<table>
<thead>
<tr>
<th>Title</th>
<th>Understanding digital television.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Tay, Joo Thong.</td>
</tr>
<tr>
<td>Date</td>
<td>1998</td>
</tr>
<tr>
<td>URL</td>
<td><a href="http://hdl.handle.net/10220/1788">http://hdl.handle.net/10220/1788</a></td>
</tr>
<tr>
<td>Rights</td>
<td></td>
</tr>
</tbody>
</table>
Understanding Digital Television

(presented by Tay Joo Thong, Vice President (Engineering) TCS/Chairman, Singapore Digital Television Technical Committee)

Colour TV was introduced to the world in the 50's. Viewers knew the value of colour from black and white. The price of a colour set was then very high and not affordable. The public did not want colour TV. There was public outcry. The press complained that the scientists and engineers should have better things to do than to invent colour TV. The same scene is repeated with Digital TV (DTV). USA and UK begin DTV transmission this month. Many other countries and media owners are watching closely and planning to introduce this new technology. In a UK market survey 70 per cent of the public do not know what DTV is. After explaining the benefits of DTV like more programming and more choices, 35 per cent indicated that it had no value at all. An even greater percentage of viewers gave the thumbs down on interactive television, home shopping and pay per view. However, when pointed out the technical side of DTV, like better quality pictures and sound, a higher percentage of 46 per cent thought this would be of some value. The result of this survey suggests that a major marketing effort will be required to get the public interested.

So I hope that in this small way this presentation will help in the understanding of digital TV.

The word digital has to do with the representations of information in a series of ones and zeros or bits and bytes. A signal that is in digital form can be stored in harddisks, processed and manipulated in many different ways to suit specific applications. Digital has been with the broadcasting industries for many years. Graphics, high end special effects for commercials, trailers and promotional materials use a lot of digital. Broadcast stations, whether it is CNN or TCS digitised the analogue picture and sound in the studios and stored them in hard disks for production, postproduction and distribution. The digital signals can be processed in computer systems similar to manipulation of data processing in our ordinary PC. The results are better quality signals, consistency, less outages and flexibility in operations. In most cases the use of digital equipment reduces costs. Recognising the benefits of working with digital, ITU adopts world wide standards for digital signals. Standards such as ITU-R BT601 and ITU-R BT.656 are recommended for broadcasters and manufacturer. This has led to proliferation of digital equipment such as non-linear editing systems, servers, digital mixers, cameras and computer graphics.

The transmission of TV over the air digitally remained elusive until recently. For ten years reseachers in Europe, Japan and USA had been grappling with problems to digitise and transmit the signal to the home. Uncompressed digitisation occupies a large bandwidth. The development of MPEG compression technology and the availability of chip sets overcome a major problem. This technology has enabled the high bit rates from 270Mbits-1.5 Gigabits to be reduced to a manageable size. Development of the transmission technology of OFDM modulation and 8 VSB modulation made possible to transmit over the air about 24 Mbits to the home. Home
TV set has to be redesigned to receive this megabits. It is no longer valid to think of the analogue signal with its synchronising pulses and varying amplitudes. We have to think bitstreams. A bitstream can be divided into 4 to 6 TV channels. Each bit stream will have associated information such as programme map table, network identification number, programme identification and bits for indicating whether programme is in bilingual and so on. Besides conventional TV, new value added services are possible. It would be up to the imagination of the creative people to think through how this new media can be put to effective and profitable use.

New equipment are required for this new technology. Unfortunately experts could not agree on a common digital TV standard. Just like the analogue TV world of PAL, NTSC and SECAM the digital world will be divided into three standards. ATSC developed in the USA, DVB from Europe and ISDB from Japan (please see attached article). All the three standards employ the underlying technology of MPEG2 Compression. The main differences are in the modulation of the bitstreams. ATSC uses a 'single carrier with vestigial sideband modulation. DVB and ISDB use multicarrier either 1705 or 6817 OFDM. ISDB and DVB are similar in many aspects except that the ISDB uses the segmentation of the spectrum to ensure flexibility in services and reception. So far USA, Canada, Taiwan, and Korea have adopted ATSC. Europe, Australia and New Zealand adopted DVB. Singapore has completed a comprehensive trial of the three competitive systems. A technical committee is currently evaluating the data collected with the help of experts from Europe, USA and Japan.

Digital television offer viewers clearer and sharper images, higher definition pictures, more channels, wide screen formats and surround sound. Multimedia services such as world wide web pages, video on demand on the Internet and related value added services are also possible. USA has adopted HDTV and surround sound. UK has opted for multichannel video with stereo sound. All are expected to offer interactive TV in the months ahead. In the case of Singapore, the Digital Television Technical Committee has been asked by SBA to look into robustness of the digital signals under local conditions, television mobile application and interoperability with network such as cable, satellite and Singapore One. Availability and cost of equipment are also important factors to consider. SBA is expected to release a number of digital channels in the broadcast frequency spectrum to broadcasters. This would enable more than 50 digital television services to be offered to home viewers and industry.

Briefly I will explain the various block of a complete digital television infrastructure. Starting from the production side, the cameras digitise the images from the studio. The bit rate varies from 270Mbits to 1.5 Gigabits. This bit rate is too large to beam out in the transmission media. It has to be compressed into a manageable bit stream by an Encoder. The Transport Multiplexer enables the multichannels and data services to be combined and beamed using the same transmitter and antenna. At the receiver side either a set top box or an integrated digital TV set is required to carry out the reverse process of recovering the images. Broadcasters will have to invest in new hardware to carry digital signals to the homes. It is estimated that a new channel will cost around $15-20 million excluding programming costs.

Let me go briefly into another level of detail. It would be useful to know the format of the bitstream. I have selected DVB as an example. The bitstream from the transport multiplexer consists of video, audio, data and related information.
The bitstream known as transport stream can be received by a set top box or integrated digital television (iDTV). It consists of a succession of 188-byte long of packets of information. The packets contain information relating to the programmes and associated services. The programme association table gives a list of programmes available in each bitstream. Each programme is associated with a packet identifier (PID). The PID points to a Programme Map Table that contains details of the programme such as language, conditional access, subtitling, copyright information and so on. The DTV broadcaster can define/set its own private data if required in the bitstreams.

UK starts DTV transmission this month. I will go through some aspects of the services as an understanding of what can be done with this new technology. The digital terrestrial TV service will take up six multiplexers (equivalent of six analogue channels). Five digital channels can squeeze into one multiplexer. As such a total of 30 Digital TV channels will be offered. BBC will operate one multiplexer and transmit four channels to about 90% of the population with 81 transmitters. OnDigital (a partnership of Carlton and Granada) will offer at least 15 channels with three multiplexers. There will be top movies from Hollywood and around the world, big sport events, the Best of British drama, entertainment, children and current affairs programmes. All can be received with the same antenna that is used to receive existing analogue TV services. A set top box will enable subscriber to have a basic package of 12 channels and option for up to three premium channels. They will be able to receive five free to air channels, new free channels from the BBC and ITV and enhance data services. Each of the channel will use a capacity of about 5Mb/s (for vision and sound) to give a picture quality comparable to existing PAL service. Reception equipment will be available by end 1998. Manufacturers like SONY, Panasonic, Phillips etc. are planning to launch set top boxes and iDTV. Prices are expected to start from US$300 for a set top box.

In the US about 41 stations will beam digital signals this November. Most are committed to HDTV broadcasts with a fixed bit rate of 19.3 Mb/s. When the entire industry digital build up is completed, broadcasters would have invested approximately US$16 billion.

In Japan, trial runs of the ISDB system started last week. The Ministry of Post and Telecommunications has set Yr2003 as start of commercial service. They will focus on HDTV, surround sound, TVMobile and multimedia applications.

I believe Singapore broadcasters would be keen to look at new ways of doing things. Currently the national broadcasters are limited to four channels. With digital, there would be wider choice of programmes, interference-free reception, excellent picture and sound, widescreen viewing, electronic programme guides, Interactivity and data broadcasting and also High Definition Television. Transmitting digital over the air would have the advantage of hassle-free installation especially with iDTv, wider coverage, portable and mobile reception and customised programming. The Television Corporation of Singapore is working with the transport companies and LTA to bring digital to the MRT, LRT, buses and taxis.
Lastly let me present to you quickly some of the issues in the implementation of DTV

- which systems
- on what frequency channel
- how many channels
- HDTV??
- types of Programming
- types of data services
- how many will buy
- how much investment
- how much revenue
- fragmentation
- regulatory issues
- who/what other players
- threat from cable/satellite and other media
- what new ways of creating content
- training

Thank you.

If you have any query please contact: Tay Joo Thong
Vice President (Engineering)
Television Corporation of Singapore
Tel: (65)3503122
Fax: (65)2561183
Email: jootong@tcs.com.sg

[For more information on DTV, please see attached report by courtesy of Mr Om P Khushu, Director (ABU)]
# TABLE OF CONTENTS

1. Introduction

2. Systems Overview
   2.1 The ATSC system
   2.2 The DVB-T system
   2.3 The ISDB-T system

3. Specifications
   3.1 Source coding
   3.2 Multiplexing
   3.3 Access control
   3.4 Channel coding and modulation scheme
   3.5 Bit rates

4. Performance
   4.1 System efficiency
   4.2 Multipath interference
   4.3 Impulsive noise

5. Planning and Implementation
   5.1 Protection ratios
   5.2 Frequency planning
   5.3 Network implementation
   5.4 Peak to average power

6. Time Schedule and Implementation
   6.1 Receiver complexity
   6.2 Practical verification
   6.3 Plans and time schedule

*Courtesy by Inter-Union Technical Committee (IUTC)*

*World Broadcasting Unions*
1. Introduction

Digital television is already successfully operated on satellite and cable. The considerable amount of R&D that was spent on all relevant aspects means that digital terrestrial television is also mature.

However, this intensive activity has resulted in more than one system being defined and proposed. Organisations considering the setting up of digital terrestrial television services are faced with an extra question to solve: which system to adopt? The purpose of this contribution is to help such users select the system which is most suitable to their needs.

Three proposed systems can be identified at this moment. The first two are at a later stage of development. These systems are:

a) The ATSC system, developed in the USA.
b) The DVB-T system, developed in Europe.
c) The BST-OFDM system, developed in Japan.

2. Systems Overview

2.1 The ATSC system

The ATSC system was specifically designed to permit an additional digital transmitter to be added to each existing NTSC transmitter in the United States of America, with comparable coverage and minimum disturbance to the existing NTSC service in terms of both area and population coverage. This capability is met and even exceeded.

The system is quite efficient and capable of operating under varying conditions, i.e., clear channel availability or, as implemented in the US, constrained to fit 1600 additional channels into an already crowded spectrum, and reception with roof-top or portable antennae.

The system was also designed to be immune to multipath and to offer spectrum efficiency and ease of frequency planning.

Signals conforming to the ATSC system can travel on cables and the United States cable industry is just beginning its conversion to digital. The ATSC 16-VSB mode is suited for cable since it can double the capacity on this delivery media. The ATSC has been tested and proven to work reliably over satellite at the same or higher bit rates.
As recalled in the Introduction section of this document, the ATSC system was designed to permit an additional digital transmitter to be added to each existing NTSC transmitter in the United States of America with comparable coverage and minimum disturbance to the existing NTSC service in terms of both area and population coverage. Variations can be achieved in the programme formats as mentioned in the relevant Section (SD or HD), and there is a great potential for data-based services utilising the opportunistic data transmission capability of the system. The system can accommodate fixed (or possibly portable) reception with no resultant loss in payload.

2.2 The DVB-T system

The DVB-T system was essentially designed with built-in flexibility, in order to be able to adapt to all channels: it is capable of coping not only with clear channel but with interleaved planning, and even co-channel operation for the same programme by different transmitters (single-frequency networks).

It also permits service flexibility, with the possibility of reception by roof-top antennae and also, if desired, of portable reception. Mobile reception has been demonstrated at speeds up to 170 km/h in a clear channel environment. The form of coverage can also be tailored to the user's needs.

The system was also designed to be robust against interference from delayed signals, either echoes from terrain or buildings or signals from distant transmitters in a single frequency network, a new tool which it brings to TV service planning to improve spectrum efficiency which is necessary in the case of particularly crowded spectrum as it is the case in Europe.

The DVB-T compliant signals can also be carried over cables. However, the DVB-T specification is part of a family of specifications covering also satellite (DVB-S) and cable (DVB-C) operation. All use MPEG-2 coding for video and audio and MPEG-2 type of multiplexing. They have common features in the error protection strategy to be used. The main difference is the modulation method which is specific to the relevant bearer (satellite, cable or terrestrial). The available data capacity is also different, as higher bit rates are offered on cable and satellite. However, transferring programmes from one bearer to another is possible provided that the bit rate is available.

The DVB-T system features a number of selectable parameters, which allows it to accommodate a large range of carrier to noise ratio and channel behaviour, allowing fixed, portable, or possibly mobile reception, with a trade-off in the usable bit rate. Table 1 summarises the system possibilities. The range of parameters allows the broadcasters to select a mode appropriate to the application foreseen. For instance, a very robust mode (with correspondingly lower payload) is needed to ensure portable reception. A moderately robust mode with a higher payload could be used where the service planning uses interleaved channels. The less robust modes with the highest payloads can be used if a clear channel is available for digital TV broadcasting.

This highlights the DVB-T specific flexibility, which allows the user to tailor the
system by using the most appropriate mode among the different possible modes of operation proposed. Comprehensive discussion of the optimum use of all parameters is complex and would be lengthy. However, the following features should be kept in mind:

* the hierarchical modes when applicable split the channel in two with different (and adjustable) requirements in terms of C/N. This permits different reception conditions for the same or for different programme content;

* the code rate and the modulation scheme can be selected in order to lower down the C/N requirements to the desired form of service;

* the selection of the 2k mode instead of 8k makes mobile reception easier. However, it only permits the implementation of small single frequency networks of transmitters (SFN) as will be explained below.

Examples of such services not using hierarchical modes are given in Table 1.

<table>
<thead>
<tr>
<th>Bit rate</th>
<th>Modulation</th>
<th>Code rate</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Mbit/s</td>
<td>QPSK</td>
<td>1/2</td>
<td>channel featuring a high level of interference</td>
</tr>
<tr>
<td>15 Mbit/s</td>
<td>16 QAM</td>
<td>2/3</td>
<td>Wide area portable reception</td>
</tr>
<tr>
<td>26 Mbit/s</td>
<td>64 QAM</td>
<td>3/4</td>
<td>Maximise data rate in a clear channel</td>
</tr>
</tbody>
</table>

Table 1: Examples of DVB-T parameter use for various services.

2.3 The ISDB-T system

The ISDB-T system has been designed to have enough flexibility to send not only television or sound programmes as digital signals but also offer multimedia services in which a variety of digital information such as video, sound, text and computer programmes will be integrated. It aims to make use of the advantages provided by terrestrial radio waves so that stable reception can be provided by compact, light and inexpensive mobile receivers in addition to integrated receivers used at home by using BST (Band Segmented transmission) -OFDM scheme. Two transmission bandwidth are prescribed, 5.6 MHz and 432 kHz, each oriented to particular types of broadcasting services. The 5.6 MHz bandwidth is mainly for digital broadcasting of television programmes, while the 432 kHz bandwidth is mainly for that of audio programmes. These two modes share all other parameters such as encoding format, multiplexing format, and OFDM carrier interval and frame configuration. Terrestrial ISDB provides hierarchical transmission features using different carrier modulation schemes (DQPSK, QPSK, 16QAM, 64QAM) and internal encoding rate (1/2, 2/3, 3/4, 5/6, 7/8). This enables part of the band to be allocated to signals for stationary reception and the rest to signals for mobile reception which means that audio and data broadcasts for automobile and portable receivers can be performed simultaneously with television broadcasts for home use. Each hierarchical level can be set for each BST-Segment having a bandwidth of 432 kHz. Such information can be sent to receivers by TMCC(Transmission and Multiplexing Configuration Control) signal allocated to part of the OFDM carrier.
Because the wide bandwidth and narrow bandwidth in terrestrial ISDB share the same OFDM parameters, the 5.6 MHz wide band can include the 432 kHz narrow band directly. Consequently, a 432 kHz receiver can receive some 5.6 MHz services, and a 5.6 MHz receiver can receive all services broadcast at 432 kHz. Figure 1 shows the concept of this feature.

![Diagram showing service and receiving image for terrestrial ISDB system.](image)

**Fig.1**: Service image and receiving image for the terrestrial ISDB system
3. Specifications

3.1 Source coding

3.1.1 Video coding

a) ATSC system

The ATSC system allows the following formats:

<table>
<thead>
<tr>
<th>Vertical lines</th>
<th>Pixels</th>
<th>Aspect ratio</th>
<th>Picture rate*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1080</td>
<td>1920</td>
<td>16:9</td>
<td>60P, 30P, 24P</td>
</tr>
<tr>
<td>720</td>
<td>1280</td>
<td>16:9</td>
<td>60P, 30P, 24P</td>
</tr>
<tr>
<td>480</td>
<td>704</td>
<td>16:9 and 4:3</td>
<td>60P, 60I, 30P, 24P</td>
</tr>
<tr>
<td>480</td>
<td>640</td>
<td>4:3</td>
<td>60P, 60I, 30P, 24P</td>
</tr>
</tbody>
</table>

* "Picture rate" refers to the number of fields or frames per second, progressive (P) or interlace (I). Both 60.00 Hz and 59.94 Hz picture rates are allowed. Dual rates are allowed also at the picture rate of 30 Hz and 24 Hz.

Table 2: ATSC picture formats

b) DVB-T and ISDB-T Systems

The DVB-T and ISDB-T Systems are fundamentally a delivery means for MPEG-2 video. While the MPEG-2 Main Profile @ Main level can accommodate SDTV, the Main Profile @ High Level allows line rates up to 1152 active lines (which includes 1035, 1080, 1152 lines, etc.). MPEG-2 video also allows field rates up to 60 Hz, and active samples of up to 1920 samples, up to a ceiling on luminance samples.

3.1.2 Audio coding

The ATSC system uses the Dolby AC-3 system which is described in an ITU Recommendation and is proprietary, although dolby has made a firm commitment to license AC-3 on reasonable and non-discriminatory terms.

The DVB-T and ISDB-T systems use a standard MPEG-2 audio coding, agreed as part of the world-wide MPEG standards for which usual IPR agreements in the ISO have been granted (engagement of the right-holders to yield licenses on fair and non-discriminative basis).

3.2 Multiplexing

The ATSC, ISDB-T and the DVB-T systems use an MPEG-2 TS standard multiplex. This multiplex is the backbone of both the ATSC, and the DVB-T systems and can be used for the whole television system, including contribution links. Further, Internet Protocol can be carried over the MPEG-2 TS used in DVB-T.
3.3 Access control

This is important for the proper introduction and management of digital terrestrial television operation, but it is generally separate from the system specification. Any conditional access system compatible with MPEG-2 TS can be used in the three systems. The DVB-T system offers a common interface for conditional access systems.

3.4 Channel coding and modulation

The main differences among the three systems are their use of the RF resource.

The ATSC uses a single carrier per channel, modulated at high speed by a modulation method referred to as VSB. Two modes of operation are available, having the same symbol rate but with different levels of net data rate, robustness and coverage.

The DVB-T uses a large (thousands) number of carriers per channel modulated in parallel at lower speed, a method referred to as OFDM. Each carrier is modulated according to a user-selectable range of methods. Further, a "guard interval" separates the transmitted symbols, which brings properties concerning insensitivity to echoes, as well as operation of networks of multiple transmitters on the same frequency, at the expense of some loss in overall bit rate.

The ISDB-T uses a modulation method referred to as Segmented OFDM, which consists of a set of common basic frequency blocks called BST-Segments. In addition to the properties of OFDM, the BST-OFDM provides hierarchical transmission features by using the different carrier modulation schemes and coding rates of the inner code for the BST-Segment.

a) ATSC system

The VSB carrier system has two modes: the 8-VSB "simulcast terrestrial" intended to be more immune to NTSC environment and the 16-VSB "high data rate mode" primarily developed for cleaner cable channels. All test results presented in this document refer to the "simulcast terrestrial" mode using 8-VSB modulation.

Although the system was developed and tested with 6 MHz channels, it can be used with any channel bandwidth (6, 7 or 8 MHz) with corresponding variations in the data capacity. The relevant specifications have been contributed to the ITU.

b) DVB-T system

The DVB-T system makes provision for selection between:

- four values of guard interval 1/32, 1/16, 1/8 or 1/4 of the time
- five inner code rates (modulation efficiency) 1/2, 2/3, 3/4, 5/6, 7/8
- three modulation schemes
- two modes of carrier arrangement in the channel approximately 2k and 8k carriers
- hierarchical mode of operation option with 16-QAM and 64-QAM, uniform or non-uniform

Although the system was developed and tested with 8 MHz channels, it can be used with any channel bandwidth (8, 7 or 6 MHz) with corresponding variations in...
the data capacity. The relevant specifications have been contributed to the ITU.

c) ISDB-T System

ISDB-T System makes provision for the following:

- Channel bandwidth: 5.6 MHZ, 432 kHz
- Guard interval rate: 1/32, 1/16, 1/8 or 1/4 of the time
- Inner code rates: 1/2, 2/3, 3/4, 5/6, 7/8
- Carrier modulation schemes: DQPSK, QPSK, 16-QAM, 64-QAM
- Carrier spacing: 4 kHz, 1 kHz

Although the system was developed and tested with 5.6 MHZ and 432 kHz channels, it can be used with any channel bandwidth (432 kHz X N) with corresponding variations in the data capacity. The inner code rate and the carrier modulation scheme can be set independently for each BST segment. The relevant specification have been contributed to the ITU.

3.5 Bit rates

a) ATSC system

The net (error corrected) bit rate available in a 6 MHz channel (payload data rate) is 19.28 Mbit/s in the terrestrial broadcast mode.

b) DVB-T system

The net (error corrected) bit rate available in 6 MHz and 8 MHz channels depends on the user’s options concerning type of service, coverage, etc. as will be considered later. It can be summarised by Tables 3 and 4.

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Inner code rate</th>
<th>1/4</th>
<th>1/8</th>
<th>1/16</th>
<th>1/32</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>4.98</td>
<td>5.53</td>
<td>5.85</td>
<td>6.03</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>6.64</td>
<td>7.37</td>
<td>7.81</td>
<td>8.04</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>7.46</td>
<td>8.29</td>
<td>8.78</td>
<td>9.05</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>8.29</td>
<td>9.22</td>
<td>9.76</td>
<td>10.05</td>
</tr>
<tr>
<td></td>
<td>7/8</td>
<td>8.71</td>
<td>9.68</td>
<td>10.25</td>
<td>10.56</td>
</tr>
<tr>
<td>16-QAM</td>
<td>1/2</td>
<td>9.95</td>
<td>11.06</td>
<td>11.71</td>
<td>12.06</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>13.27</td>
<td>14.75</td>
<td>15.62</td>
<td>16.09</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>14.93</td>
<td>16.59</td>
<td>17.56</td>
<td>18.10</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>16.59</td>
<td>18.43</td>
<td>19.52</td>
<td>20.11</td>
</tr>
<tr>
<td></td>
<td>7/8</td>
<td>17.42</td>
<td>19.35</td>
<td>20.49</td>
<td>21.11</td>
</tr>
<tr>
<td>64-QAM</td>
<td>1/2</td>
<td>14.93</td>
<td>16.59</td>
<td>17.56</td>
<td>18.10</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>19.91</td>
<td>22.12</td>
<td>23.42</td>
<td>24.13</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>22.39</td>
<td>24.88</td>
<td>26.35</td>
<td>27.14</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>24.88</td>
<td>27.65</td>
<td>29.27</td>
<td>30.16</td>
</tr>
<tr>
<td></td>
<td>7/8</td>
<td>26.13</td>
<td>29.03</td>
<td>30.74</td>
<td>31.67</td>
</tr>
</tbody>
</table>

Table 3: Net data rates in 8-MHz channels with the DVB-T system (Mbit/s)
Table 4: Net data rates in 6-MHz channels with the DVB-T system (Mbit/s)

c) ISDB-T System

The net (error corrected) bit rate available in 6 MHz channels depends on the user’s options concerning types of hierarchical mode, service, coverage...etc. as will be considered later. It can be summarised by Tables 5 and 6.

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Inner code rate</th>
<th>1/4</th>
<th>1/8</th>
<th>1/16</th>
<th>1/32</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>3.69</td>
<td>4.10</td>
<td>4.34</td>
<td>4.48</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>4.92</td>
<td>5.47</td>
<td>5.79</td>
<td>5.97</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>5.54</td>
<td>6.15</td>
<td>6.52</td>
<td>6.71</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>6.15</td>
<td>6.84</td>
<td>7.24</td>
<td>7.46</td>
</tr>
<tr>
<td></td>
<td>7/8</td>
<td>6.46</td>
<td>7.18</td>
<td>7.60</td>
<td>7.83</td>
</tr>
<tr>
<td>16-QAM</td>
<td>1/2</td>
<td>7.39</td>
<td>8.21</td>
<td>8.69</td>
<td>8.95</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>9.85</td>
<td>10.94</td>
<td>11.58</td>
<td>11.94</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>11.08</td>
<td>12.31</td>
<td>13.03</td>
<td>13.43</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>12.31</td>
<td>13.68</td>
<td>14.48</td>
<td>14.92</td>
</tr>
<tr>
<td></td>
<td>7/8</td>
<td>12.92</td>
<td>14.36</td>
<td>15.20</td>
<td>15.67</td>
</tr>
<tr>
<td>64-QAM</td>
<td>1/2</td>
<td>11.08</td>
<td>12.31</td>
<td>13.03</td>
<td>13.43</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>14.77</td>
<td>16.41</td>
<td>17.38</td>
<td>17.90</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>18.46</td>
<td>20.51</td>
<td>21.72</td>
<td>22.38</td>
</tr>
<tr>
<td></td>
<td>7/8</td>
<td>19.39</td>
<td>21.54</td>
<td>22.81</td>
<td>23.50</td>
</tr>
</tbody>
</table>

Table 5: Net Data rate of the 432 kHz ISDB-T system (Kbps)
Table 6: Net data rate of the 5.6 MHz ISDB-T system (Mbps)

4. Performance

4.1 System efficiency

Although it is not straightforward to compare the ATSC and DVB-T "efficiency" in terms of resource usage, an interesting tool is to draw the curve of bit-rate vs. C/N in the same bandwidth and for comparable error criteria. For the DVB-T system, this implies a selection of a particular guard interval value (in μs) to keep comparable with the ATSC system (which should correct echoes up to 18 μs at -1 dB). The ATSC curve is only one point, while the DVB-T yields a family of points corresponding to the mentioned curve.

For a Gaussian channel in which the only impairment present is white noise, the required C/N for the ATSC system is 1.5 to 2 dB less than that of the DVB-T at the same bit-rate. This confirms the optimisation of the ATSC system for the cases where these conditions apply.

Concerning the ATSC, no figures were available for other channel types such as the Rice channel which is representative of reception with a rooftop antenna, or the Rayleigh channel which is representative of portable reception. DVB-T simulations and field tests have exhibited good results in Rice and Raleigh channels (see Figure 3).
<table>
<thead>
<tr>
<th>Parameters</th>
<th>ATSC</th>
<th>DVB-T</th>
<th>ISDB-T</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Used bandwidth</strong></td>
<td>5.38 MHz (-3 dB)</td>
<td>6.66 MHz, 7.6 MHz</td>
<td>5.62 MHz</td>
</tr>
<tr>
<td><strong>Number of radiated carriers</strong></td>
<td>1</td>
<td>1705 (2k mode)</td>
<td>1405 (Mode 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6818 (8k mode)</td>
<td>5617 (Mode 2)</td>
</tr>
<tr>
<td><strong>Modulation methods</strong></td>
<td>8-VSB</td>
<td>OFDM (QPSK, 16QAM, 64QAM)</td>
<td>Segmented OFDM (DQPSK, QPSK, 16QAM, 64QAM)</td>
</tr>
<tr>
<td><strong>Spectrum shaping</strong></td>
<td>Root raised cosine roll off, R=5.8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Active symbol duration</strong></td>
<td>92.9 ns</td>
<td>256 µs (7MHz, 2k mode)</td>
<td>250 µs (Mode 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1024 µs (7MHz, 8k mode)</td>
<td>1 ms (Mode 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>224 µs (8MHz, 2k mode)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>896 µs (8MHz, 8k mode)</td>
<td></td>
</tr>
<tr>
<td><strong>Carrier spacing</strong></td>
<td>3906 µs (7MHz, 2k mode)</td>
<td>976 µs (7MHz, 8k mode)</td>
<td>4 kHz (Mode 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4464 µs (8MHz, 2k mode)</td>
<td>1 kHz (Mode 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1116 µs (8MHz, 8k mode)</td>
<td></td>
</tr>
<tr>
<td><strong>Guard interval</strong></td>
<td></td>
<td>1/4, 1/8, 1/16, 1/32 of active symbol duration</td>
<td>1/4, 1/8, 1/16, 1/32 of active symbol duration</td>
</tr>
<tr>
<td><strong>Overall symbol duration</strong></td>
<td>77.3 µs (segment)</td>
<td>264, 272, 288, 320 µs (7MHz, 2k mode)</td>
<td>257.8125, 265.625, 281.25, 312.5 µs (Mode 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1048, 1088, 1152, 1280 µs (7MHz, 8k mode)</td>
<td>1031.25, 1062.5, 1125, 1250 µs (Mode 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>231, 238, 252, 280 µs (8MHz, 2k mode)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>924, 952, 1008, 1120 µs (8MHz, 8k mode)</td>
<td></td>
</tr>
<tr>
<td><strong>Transmission frame duration</strong></td>
<td>48.4 ms</td>
<td>68 OFDM symbols</td>
<td>204 OFDM symbols</td>
</tr>
<tr>
<td></td>
<td></td>
<td>One super-frame consists of 4 frames</td>
<td></td>
</tr>
<tr>
<td><strong>Inner channel code</strong></td>
<td>Trellis 2/3</td>
<td>Convolutional code</td>
<td>convolutional code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rate: 1/2, 2/3, 4/5, 5/6, 7/8</td>
<td>Rate: 1/2, 2/3, 3/4, 5/6, 7/8</td>
</tr>
<tr>
<td><strong>Inner interleaving</strong></td>
<td>12 (independently encoded streams interleaved in time)</td>
<td>Frequency interleaving</td>
<td>Time and Frequency interleaving</td>
</tr>
<tr>
<td><strong>Outer channel code</strong></td>
<td>RS (207,187)</td>
<td>RS (204,188)</td>
<td>RS (204,188)</td>
</tr>
<tr>
<td><strong>Outer interleaving</strong></td>
<td>52 segment convolutional byte interleaved</td>
<td>Bytewise convolutional interleaving, I=12</td>
<td>Bytewise convolutional interleaving, I=12</td>
</tr>
</tbody>
</table>

*: The ASTC system and the ISDB-T system can be re-scaled to 7 and 8 MHz system, and the DVB-T system can be re-scaled to 6 MHz system by changing its sampling frequency.

Table 7: Transmission parameters of the different systems
4.2 Multipath interference

a) ATSC system

The ATSC reports specify withstanding -1.8 to +18 μs single echo. Theoretically, in a noise free signal, ghosts of amplitude up to 0 dB with respect to the largest signal can be cancelled. In practical implementation, the complete prototype receiver demonstrated in field and laboratory tests showed cancellation of -1 dB amplitude ghosts under otherwise low noise conditions, and -3 dB amplitude ghost ensemble with noise where the signal was 2.25 dB above the receiver’s noise-only reception threshold.

b) DVB-T system

The DVB-T system is specifically designed to withstand high amplitude and long delay multiple echoes. Its degree of resistance depends on the coding option used: with rate ⅓ coding the loss of noise margin with a single 0 dB echo within the guard interval is 3 dB and with rate 2/3 coding it is 6 dB. These figures are from simulations and have been confirmed by laboratory tests. Beyond the guard interval, the sensitivity rises steeply (for example, an echo 10 dB below main signal is just tolerable when its duration is 109% of that of the guard interval, the level being 20 dB below main signal if the duration is 123%). Correspondingly, sensitivity to multiple echoes was also tested in configurations simulating various reception conditions as shown in Table 8.

<table>
<thead>
<tr>
<th>Reception condition</th>
<th>Max echo delay (ms)</th>
<th>Measured margin loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8k / 64-QAM, Δ = 1/8, FEC = 2/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed (Ricean channel)</td>
<td>5.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Portable (Rayleigh channel)</td>
<td>5.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Dense SFN (Rayleigh channel)</td>
<td>23</td>
<td>2.9</td>
</tr>
<tr>
<td>Regional SFN (Rayleigh channel)</td>
<td>100</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Table 8: Margin loss ΔC/N with multiple echoes (at BER 2.10⁻⁴ after Viterbi decoding).

4.3 Impulsive noise performance

a) ATSC system

In tests, the ATSC system withstood a 180μs burst at a repetition rate of 10 Hz in 8-VSB mode and a 120 μs burst at a repetition rate of 10 Hz in 16-VSB.
b) DVB-T system

Tests were carried out giving the tolerable C/I level as a function of the pulse frequency, for various levels of noise margin loss. The results are shown in Fig. 2 (note that for a given level of I power, the amplitude of the pulses increases as their repetition rate decreases). The values of $\Delta C/N$ are the loss in noise margin, and $\infty$ corresponds to the threshold of operation.

![Impulsive Noise Performance 8k - 64QAM 2/3 - $\Delta = 1/4$](image)

Fig. 2: Performance of DVB-T system with impulsive noise.

5. Planning and Implementation

5.1 Protection ratios

Only co-channel protection ratio will be considered here because they are more inherent to the system and not to the particular implementation used for the tests.

a) ATSC system

On the basis of correlation with threshold of visibility measurements, the results in Table 9 were found with bit error rate measurements. The ATSC system is referred to as "ATV"; NTSC only is considered in 6 MHz channel environment. The tests were carried out with a population of typical NTSC receivers for the USA.

<table>
<thead>
<tr>
<th>Carrier to noise</th>
<th>15.19 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-channel ATV into NTSC</td>
<td>34.44 dB</td>
</tr>
<tr>
<td>Co-channel NTSC into ATV</td>
<td>1.81 dB</td>
</tr>
<tr>
<td>Co-channel ATV into ATV</td>
<td>15.27 dB</td>
</tr>
</tbody>
</table>

Table 9: Co-channel protection ratios for ATSC
b) DVB-T system

For ease of introduction of services in various transmission configurations (e.g., taboo channels), the DVB-T system offers a wide range of options to adapt to the existing RF spectrum situations. Figure 3 illustrates the flexibility of the system.

<table>
<thead>
<tr>
<th>Carrier to noise</th>
<th>Continuous interference*</th>
<th>Tropospheric Interferences**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-channel DVB-T into G-PAL</td>
<td>40 dB</td>
<td>34 dB</td>
</tr>
<tr>
<td>Co-channel DVB-T into I-PAL</td>
<td>41 dB</td>
<td>37 dB</td>
</tr>
<tr>
<td>Co-channel DVB-T into K-SECAM</td>
<td>41 dB</td>
<td>35 dB</td>
</tr>
<tr>
<td>Co-channel DVB-T into DVB-T</td>
<td>identical to minimum C/N</td>
<td>requirement (see Fig. 3)</td>
</tr>
</tbody>
</table>

* protection ratios for continuous interference refer to impairment grade 4.
** protection ratios for tropospheric interference refer to impairment grade 3.

**Table 10:** Co-channel, analogue and digital television interfered with by digital television for DVB-T

<table>
<thead>
<tr>
<th>Minimum C/N requirement (dB)</th>
<th>Co-channel interfering signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-8</td>
</tr>
<tr>
<td>8</td>
<td>-2</td>
</tr>
<tr>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>26</td>
<td>16</td>
</tr>
</tbody>
</table>

**Table 11:** Co-channel, digital television (DVB-T) interfered with by analogue Television
Required C/N and net bit-rate as a function of the modulation scheme, code rate and guard interval length for different channel profiles. For a given configuration, the lower end (lower C/N) of the bold segment corresponds to rooftop antenna reception (Rice channel) while the higher end corresponds to indoor portable reception (Raleigh channel).

Fig. 3: Net bit rates for 8 MHz channels
5.2 Frequency planning

a) ATSC system

The frequency planning for the ATSC system aims at the purposes for which the system has been designed and need not be repeated here (see Sec 2.1), goals that were met and even exceeded in the United States of America.

b) DVB-T system

In defining coverage it is indicated that due to the very rapid transition from near perfect to no reception at all, it is necessary that the minimum required signal level is achieved at a high percentage of locations. These percentages have been set at 95 for "good" and 70 for "acceptable" reception.

Minimum median power flux densities were calculated for:

- 3 different receiving conditions:
  - Fixed antenna reception;
  - Portable outdoor reception,
  - Portable indoor reception at ground floor;
- 4 frequencies representing Band I, Band III, Band IV and Band V:
  - 65 MHz;
  - 200 MHz;
  - 500 MHz;
  - 800 MHz;
- 5 representative C/N ratios in the range 2 dB to 26 dB in steps of 6 dB.

The total number of configurations is therefore $2 \times 3 \times 4 \times 5 = 120$.

The analysis was carried out for all cases, and the results are too bulky to be reproduced here. For each of the above configurations, the following parameters were determined:

- minimum power flux density at receiving place,
- minimum equivalent field strength at receiving place,
- minimum median power flux density at 10 m, 50% of time and 50% of locations,
- minimum median equivalent field strength at 10 m, 50% of time and 50% locations.

The parameters used for antenna gain were taken in ITU-R Rec. 419 for fixed reception. Building penetration loss figures were derived from ITU-R Rep. 1203 for VHF and from experiments for UHF. Portable antenna gain was also obtained by experiments.

The resulting tables apply to "conventional" frequency planning with single transmitter coverage, and not to SFN networks discussed below.
5.3 Network implementation

a) ATSC system

The system being single carrier behaves in a way somewhat comparable to that of analogue television transmission. Opening a new transmitter requires the availability of a channel and power level compatible with the existing ones in respect of the applicable protection ratios.

This implies that the coverage of a given area by more than one transmitter requires multiple channels as in the case of analogue television. In particular, any secondary transmitter to extend the service area of an existing one taps the RF resource.

The system is suitable to different situations where service areas can be isolated or extremely dense as in the East and West coasts of the US. The system is also very well suited to provide regional networks made up of multiple programmes having local content or multiple programmes of different content in order to resolve scheduling conflicts or to create new revenue streams. The number of multiple programmes is dependent on content and resolution desired.

b) DVB-T system

The system can be used to build network systems either using conventional frequency planning or to use the inherent capability of COFDM with guard intervals to withstand multipath to set up single frequency networks (SFN) transmitting the same content with the following benefits:

- improved spectrum efficiency,
- smaller frequency re-use distance,
- improved power efficiency, better tailored to the desired coverage,
- more even coverage and possibility of tailoring the coverage area,
- "gap-fillers" without extra frequency resource.

There are essentially two ways of using this advantage:

- Gap-fillers are the operation of the system with echoes created voluntarily. It permits the elimination of residual shadowed areas by passive reflectors or small active relays without having to change the carrier frequency for the reflected or relayed signal. The signal is picked-up at a location where reception conditions are satisfactory and then re-amplified and re-broadcast on the same frequency. These "gap-fillers" do not require any additional frequency and their intrinsic simplicity ensures very low cost.

- Dense networks transmitting the same programme on the same frequency can be built. The limitation to the use of the technique is the possibility that distant transmitters are delayed more than allowed by the guard interval and therefore behave as interfering signals. As a rule of thumb, the guard interval should allow the signal to propagate over the distance between two transmitters in the network. As this guard interval may vary from 224 µs (1/4 guard interval value, 8k mode) to 7 µs (1/32 guard interval value, 2k mode), the corresponding distances are about 65 km and 2 km respectively. A variety of SFNs can
therefore be implemented: large (regional, possibly national, depending on the regional programming variations required), local (e.g. to serve an urban area), not preventing the use of gap-fillers to fill-in gaps in the coverage of the main transmitters. The selection of the configuration (2k or 8k, value of the guard interval) permits an optimised usage of the resource, minimising the bit rate penalty.

The gain in frequency and power efficiency requires the synchronous operation of all the transmitters of the network. Efficient methods are specified for this purpose. The synchronous operation of remote multiplexers has been demonstrated in a practical network which included dark fibre, SDH links, and an ATM link followed by a satellite link.

Last, the use of hierarchical mode also permits an increase in power efficiency.

5.4 Peak to average power

a) ATSC system

Measurements indicated a peak to average power ratio of 5.9 dB for 0.01% of the time.

b) DVB-T system

Although comprehensive results are not available, measurements carried out by CRC indicate an inferiority of about 2 dB of the OFDM with respect to VSB modulation for the same proportion of time.

6. Time schedule and Implementation

The fact that 7 experimental ATSC stations are already working in the US, a DVB-T experimental service has been on air in the UK since June 1996, DVB-T experimental networks have been demonstrated in Germany and Spain, proves there is no question about the technical feasibility of efficient systems that will permit such digital terrestrial services to be set up.

6.1 Receiver complexity

A complete receiver (sometimes referred to as IRD for integrated receiver-decoder) implies a number of elements, most of which do not depend on the choice of the ATSC or DVB-T system, although they are influenced by the type of service that is implemented. These are mainly: demultiplexing, video decoding (one of the most complex functions of the receiver), display, power supply and control, interfaces, APIs (Application Programming Interface) and miscellaneous. The differences between the ATSC and DVB-T receiver are to be found in the audio decoding and, of course, in the demodulation circuitry.

---

2Although receivers can be made without it, the use of API is very likely, for purposes of the electronic programme guide (EPG), etc.
The audio decoder is a modest part of the costs and is already well mastered by the IC manufacturing industry. In fact, its weight is so small that the DVD (digital video disk) specifications require both decoders to be present simultaneously.

Multipath operation requires the ATSC receiver to be fitted with a powerful equaliser in order to compensate long and strong echoes, as is the case for any single carrier system.

The COFDM demodulator requires a fast discrete Fourier transform function (FFT), either on 2048 (2k) samples or 8192 (8k) depending on parameter selection (the choice is to be based on service considerations). Both 2k and 8k FFT integrated circuits have been available since 1995. The same chip can be used for 6 MHz bandwidth. While the added complexity is negligible in the medium to long term, it is comparable in the short term to that of the equaliser needed by the ATSC system.

6.2 Practical verification

Both the ATSC and the DVB-T systems have been thoroughly tested. The ATSC system has been implemented and is on air at seven experimental stations in the United States with more to come on line in the weeks ahead.

For the DVB-T system, a wide range of configurations have been tested in the U.K., Germany and Spain. The interworking of DVB-T modulators and demodulators designed and built by separate teams in at least five different laboratories has been verified, confirming that the system specifications are clear and unambiguous. An experimental DVB-T service has been broadcast continuously in the UK since June 1996 and extensive field trial results are available. Experimental transmission and field trials have been demonstrated in the Netherlands, Italy, Germany and Spain.

For the ATSC system, at least one manufacturer has announced plans to begin offering receivers by the Spring of 1998 and several more by the Fall of 1998. Concerning equipment, encoders and demodulators are being produced by at least one manufacturer with plans announced by several others.

For the DVB-T receiver, chip sets have been announced by at least four manufacturers, with the first chip set expected to be available in Summer 1997. Modulators are available from at least five manufacturers, and several manufacturers are offering transmitters optimised for DVB-T.

6.3 Plans and time schedule

In the United States of America, the ATSC modulation and transport system and video and audio coding are standardised by the FCC. Specific video formats are not mandated. The FCC has ordered a rapid rollout of the ATSC system in the US according to the following schedule:

- 26 stations in the top 10 markets on the air by December 25, 1998
- Major network affiliates in the top 10 markets on the air by May 1, 1999
• Affiliates in the top 30 markets on the air by November 1, 1999
• All commercial stations in the air by May 1, 2002
• All non commercial or public stations on the air by May 1, 2003
• A total of 1600 full power ATSC stations will be operating by that time

Under this plan 43% of TV households in the US will be able potentially to receive at least one ATSC signal by May 1, 1999 and 50% will by November 1, 1999.

Two countries in Europe, Sweden and UK, have a legal framework in place and have announced the start of services using DVB-T. In the UK the first operational (as opposed to experimental) transmitters will be in service by the end of 1997 and a full service with six multiplexes available at each transmitter site is expected to start in mid-1998. In Sweden, the first operational transmitters are expected to be on air in September 1997 and a full service will start in March 1998. Further trials are planned for late 1997 in Denmark, Finland and Ireland.