tool for those close spaced translators with the same program content.

Finding 10.

The DVB system was seen to offer greater flexibility to handle the variety of co-channel translator situations expected for the Australian environment. Particularly in the longer term when PAL is phased out the potential of single frequency networks will be useful in optimizing spectrum efficiency.

Ability to use existing transmitters

The Panel discussed the linearity requirements of both systems and the pre correction filter requirement in the ATSC system. On balance it was considered that either system could operate through suitably upgraded existing plant.

Finding 11

Both ATSC and DVB could be used with suitably upgraded existing transmitters.

OPERATIONAL MODES SUPPORTED

These criteria are considered to be important in meeting broadcasters' and the Government's service objectives for DTTB. Key objectives for the Government are for closed captioning and for HDTV. The Panel needed assurance that support would be available from DVB for HDTV, given the lack of enthusiasm for that service objective in Europe. Equally, the Panel needed to be sure that selection of the ATSC system would not restrict Australia to 60 Hz based standards.

Satisfactory assurances on the key elements were forthcoming from both parties.

HDTV support

Both DVB and ATSC had well documented standards to provide HDTV. The issues discussed included the alternatives of using 60Hz picture rates and the implications of being a pioneer in providing a 50Hz based HDTV broadcasting. The option of using 60Hz was agreed to be impractical given the legislated requirement to simulcast programs on DTTB and PAL. The Panel then addressed the potential availability of HDTV receivers for the Australian market. Suitable assurance of intentions to supply the Australian market with HDTV reception capacity were supplied that were not constrained to the modulation system choice. Once it was agreed that the picture rate to be used would have to be 50Hz, the issues of origination equipment did not need to be taken into account.

Finding 12

The Panel agreed both systems could provide the capability for and support HDTV broadcasting. While each offered advantages over the other in some of the details there was no significant overall advantage.

Support for closed captions

The need to provide closed captioning is a part of the legislated requirements. The Panel noted that closed captions were defined in the MPEG-2 transport stream and can consequently be supported by either DVB or ATSC.

Finding 13

Both ATSC and DVB are able to fully support closed captionning.

Support for multi language audio

The Panel noted that the audio systems being developed for both systems would give enough flexibility to support multiple language audio channels by using additional elementary audio program streams.

Finding 14

Either Stem can support multiple language requirements.

Audio System

There are different views on the relative performance quality of AC3 and MPEG-2 5.1 channel sound systems. On balance, AC3 was seen to have advantages, particularly bearing in mind the relative market penetration.

While not directly related to the Panel's terms of reference, the operational implications of importing programs which have already been coded to 5.1 audio were discussed by the Panel. It was noted that consumer products are now using chipsets for decoding the 5.1 channel sound that can interpret either audio standard. As there are defined ways of accommodating AC3 in the MPEG-2 transport stream as well as MPEG-2 audio, it was considered that this subject could be addressed in the detailing of the final Australian standard, without differentiating between the systems.

Finding 15

While the Panel tended to favour the Dolby Digital system for surround sound it was believed that it could, if so decided, be used with either ATSC or DVB and so need not influence the modulation system choice.

OVERALL SYSTEM AND RECEIVER ELEMENTS

While each of the twelve individual elements in these categories were examined in some detail, the Panel was unable to identify any specific advantages or disadvantages that would distinguish between the two systems. Considerable time was devoted to addressing the need for specific tailoring of receivers for the Australian market. It was recognised that this was unavoidable for either system. On some elements such as lock-up time the Panel did not have

FINAL RECOMMENDATION

As a consequence of it deliberations the Australian DTTB Selection Panel unanimously agreed to recommend the DVB modulation system be adopted for Australia.

SUBSEQUENT CONSIDERATIONS

With the decision on the modulation system finalized the Panel concentrated on the other crucial decisions that would be needed to commence work on a detailed Australian standard and to develop the associated standards that will be needed to implement the DTTB HDTV service in 2001.

Service Information.

In developing the full standard for Australia it was recognised that the Service Information content would be crucial to successful implementation. A project group of experts was tasked to conduct an analysis of the DVB SI standards and the ATSC PSIP standards. There was a view that the ATSC standards still in development may provide advantages, particularly for the commercial network/affiliate broadcasters that are a significant part of Australian broadcasting.

The Project Group report provided a comparative analysis that demonstrated that the DVB SI standard meets more of the Australian requirements and required less adaptation than the ATSC PSIP standard at that stage of development. Clearly the ability to cover the requirements for COFDM modulation provided a significant advantage, but the analysis identified many other points where DVB SI was closer to meeting the Australian requirements.

Audio

Recognizing that surround sound is an important part of a complete HDTV broadcasting system, the Panel established a group of experts to report on the best option for the sound system for Australia. On the basis of a careful study of the technical quality, available attributes and total broadcasting system suitability the expert group report clearly indicated that Dolby AC3 would provide the best total sound system to include with DTTB.

It was noted that some material required for broadcast may be received already coded with MPEG 1 stereo sound. It was accepted that transcoding from MPEG 1 would compromise the quality achieved.

The Panel agreed to recommend the use of Dolby Digital for the sound system but also that MPEG1 audio should also be a requirement. The economic implications of the decision were taken into account with the studies providing information on the growing range of economical audio decoding integrated circuits that handle both AC3 and MPEG audio decoding.

VIDEO HDTV PRODUCTION

Having decided that Australia would need to use a 50Hz high definition video format, the Selection Panel addressed the need to establish the most suitable standard to use for production in Australia. The range of current 50Hz full HDTV equipment available is seen to be very limited and with the lack of interest in HDTV in Europe, the options for developing production equipment for just the Australian market were seen to be restrictive. Discussions with some of the main suppliers of camera and VTR equipment had indicated the possibility that a modified version of the common image 1920 pixel by 1080 active line format which used a total line count of 1125 could be made. The 50Hz version being a relatively simple adaptation of the 60Hz version being developed for the USA market.

Australian experts had been working with the suppliers on a suitable modification of the ITU-R BT709 standard to include the 50 Hz 1125 line standard and the suppliers assured the broadcasters that they would be able to supply equipment to that modified standard within the time frame needed.

Based on this advice the Selection Panel chose to recommend the use of 1920 by 1080 with a total line count of 1125 lines as the preferred Australian HDTV production standard.

Singapore Announces Choice Of National Digital Television Standard

Singapore Broadcasting Authority

Singapore, 25 May 1999

The Singapore Broadcasting Authority (SBA) is pleased to announce the adoption of the European Digital Video Broadcasting (DVB) standard as the terrestrial digital television standard (DTV) in Singapore. The DVB standard was selected following the recommendation of the Singapore Digital Television Technical Committee which was appointed by SBA in November 1997. A list of the committee members is attached as Annex A. The Committee's Final Report is attached at Annex B. To ensure that Singapore selects the standard best suited to its requirements, the DTV Technical Committee conducted comparative field trials of the world's three DTV standards, namely, the American Advanced Television Systems Committee (ATSC) standard, the European DVB standard and the Japanese Integrated Services Digital Broadcasting - Terrestrial (ISDB-T) standard. The trials were successfully conducted with the considerable support of the broadcasters, industry, and the standard agencies - the ATSC Group from the United States, the DVB group from Europe, and the Digital Broadcasting Experts Group (DiBEG) from Japan - over a five-month period from May to September 1998. This was the first time that all three standards were tested comprehensively in one country. Field tests of mobile reception in an MRT tunnel were also conducted between January and February 1999. The Committee evaluated and compared the standards based on nine criteria: characteristics of transmitted signals including mobile reception; availability of DTV equipment; cost of implementation; applications; interoperability with broadcasting, IT and telecommunications networks; potential for growth; spectrum efficiency; scalability and security. The results are summarised in a DTV Standard Ranking Table, which is attached as Annex C.

ASSESSMENT OF THE DTV STANDARDS

SBA's assessment of the DTV Technical Committee's findings is that all three standards were of exceptional quality, and each demonstrated competitive advantages over the others.

ISDB's strength is in resilience to signal distortions, making it robust under mobile conditions. ATSC performed well in terms of its effective and efficient signal coverage and HDTV. DVB did well in all the criteria. It led the rankings in 7 out of 9 criteria, namely availability of equipment, cost of implementation, applications, interoperability, potential for growth, scalability, and security.

SBA notes DVB's robustness in receiving signals under both fixed and mobile conditions, which is critical for a highly built-up city like Singapore. Another important criterion that favoured the DVB standard was the ready availability of equipment for consumers as well as operators. In addition, DVB is readily compatible with cable, IT, and telecommunications infrastructure, and Singapore ONE, Singapore's nationwide broadband network. This means that Singaporeans can expect to access a host of innovative multimedia services through their DTV sets.

Apart from the recommendation on the national DTV standard, the DTV Technical Committee made twelve other recommendations on the implementation of DTV in Singapore. SBA generally agrees with the recommendations except for the following:

a. The DTV Committee recommends that we allow niche services such as mobile TV to adopt a different standard if there is such demand. SBA feels that the terrestrial standard should be common across all services, so that the market is not segmented.

b. The DTV Committee recommends that Singapore consumers have access to DTV terrestrial, cable and satellite, using an integrated television set or a set-top box. SBA feels that there is no need to mandate that there should be one integrated set-top box which can access DTV terrestrial, cable and satellite. We should leave it to the market to decide on the various configurations and pricing of the set-top box.

c. The DTV Committee recommends that DVB be the common standard across terrestrial, cable and satellite broadcasts. SBA has decided to defer the decision on the digital cable standard as digital cable technology is still evolving.

d. The DTV Committee recommends that SBA mandates a dominant electronic programme guide (EPG). SBA has decided to give broadcasters maximum flexibility in the creative development of EPGs, but will stipulate such standards as are necessary to ensure that consumers can access and navigate all services with ease.

Mr Lim Hock Chuan, SBA's Chief Executive Officer, said, "After much deliberation, SBA decided on DVB as the national terrestrial digital TV standard as it best meets Singapore's needs. This marks the beginning of a new and dynamic era in television broadcasting in Singapore. We hope that this decision will prompt our local broadcasters, as well as equipment manufacturers, software developers, content providers and other interested parties, to push ahead with research and development in digital TV and multimedia services, not just for Singapore, but also for the region and beyond."

Mr Lim added, "We plan to initially allocate a digital frequency each to our existing broadcasters, the Television Corporation of Singapore (TCS) and Singapore Television Twelve (STV12) to enable them to embark on DTV early. We would also like to encourage industry players interested in launching DTV services and applications to discuss their plans with us."

SINGAPORE NATIONAL DTV COMMITTEE

To better co-ordinate the development of DTV in Singapore, SBA will be forming an industry-led National Digital TV Committee to look into three broad areas of DTV implementation, namely technical, promotional and content development. Membership will be open to all companies and organisations that support the implementation of DTV in Singapore. Mr Lee Cheok Yew, Chief Executive Officer of the Television Corporation of Singapore (TCS) and Chairman of the Association of Broadcasters, Singapore (ABS), has been appointed as the Chairman of the National DTV Committee.

ANNEX A

SINGAPORE DIGITAL TV TECHNICAL COMMITTEE MEMBERS

Group A (Broadcasters & Service Providers)

Television Corporation of Singapore
Singapore Television Twelve
SIM Communications
Singapore Cable Vision
Singapore Telecommunications
ST Teleport
Walt Disney Television

Group B (Regulatory/Government Bodies & Research/Tertiary Institutions)

Singapore Broadcasting Authority
Telecommunication Authority of Singapore
Housing Development Board
National Computer Board
Economic Development Board
Command Control Communications & Computer Systems Organisation (MINDEF)
Ministry of Education
Centre for Wireless Communication (NUS)
Centre for Signal Processing (NTU)
Nanyang Technological University
Nanyang Polytechnic
Singapore Polytechnic

Group C (Suppliers from Broadcast/Computer Industry)

Avid
Deutsche Telekom
General Instrument
Hitachi
IPK Broadcast Systems
JVC
Microsoft
National/Panasonic
NEC
Nera
Philips
Samsung
Scientific Atlanta
Sharp
Sony
Tektronic
Thomson Consumer Electronics
Toshiba

ANNEX B

SINGAPORE DIGITAL TELEVISION TECHNICAL COMMITTEE

FINAL REPORT

BACKGROUND

Digital technology is in the forefront of new products and services in the computer, telecommunications and broadcasting industry. With the acceptance of digital TV standards by the ITU and supported by the industry, over the air transmission of television programmes digitally to consumer TV sets will gain wide approval. Digital opens the possibilities of more channels and better quality sound and pictures to viewers. As the signals are in packetised bitstreams the technology enables the reception of data similar to that of Internet and related information technology services. It will create opportunities for new media products and services enhancing choice for the consumers and opportunities for knowledge driven industry in Singapore.

USA and UK have started commercial services in late 1998 using different systems. There are three competing standards in the world for digital terrestrial transmission. The three competing systems are the American Advanced Television System Committee (ATSC) system, the European Digital Video Broadcasting (DVB) system and the Japanese Integrated Services Digital Broadcasting (ISDB) system. At the time of this report the ATSC and the DVB systems are accepted by the ITU-R Study Groups 10 & 11 Recommendations on Digital Terrestrial Television Broadcasting (DTTB) respectively for adoption as world standards. The ISDB system is in the process of adoption by the ITU. So far Europe, Australia and New Zealand have adopted DVB and South Korea, Taiwan, Argentina, Canada and USA chose ATSC.

SBA in recognition of the importance of this technology has appointed a technical committee known as the Singapore Digital Television Technical Committee to conduct field trials and recommend a standard for Singapore. The Committee comprises members of the industry, government agencies and broadcasters. It is chaired by the Vice President of Engineering of the Television Corporation of Singapore.

TERMS OF REFERENCE

The terms of reference are:

(a) Need for robust reception of digital TV signals in Singapore's heavily built-up environment

(b) Need for robust reception in moving vehicles given the possibility of transmitting of programmes for viewers on the move and information related applications

(c) Compatibility with Singapore CableVision's (SCV) cable network

(d) Interoperability with Singapore ONE's broadband multimedia services

(e) Cost of implementation

(f) Availability and price of receiver sets

FIELD TRIALS

Field trials were conducted island-wide on the following dates:

ATSC: 8th June to 19th June 1998

DVB-T: 29th June to 10th July 1998

ISDB-T: 24th August to 4th September 1998

The field trials were conducted with the cooperation and support of the standard agencies and suppliers who made possible the loan of expensive equipment free of charge. We are very pleased with the contribution of the experts from USA, Europe and Japan who facilitated this project - the first in the world to carry out tests of the three competing systems.

RESULTS

To assist the Committee, working groups for data validation, propagation and prediction, set-top boxes, and systems were formed. A Selection Panel comprising representatives from the Singapore Broadcasting Authority, Nanyang Technological University, Centre for Signal Processing, Television Corporation of Singapore, Singapore Television Twelve, SIM Communications, Singapore Cable Vision, Centre for Wireless Communication and the Housing and Development Board was set up to arrive at a recommendation to SBA. The key findings are as follows:

Characteristics of Transmitted Terrestrial Signal

(a) Robustness

Digital signals are received better as compared to analogue. For reception by fixed antennas all the three systems can be received well when the power of the transmitters are adequate to give sufficient level at the input of a TV set. Mobile reception is possible with both ISDB and DVB. For reception in the moving vehicles, the ISDB signal is more rugged as compared with DVB. Mobile reception using the ATSC system is not possible.

(b) Immunity to Electrical Interference

Test results from other field trials and laboratory tests indicate that interference from impulsive noise sources will affect DVB and ISDB systems more than ATSC. The results of the field trial here did not indicate this as an important parameter that will adversely affect the implementation of digital TV.

(c) Resilient to Multipath Distortions

Signals that are bounced off from buildings will cause multipath distortions of the signals leading to data errors and no reception. DVB and ISDB signals are less susceptible to multipath distortions. Although there are contentious issues on this, the Panel feels that the OFDM and the multi-protection system used by DVB and ISDB has the advantage. The heavily built-up nature of Singapore dictates that we give more emphasis to this factor in the decision making process.

(d) Effective and Efficient Coverage

ATSC signals have a lower reception threshold and theoretically would have better coverage for lower power. We think this is not significant because of the small size of Singapore and the possibility of deploying lower power transmitters using same frequency for effective coverage.

(e) Receivable using Indoor Antenna

Tests with indoor antenna were inconclusive. Nevertheless the Panel is of the view that indoor antenna will play an important part in the reception of digital TV signals. Other broadcasters recognize this factor and efforts are being made to design special indoor antennas for the reception of digital TV. In Singapore viewers use indoor antennas wherever possible for their second or third sets. With digital, as the signal threshold is lower, we expect to see more use of this mode of reception.

(f) Reception at Poor Analogue Reception Areas

It is expected that poor reception areas for the existing analogue services will receive TV better in digital. The Panel considered that DVB and ISDB would have an advantage to enlarge coverage of good reception with digital transmission given that the Singapore landscape gives rise to significant multipath.

(g) Adjacent Analogue/Digital Channels Performance

The Panel considered this to be important given the need to use frequencies efficiently. Given adequate filtering and conformance with the relevant standards it is possible to use channels adjacent to analogue channels with any of the three systems.

(h) Co-Channel Performance

This parameter was not tested as it is not likely that there will be overlapping frequencies used for digital, analogue and other services.

(i) Mobile Performance

The Panel agreed that this is important in view of interest in the industry to have this application. Taking into account the field trials that were carried out with the three standard agencies and the recent field trials in MRT trains by TCS and SMRT engineers, the Panel felt that this factor has a very high weightage. It also noted that ATSC could not do mobile and attempts by them to consider mobile using a different technique are given a lower priority for consideration. It is noted that the interests in mobile applications are not high in ATSC countries. Even in DVB countries, this application is not considered, except in Germany where interest is high. Singapore and Japan have indicated the possibility of starting services for moving vehicles. Between the two systems (DVB and ISDB) that did well in mobile applications, ISDB was the better performer.

Availability of DTV Equipment

The Panel has to consider the wide range of equipment that is available for implementation as soon as possible. The equipment can be classified into three broad groups comprising broadcast transmitters, encoders, multiplexes, network systems, computer systems, set top boxes and integrated television receivers. Also the equipment has to be available in both multi-channel SDTV as well as HDTV formats. The sound system has to be available in both MPEG and Dolby AC-3 format. The Panel agreed that for DVB, SDTV equipment is widely available whereas HDTV equipment is not yet available. Considering that HDTV is not the main driver for DTV in Singapore this factor was less important. ISDB equipment for commercial applications is not available at the moment and we consider this a critical setback to the Japanese ISDB system.

Cost

The Panel is mindful of the costs for setting up a DTV infrastructure and costs to consumers. In the selection of a system this would be an important factor.

Costs of digital equipment used in existing digital facilities such as graphics, post production and on-air presentation server systems are on the downtrend because of volume and availability of integrated chipsets. The costs of DTV equipment for encoding, multiplexing and related bitstreams processing are high but are expected to follow the same trend as the above. It is expected to cost more than $20m per standard definition channel to implement digital facilities in a broadcast centre. Consumer equipment is expected to cost about $500 for a set-top box and $3000 for an integrated television set for standard definition reception. Recent developments in chipsets and receiver technology indicate that receivers would be widely available soon. At the same time, the Economic Development Board, a member of the Singapore Digital TV Technical

Committee, is encouraging the manufacturing of digital equipment in Singapore for local and overseas export to drive cost down further.

Generally the capital costs for broadcasters would be about 50 to 100% more depending on the extent of digital production to support digital channels. Broadcasters will have to look at the viability and to what extent consumers will want services. An entirely new business thinking may be necessary to fully exploit the potential capabilities of DTV technology. It is necessary for leadership in the area of planning and implementing multi-channel digital TV on cable, satellite and terrestrial. Data services, interactive service and new ways of accessing programmes will have to be thought through by broadcasters. Good planning will ensure the viability of the projects and benefit the consumers and Singapore society in general.

The Panel felt that there is no cost advantage between the US and European systems although it is expected that the volume of trade will be higher in the ATSC countries than the DVB countries. The low level of acceptance of ISDB for the moment would pose problems for costs and availability. The Panel felt that the support from suppliers for the ISDB system is not as high as expected.

The costs of interoperability with other systems such as SCV, Singapore ONE and telecommunications companies are expected to be high initially owing to development charges. In particular we are concerned about high charges by telecommunications companies on the fibre and ATM networks, which will be extensively used in the DTV infrastructure.

Applications

(a) Mobile TV

A study has indicated that more than three million people are on the move daily. They travel by the MRTs, buses, taxis, cars and soon the LRTs. Access to programmes for people on the move is an important factor in building the Singapore society. The Television Corporation of Singapore is keen to introduce this service. It is carrying out feasibility studies with the various transport companies to establish a viable digital TV system in the transportation system. This project would leverage on ideas, talent, resources, capital and markets that would make us the leading country in this area of technology.

The Panel concluded that the DVB and ISDB systems will work for this application.

(b) HDTV

High Definition Television for viewers means good quality pictures and sound. HDTV application is possible in all three systems, but the two leading broadcasters TCS and STV12 are not placing priority on this service. However, we have studied the availability of this application in the three systems so as to provide choice to customers. Equipment for the DVB standard is expected to be available by the year 2000.

(c) SDTV

It is possible to transmit a number of standard definition digital TV programmes within a frequency band normally occupied by one analogue channel. This means that with this technology the number of digital TV programmes for over the air services will increase to about six times. The Panel felt that DVB would be stronger on this point due to the commercial availability of equipment.

(d) Interactive Multimedia Services

This is an important application for cable in view of the ADSL and Cable Modem service. Wireless over the air services is possible and development is being done to improve on the back channel using telephone return path, GSM and VSAT. It is expected other new emerging technologies will complement digital TV broadcasting to enable interactive services. Broadcasters value the interactivity in the new digital pipe offered by digital television. Work is in progress for an interactive set top box that can do this for both cable and terrestrial applications. The Panel concluded that the specifications/design of the DVB and ISDB systems are more adaptable to this application.

(e) Portable Television

There is an advantage for ISDB and DVB with the use of distributed lower power transmitters using Single Frequency Network. Both ISDB and DVB systems enable clear reception with portable television sets regardless of location.

(f) Close Captioning

This is available in the transport bit streams of DVB and ISDB as well as ATSC.

(g) Pay-per-view/Video On Demand

This is also available with more emphasis from the DVB group.

(h) Multi-Language Transmission

This is possible as all systems have enough flexibility to transmit multiple audio channels.

(i) Conditional Access/Subscriber Management

There are capabilities for set top boxes of the three systems to provide conditional access and subscriber management systems.

(j) 5.1 Multi-channel Sound

The Panel studied this carefully and agreed that in view of the market penetration of Dolby sound systems worldwide and in Singapore, a DTV system should incorporate Dolby AC-3. After lobbying the DVB agency together with our counterparts in Australia, DVB has agreed to our request to incorporate Dolby AC-3 in its standards. Singapore broadcasters will now have a choice of transmitting either MPEG or Dolby AC-3.

Interoperability

(a) Cable Network

There should be no major problem in interoperability of over the air transmission with cable networks. There is an advantage in the DVB system, as the satellite programmes into and out of Singapore will be mostly using the DVB standard. The Panel agrees that operational and quality issues could be reduced by selection of a standard that is common to terrestrial, cable and satellite. It felt that DVB has an advantage on this point.

(b) Telecommunications Network

Tests carried out with Singtel indicated that transport streams can be carried by microwave systems or the ATM networks using optical fibres. The field trials for the DVB system took advantage of the recently introduced ATM service from Singtel. The result was positive. We did not use the ATM and fibre network for the ISDB and ATSC trials as equipment was unavailable at the time. However we have reason to believe the two systems are equally capable of operating with the existing telecommunication networks, based on data available from other countries.

(c) MATV Systems

More than 80% of Singaporeans receive over the air signals via fixed master antenna systems. Tests carried out indicated better reception as compared with existing analogue services. With the correct power transmission, any of the three systems would provide a rugged signal.

(d) Satellite Reception

The DVB system has an advantage given its current deployment for satellite services in Singapore and the region.

(e) Consumer Equipment

Existing TV sets and antennae can be used for reception of digital television. Consumers however need to install set top boxes. Analogue signals by broadcasters will continue to be simulcast until the penetration of digital receivers in the homes reach a certain level. All systems have this feature.

The Panel is concerned that the ATSC system is based on 60Hz, 6MHz channel although there is assurance of possible adaptation to fit 50Hz, 8MHz countries.

Potential for Growth

There are immense opportunities in the areas of media production, programming, multimedia and developing of digital products and services in this new technology. All systems have potential for growth into new industries. With regards to the development of the standards and system we felt that the DVB and ISDB use a technology that has more room for growth than the dated technology used in the ATSC system.

Spectrum Efficiency

(a) Use of Adjacent Channels

Existing analogue system does not permit the use of adjacent frequency bands for transmission. With digital this is possible. There is insufficient technical information to decide which is a better system. However tests carried out elsewhere indicated that there is sufficient protection of existing channels with digital signals interleaved. The level of interference would be protected by standards under the recognition of ITU. For Singapore there is close coordination with neighbouring countries to resolve this.

Digital makes possible the efficient use of the broadcasting spectrum. It is possible for independent content providers to share the same frequency channel for digital TV services. The Panel recognised that coordination and proper planning would be needed to effect this.

Scalability

(a) Open Architecture

All systems advocate open concepts where hardware and software can be upgraded easily by suppliers. Broadcasters would not be concerned with proprietary standards that will lead to higher costs.

(b)Consumer Set Top Boxes

These can be made by a number of reputable suppliers. Except for the ISDB systems there are manufacturers that can make this equipment for Singapore and possibly in Singapore. The adoption of a common standard would ensure lower costs and accessibility. The Panel agreed that the software in the digital consumer equipment is likely to remain stable as long as possible. Upgrading of the software would be possible.

ANNEX B

RECOMMENDATIONS

The Selection Panel met five times to deliberate on a decision. At its meeting on Friday 26 February 1999 the Panel unanimously agreed to recommend DVB-T for use in over-the-air broadcasting in Singapore. The overall evaluation and assessment have resulted in twelve recommendations to SBA. These are listed below:

Recommendation One

- ***"that Singapore adopt DVB as the Digital Television Standard of transmission."***

The Selection Panel unanimously agrees to recommend DVB as the common digital television standard for the masses in Singapore. The Panel believes that both the consumers and broadcasters in Singapore will benefit from this standard. The Panel recognises that the specification of the DVB standard is comprehensive and provides a new technology platform for broadcasters and manufacturers to create a host of television, multimedia and economic activities. Besides the technical aspects, the Panel also took into consideration the availability of equipment, applications and consumer pricing.

The strengths and weaknesses of each of the DTV standards were established after careful evaluation of the three standards. The Panel has considered the fact that ATSC has strong technical advantages in a number of areas as explained above. ISDB-T is also strong in some aspects of its technology.

Although DVB has its weaknesses, its technology is selected as the chosen standard for its ability to perform under heavily built-up and high rise areas, potential for mobile applications and availability of equipment.

The Panel also proposes to SBA to leave the option open for consideration of the other systems for adoption in other areas of applications should there be such a demand.

Recommendation Two

- ***"that Singapore consumers have access to DTV terrestrial, cable and satellite, using an integrated television set or a set-top box."***

The Panel noted that there are cable set-top boxes in Singapore homes provided by SCV. It is of the view that in the long run the consumers' interests will be best served using only a single set-top box that can receive DTV from the three delivery platforms (terrestrial, cable and satellite). However it is not possible for now because of the uncertainty of standards and economics in this technology.

As such, it is proposed that there should be access to programmes from wireless delivery systems such as DTTB (Digital TV Terrestrial Broadcasting) with provision for DSR (Direct Satellite Reception) as and when permitted by Government, using a separate box different from SCV's. For interoperability of the two set-top boxes, the Panel is of the opinion that a common DTV standard will be useful so that consumers can receive DTV terrestrial signals from both set-top boxes.

Recommendation Three

- ***"that a dominant electronic programme guide (DEPG) be adopted as soon as possible for cable and terrestrial television."***

Consumers like to access content quickly and correctly when a television set is switched on. With the introduction of digital TV, Electronic Programme Guides (EPG) are being used to facilitate navigation through the list of new channels. However without any form of guidelines in effect, programmes especially with national and community interests might get hidden under complicated menus and icons.

A dominant EPG (DEPG) not only will ensure that important messages are not obstructed but will also help to accelerate the familiarisation process of using the EPG. The DEPG should preferably be a requirement for Singapore.

The Panel is also of the opinion that this dominant EPG can only be implemented with strong participation by all the major broadcasters, with the cooperation of other operators.

Recommendation Four

- ***"that besides the existing sound format (both stereo and Pro-Logic surround sound), it is strongly recommended that a 5.1 multi-channel sound format be implemented."***

With growing popularity of home theatre systems in Singapore, 5.1 multi-channel sound setup will be an enjoyable enhancement to home viewers. 5.1 multi-channel sound format adds realism in the reproduced sound effect accompanying the picture. Cinemas with this feature have created acceptance and demand for higher standard of sound in television. As such equipment like set-top boxes should be '5.1 multi-channel sound' ready. This is possible by providing an encoded audio bitstream output that is compatible with external multi-channel sound decoder. Viewers would enjoy these audio enhancements during DTV transmission, as broadcasters should be ready to provide this feature.

In view of the popularity of Dolby AC-3 in films, LDs, DVDs and the availability of AC-3 processors worldwide, the Panel feels that AC-3 sound for DTV should be incorporated in the DVB standards. We are pleased to note that DVB has agreed to amend the standards to include the transmission of Dolby AC-3 sound without needing to simultaneously transmit the MPEG-2 sound. This decision would allow broadcasters a choice of transmission of MPEG-2 or Dolby AC-3 sound in their DTV multi-channel sound transmission.

Recommendation Five

- ***"that Singapore support and encourage the provision of ancillary data services to enhance the programming content of the DTV channels."***

Within the DTV data packets there are opportunities for broadcasters to use part of the spectrum for ancillary data. This would include information subtitling, teletext, EPGs, related information services and a host of other digital products yet to be designed.

Recommendation Six

- ***that Singapore encourage the use of the DTV spectrum for independent data services such as Broadband Internet to enable broadcasters to take advantage of the content and related services complementary to the Singapore ONE network."***

One of the key advantages of digital over analogue is the capacity to provide data over the bitstreams used by broadcasters. The specification of DTV standards allows for this. Broadcasters can use this property to provide new services to consumers and generate new revenue streams. Services like video-on-demand, broadband Internet, interactive TV are some of the possible applications that can be offered to viewers.

With the immense amount of content on the World Wide Web, the Panel feels that DTV can take advantage of this through the Singapore ONE network to create digital content.

Recommendation Seven

- ***"that broadcasters work closely with the computer and the telecommunications industries to plan and develop common transmission and consumer interface technology."***

Technology is already integrating telecommunications and computers. Web TV, digital TV computer cards and software demodulation are also closing the convergence gap.

The Panel feels that these trends indicated that the three technologies are merging and that the three industries should work towards cross carriage of services. The Panel suggests that one of the ways to achieve this is to establish a task force to study the issue of convergence.

Recommendation Eight

- ***"that Singapore establish a body to look into the implementation of a national digital television infrastructure and digital broadcasting service."***

The management and operation of TV frequencies will be increasingly complex with digital TV. The service information identification codes for networks, services (collectively known as SI) and so on will have to be agreed upon and managed.

In view of the use of interleaving of digital channels between analogue channels, standards of transmission have to be strictly adhered to. Digital is different from existing analogue systems. The service management information, programming and delivery are inherently more complex. Commitment at all levels of the broadcast industry is necessary: the Government, SBA, programme makers, multiplex operators, broadcasters, and transmission providers. Receiver manufacturers and system integrators must all work together for successful implementation. As such, the Panel is of the opinion that for DTV in Singapore to be successful, a coordinated approach by a national committee comprising TV broadcasters, SBA and relevant agencies will ensure a successful launch of DTV in Singapore. It is hoped that Singapore can serve as a working model for countries in this region going digital in the years ahead.

Recommendation Nine

- ***"that if terrestrial means for the reception of TV signals are available, they could cater for technological developments."***

The Panel feels that availability of terrestrial means of television reception, such as the Master Antenna Television (MATV) system, would promote DVB-T and its related multimedia and mobile applications. They would also encourage future developments of over-the-air digital technologies and provide more delivery options.

Recommendation Ten

- ***"that Singapore introduce legislation to authorise access to buildings for the purpose of installation and operation of DTV transmission systems."***

For good reception of DTV and spectrum efficiency there is a requirement to have low power transmitters to act as gap fillers, similar to those used for paging services. Already faced with the problem of many built-up areas in Singapore, broadcasters may face more problems, from the owners, to access the buildings.

In order to ensure the success of implementing DTV infrastructure, the Panel recommends statutory requirements for building owners to allow broadcasters to access the space on the rooftops.

Recommendation Eleven

- ***"that Singapore encourage the training and development of engineers and creative people in production, transmission and reception of digital television."***

It is essential that the authority initiates the training and development of engineers to design, operate and maintain DTV systems. Also the creation of opportunities to develop digital television products will ensure success in DTV in Singapore, hence enhancing our image as a broadcasting hub in this region.

Funding from the Government can be used to set up digital TV training and R&D centre. This will further boost the growth of the broadcast industry through a pool of trained people and development of new products and applications.

Recommendation Twelve

- ***"that Singapore set up technical performance standards for digital transmission and reception."***

As Singapore emerges to become a leading broadcasting and multimedia hub for the region it is essential for technical standards to be established to ensure consistency and value for performance of the digital delivery system to consumers.

CONCLUSION

(a) The Selection Panel, after the assessment of all information and clarification from the standard agencies, recommends the DVB system for Singapore.

(b) We are pleased to report that there is worldwide interest in the Singapore DTV field trials. We acknowledge the significant contributions of many local and overseas organisations, which actively participated throughout the study. We thank ATSC, DVB and DiBEG which, together with the support of their manufacturers, provided invaluable information and immense support, which made the study and field trials possible in Singapore. We also thank the local industry and broadcasters who contributed many man-hours and resources, especially engineers from the Television Corporation of Singapore and staff from the Nanyang Technological University.

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ANNEX B

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ANNEX C

DTV STANDARD RANKING TABLE

The figures below reflect ranking, and are not absolute scores. A ranking of 1 indicates a better performance under the environment in Singapore compared to a ranking of 2 or 3.

No.	Criteria	ATSC	DVB	ISDB
1	**Characteristics of Transmitted Signals**			
a	Robustness of signal	1	3	2
	Immunity to Electrical Interference Effective Coverage Efficiency of Transmitted Signal Receivable using Indoor Antenna Adjacent Channel Performance Co-channel Performance			
b	Resilience to distortions	3	2	1
	Resilience to multipath distortions Mobile reception Portable reception			
c	Single Frequency Network Performance	3	1	1
2	**Availability of DTV Equipment**			
(i)	SDTV	2	1	3
	Production Distribution Post Production Transmission Reception Test & Measurement			
(ii)	HDTV for 8 MHz environment	3	1	2
	Production Distribution Post Production Transmission Reception Test & Measurement			
(iii)	HDTV for 6MHz environment	1	3	2

ANNEX C

	Production Distribution Post Production Transmission Reception Test & Measurement			
(iv)	5.1 Multi-Channel Sound	1	1	3
	Production Distribution Post Production Transmission Reception Test & Measurement			
3	**Cost of Implementation**	**2**	**1**	**3**
	Consumer Production Capital Interoperability			
4	**Applications**	**2**	**1**	**2**
	TV Mobile/Portable TV HDTV HDTV 5.1 Multi-Channel Sound Closed Captioning/Subtitling Pay-per-View TV/Video-on-Demand Multi-Language Transmission Conditional Access/Parental Lock Interactive TV/Electronic Programme guide Home Server Internet/Email/Web Applications			
5	**Interoperability**	**2**	**1**	**3**
	Cable Network Telecommunications Network MATV Systems			

	Present Consumer Equipment Usage Satellite Reception			
6	**Potential for Growth**	**3**	**1**	**2**
	Further Development in Standard New Industry Development			
7	**Spectrum Efficiency**	**3**	**2**	**1**
	Usage of 'Taboo'/Adjacent Channels Sharing of Channel Bandwidth by Multiple Programs Low Protection Ratio			
8	**Scalability**	**2**	**1**	**3**
	Open Architecture in DTV System Consumer Set-top Box			
9	**Security**	**2**	**1**	**3**
	Encryption Open Standard			

RESULTS OF RF MEASUREMENTS WITH DVB-T CHIP-SET AND COMPARISON WITH ATSC PERFORMANCE

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1 INTRODUCTION

This paper presents the results of RF measurements of a current domestic DVB-T demodulator chip-set, under various channel conditions. Results were recorded for both the standard DVB measurement criterion of quasi error-free (QEF) and for the failure point (FP), allowing a comparison between these two points to be made. These results show the excellent performance with the DVB-T system, using a domestic receiver chip-set, in both Gaussian channel conditions and in channels with severe multipath or co-channel interference.

2 DETAILS OF THE MEASUREMENTS

Measurements have been made of the performance of a domestic DVB-T demodulator chip-set in a Gaussian channel, with co-channel PAL and in a severe multipath channel (a 0 dB echo with a delay of 0.8µs and 1 Hz of Doppler). The measurements are all made for the mode used for current operational services in the UK: 2K, 64-QAM, code rate 2/3, guard interval 7µs.

For each channel, the performance to two measurement criteria has been recorded. The first criterion is for a bit-error ratio of 2×10^{-4} after the Viterbi decoder. At this error-ratio, there are essentially no uncorrectable packets in the demodulated transport stream, and so this point has often been referred to as the quasi error-free (QEF) condition[4]. The second measurement criterion is referred to as the failure point (FP), which for these measurements has been defined to be an average of two uncorrectable packets per ten seconds. This is simply the lowest rate it is practical to observe, requiring an observation interval of about $1^1/_2$ minutes. In the DVB-T mode used for current operational services in the UK, which has a transport data rate of 24 Mbit/s, this leads to an output bit-error ratio of approximately 2×10^{-7} at the failure point. Hence this is still an order of magnitude more severe than the criterion used for measurements with the ATSC system, which has been defined as an error ratio of 3×10^{-6}, the so-called threshold of visibility (TOV).

PAL co-channel measurements for protection ratios are often made with no added noise (referred to as infinite loss of noise margin). However, these measurements were made under more realistic conditions where noise was added at a level of 6 dB below that for the Gaussian channel (in other words, for a 6 dB loss of noise margin). The system would tolerate approximately 2dB more interference if measured for infinite loss of noise margin.

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[4] Strictly the definition of QEF is 1 uncorrectable transport packet per hour

3 RESULTS

The results of the measurements are given in the following table:

Gaussian channel *C/N* dB		PAL CCI channel *C/I* dB		*C/N* dB for PAL CCI channel		0dB echo channel *C/N* dB		0dB echo channel LONM dB	
QEF	FP	QEF	FP	QEF	FP	QEF	FP	QEF	FP
18.7	17.6	3.2	0.5	24.7	23.6	25.5	22.7	6.8	5.1

4 DISCUSSION

From the Gaussian channel measurements it can be seen that difference between measurements at QEF and FP is 1.1 dB. For comparison with ATSC measurements at TOV, a further allowance should be made for the more relaxed TOV criterion. This is estimated to be a further 0.2 dB. Hence for comparison purposes, the equivalent DVB-T measurement at TOV would be 17.4 dB. This is approximately 2 dB more than ATSC reported measurements, rather than the 4 dB often claimed by ATSC.

The results with co-channel PAL confirm that excellent performance is possible with co-channel signals, without the need for specially implemented rejection filters, such as are required for ATSC.

The figures for 0 dB echo performance confirm that the expected level of performance can be achieved. ATSC often quote the relatively poor results for 0 dB echo performance measured during the Australian laboratory tests [1]. A further important point here is that the difference between QEF and FP (approximately 3 dB) is much larger for such selective channels than is the case in Gaussian channels. Appropriate allowance for this difference should be made when comparing the two systems, which in any case is only possible for echoes weaker than 3 dB, the maximum the ATSC system can withstand. This is shown dramatically in the attached curves. Fig. 1 shows an erroneous multipath comparison curve taken from the ATSC FAQ (http://www.atsc.org/pub/faq.pdf). Fig. 2 shows a corrected version of this based on the figures given above, and shows that the true advantage is significantly in favour of DVB-T. It should also be noted that this only applies for static channels – reference [1] shows that ATSC is not able to deal with conditions where the channel changes, such as with flutter.

5 CONCLUSIONS

The results of RF measurements with a domestic DVB-T demodulator chip-set have been presented, and it has been shown that excellent performance has been achieved. The results compare the performance for QEF and failure point, and show that the difference is more than 1 dB in a Gaussian channel and much more still (up to 3 dB) in a selective channel. This difference is very important when comparing DVB-T with ATSC, for which results are quoted to the so-called threshold of visibility, an even more relaxed criterion than the failure point defined for these measurements. The results show that some of the claims made for ATSC are somewhat erroneous.

6 REFERENCES

[1] N. Pickford, “Laboratory testing of DTTB modulation systems”, Laboratory Report 98/01, Australia Department of Communications and Arts, June 1998.

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