Digital terrestrial television

The 8k system

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While this issue of the Review was being prepared, the DVB Steering Board agreed on the specification for terrestrial broadcasting of digital television signals (DVB-T). It is based on COFDM with two variants – one is known as the "8k system" and the other as the "2k system".

In this article, the author outlines the developments which led up to the DVB-T specification being agreed, and describes how an 8k system works.

1. Introduction

Digital terrestrial television has always been an important part of the DVB Project – but preparing a technical specification for such a system was not the first job that the Project tackled. This was due to a number of reasons:

- there was no commercial pressure to start terrestrial services in 1993 when the Project was set up;
- congestion of the terrestrial frequency spectrum in most of Europe makes it very difficult to start new terrestrial services;
- the terrestrial environment is probably the most complex delivery medium for which to design.

The DVB User Requirements for digital terrestrial television were approved in late 1994 [1]. By this stage, the work towards a DVB specification for digital terrestrial television had been in progress for some time. Much of the work was carried out by a collaborative group called the TFSC[1]. Their draft specification for digital terrestrial television was approved by the Steering Board of the DVB Project in March 1995 [2] – but it was subject to verifications and complexity evaluations, scheduled to take place during the summer and autumn of 1995.

The original draft proposal has been debated extensively. Known as the "8k system", this proposal was based on 6785-carrier OFDM[2] where each carrier is QAM[3] modulated. Because of its complexity, it was feared by some organizations that receivers would not be ready for sale in time for the

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[1] Task Force on System Comparison. (While writing the specification, the TFSC comprised the following companies: BBC, CCETT, CNS, DLR, IRT, ITC, Philips, RAI, Tele Danmark, Teracom and Thomson.)

[2] Orthogonal frequency division multiplex.

[3] Quadrature amplitude modulation.

introduction of services in 1997. Consequently, an alternative proposal was presented to the DVB Project by NTL and Deutsche Telekom AG in Autumn 1995 [3]. Often called the "2k system", this proposal uses 1696-carrier OFDM, where each carrier is DAPSK[4] modulated.

This article describes the originally-proposed 6785-carrier OFDM system (i.e. the 8k system) in relation to the User Requirements[5]. Opinions expressed in the article are those of the author alone; they do not necessarily comply with the positions adopted by supporters of other digital television projects examined by the TFSC (e.g. dTTb, HD-Divine and $^{H}DTV_{T}$).

In December 1995, after this article had been prepared, the DVB Steering Board finally agreed a *dual-mode* system which allows for either a 2k or an 8k OFDM system to be used. The 8k system – based now on 6817 carriers – is compatible with the 2k system (which now uses 1705 carriers); both systems use QAM modulation of each carrier. The 8k OFDM system agreed by the Board is based mainly on the 8k system described here.

2. Developments towards a terrestrial specification

Digital terrestrial television has been the subject of a number of national and European cooperative research projects including:

– the RACE[6] project, dTTb;

– the Nordic project, HD-Divine;

– the German project, $^{H}DTV_{T}$.

These three projects [4], [5] and [6], together with a number of other projects, have contributed to the group called DTTV-SA[7], which was established by the DVB Technical Module (DVB-TM) in January 1994.

Before the elaboration of the terrestrial specification started, the TFSC had been set up by the dTTb project, with members drawn from the dTTb, $^{H}DTV_{T}$ and HD-Divine projects. (This acknowledged the fact that, to a large extent, these three projects had common objectives.) The task of the TFSC was to outline the specifications for both an OFDM system and a single-carrier system for digital terrestrial television, and to make comparisons between these two systems for a contribution to the DVB-TM. This task was completed by September 1994.

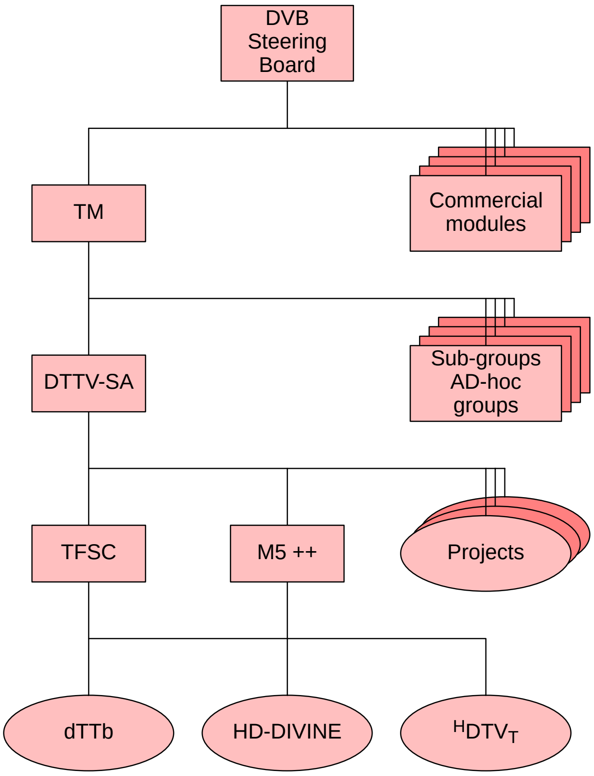
In parallel with this task, the TFSC was requested by the DVB-TM group, DTTV-SA, to write a "Strawman Specification" for terrestrial digital television. *Fig. 1* shows the organization of the work towards the draft specification.

The "Strawman Specification" was approved by the DVB-TM in January 1995 and subsequently by the DVB Terrestrial Commercial Module (TCM) and the DVB Steering Board in March 1995. The "Strawman Specification" was later refined with the addition of a few missing details, and has been renamed the *Draft specification for Digital Terrestrial Television.*

This draft specificaton is the outcome of cooperative work, based on contributions from different project groups; each group has developed digital television hardware with a number of important common features, but also with large differences as each project had different priorities.

None of the presently-available hardware implementations follow the draft specification entirely,

Figure 1
Organization of work towards the draft specification for digital terrestrial television.



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[4] Differential amplitude phase shift keying.

[5] It is planned that a future article in **EBU Technical Review** will describe the "2k system".

[6] R&D in Advanced Communications Technologies in Europe.

[7] Digital Terrestrial Television – Service Aspects.

although almost all aspects of the specification form part of the individual implementations. Hardware which accords with the draft specification is being built under the auspices of the dTTb project and will be ready in March 1996.

In order to verify the draft specification by means of the available hardware, a joint test group – comprising members from the three projects – was established. This group is an extension of the module in charge of measurements in the dTTb project, and also includes members of the $^{H}DTV_{T}$ and HD-Divine projects.

3. The User Requirements for DVB-T

The User Requirements for DVB-T, written by the TCM and published in December 1994, form the basis for the terrestrial specification. As the baseline specifications for satellite and cable had already been approved [7] [8], a number of elements of the User Requirements for the terrestrial specification were already settled. Likewise, a part of the User Requirements for the terrestrial specification related to receiver features which are not dependent on the modulation scheme in use.

The main elements of the User Requirements for DVB-T are as follows (not prioritized):

- the services should start no later than the end of 1997;
- the additional cost to the viewer at the time of introduction should be less that 450 ECUs;
- within two years of introduction, the retail price difference between a digital TV set and the corresponding analogue set should be less than 200 ECUs;
- the system should provide maximum commonality with the satellite and cable baseline systems;
- the transmission carrier should be considered as a “data container” which may contain different kinds of services, transmitted simultaneously;
- the system should be designed for fixed reception as well as static portable reception;
- the service should be optimized for use with existing transmitter sites;
- in terms of spectrum planning, the system should permit maximum use of the flexibility provided by digital broadcasting;
- the system should be designed to allow operation of single frequency networks (SFNs);
- the system should be designed so that single frequency relays (gap-fillers) can be used in the introduction phase;
- the system should provide for local and national coverage under acceptable economical and frequency management conditions;
- the system should be designed for adequate ruggedness against interference and it must minimize its own interference to existing terrestrial analogue services;
- the system should be reconfigurable in such a way that the broadcaster may trade capacity against coverage. In the first phase, a non-hierarchical system would be acceptable. In the second phase, a two-layer hierarchical system is judged to be sufficient.

4. Draft specification

4.1. Considerations

The draft terrestrial specification is based on ensuring that maximum commonality is achieved with the cable and satellite baseline systems. However, it has been necessary to consider separately those aspects that are directly influenced by the transmission media. In the case of terrestrial reception, multipath propagation must be taken into account in mountainous, hilly and built-up areas. Also, new terrestrial services have to be accommodated within the existing UHF bands and, consequently, interference to and from existing television and other services has to be minimized.

Comparisons between single-carrier and multicarrier (OFDM) systems have shown that there are considerable advantages when using an OFDM system in the terrestrial environment.

OFDM is already well known from its use in Digital Audio Broadcasting (DAB) [9]. It copes very well with multipath propagation conditions, it is robust when faced with interference and impulsive noise, and it offers a high degree of frequency economy by allowing the use of single frequency networks.

The various European projects working on systems for digital terrestrial television have mainly been focused on OFDM, for the reasons mentioned above. Frequency economy is a crucial point, because of the congested frequency spectrum throughout Europe.

By using OFDM, it is possible to design a system which:

- allows for flexibility in frequency planning;
- can provide both fixed and portable reception in the presence of strong reflections;
- is rugged against interference.

The main parameters of the OFDM system are determined from the requirements needed for SFN operation.

The carrier separation in an OFDM system (the difference in frequency between adjacent carriers) is inversely proportional to the symbol length to achieve carrier orthogonality. For this reason, the number of carriers in an 8-MHz channel is determined from the symbol length. In order to obtain a reasonably useful bit-rate, the maximum guard interval which can be used is taken to be approximately 1/4 of the active symbol length. In an SFN, signals which arrive from different transmitters, with relative time delays that are greater than the guard interval, cause interference to one another. Therefore the length of the guard interval determines the maximum transmitter distance in an SFN.

If an SFN is to be based (mainly) on existing transmitter sites (that is, with an inter-transmitter spacing of about 60 km), it is necessary to use a guard interval of approximately 250 μs. This will allow for large-area SFNs, for example for regional coverage, while national SFNs in some countries ideally would require a guard interval of approximately 500 μs. The requirement for a long guard interval determines the number of carriers in an OFDM system. A guard interval of around 250 μs can be achieved in an OFDM system if the carrier separation is about 1 kHz; in an 8-MHz channel, this results in approximately 8000 carriers. If a guard interval of 500 μs had been chosen, the number of carriers would have been 16 000. However, this large number of carriers is unrealistic for the moment, as it would not be easy to produce the receivers economically for the consumer market, with the technology that is currently available.

An OFDM signal is implemented using an inverse Fast Fourier Transform (FFT), and the receiver uses an FFT in the demodulation process. The FFT size is 2^N, where N in current hardware implementations has values of 9, 10, 11, 12, 13 or 14. The FFT size will then be 512, 1024, 2048, 4096, 8192 or 16 384, which determines the maximum number of carriers. In practice, a number of carriers at the bottom and top end of the OFDM spectrum will be left out in order to allow for separation (a guard band) between channels. The 8k system previously referred to in this article uses an FFT size of 8192.

It is estimated that an 8k OFDM system will be feasible in the near future and will just meet the

Main parameters of the draft DVB-T specification

(as at December 1995)

Input signal

MPEG-2 transport stream(s) multiplex.

Energy dispersal, outer coding and interleaving

Identical to the specification for the cable and satellite baseline systems.

Inner coding

Punctured convolutional codes, based on a mother convolutional code of rate 1/2 with 64 states, identical to the specification for the satellite baseline system.

Inner interleaving

Block-based bit-wise combined with symbol-wise interleaving. The result of this interleaving on the OFDM signal is frequency interleaving. The interleaving scheme is optimized for performance versus memory requirement.

Signal constellation and mapping

All data carriers in one OFDM frame are either QPSK, 16-QAM, 64-QAM, non-uniform-16-QAM or non-uniform-64-QAM, using Gray mapping.

OFDM frame structure

The OFDM frame consists of 68 symbols. Each symbol is constituted by a set of 1705 carriers in the “2k mode” and 6817 carriers in the “8k” mode. Each symbol is transmitted with a duration Ts, composed of two parts: a part with the duration T_U and a guard interval of duration Δ.

“2k mode”: $T_U = 224\ \mu s$, $\Delta = 7, 14, 28$ or $56\ \mu s$
“8k mode”: $T_U = 896\ \mu s$, $\Delta = 28, 56, 112$ or $224\ \mu s$

All symbols contain reference carriers. These are *continual pilots* which are carried by the same carriers on all symbols, and *scattered pilots* which are spread in time and frequency. These pilots are used by the receiver for synchronization and channel-estimation purposes.

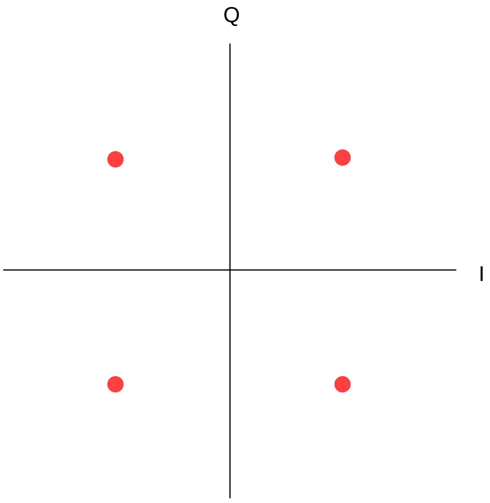
Transmission Parameter Signalling (TPS)

Transmission Parameter Signalling is carried by TPS pilot carriers and is used to convey information on guard interval length, code rate(s) and modulation.

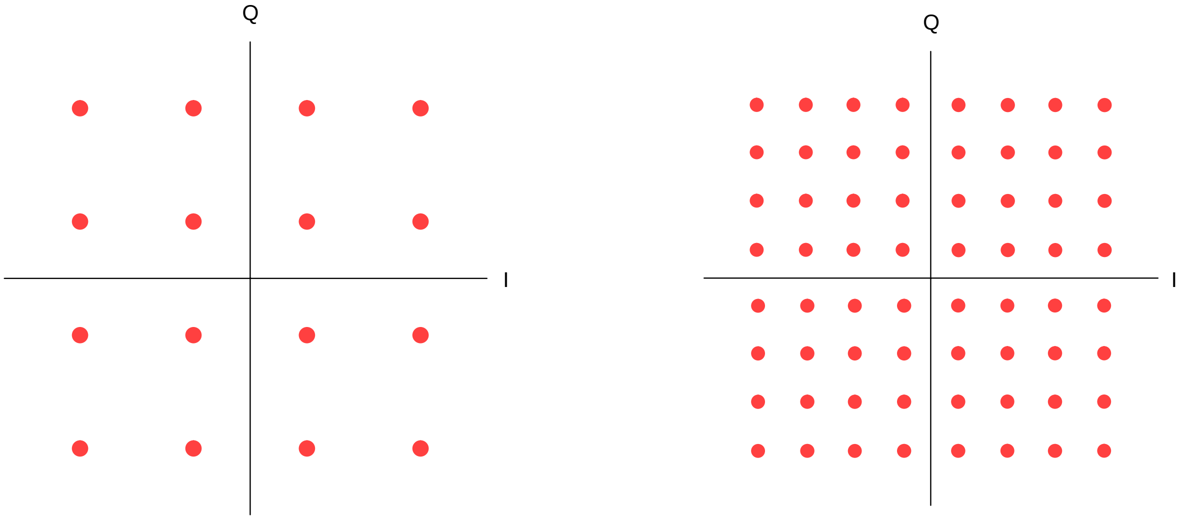
The TPS is transmitted using differential binary phase shift keying (DBPSK) of the TPS pilots over 68 consecutive symbols, which corresponds to one OFDM frame. 37 of the 68 bits available for TPS are used for information, while the remaining 31 bits are used for synchronization and error-protection purposes.

Decoding the TPS is optional, as all parameters could be found by trial-and-error. Use of the TPS will, however, reduce the acquisition time.

Figure 2
Constellation diagrams.

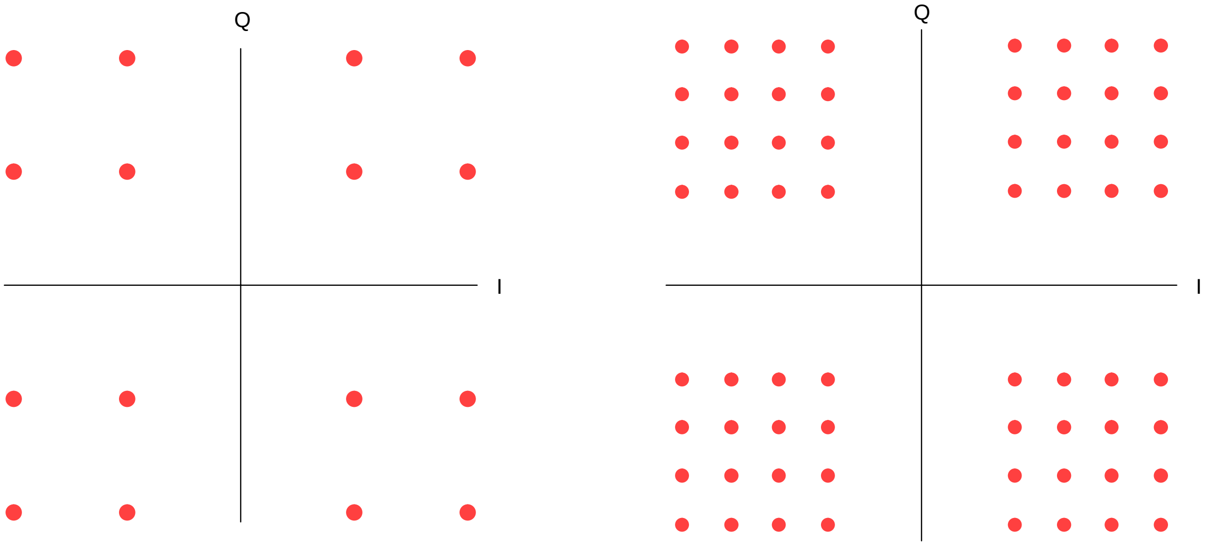


QPSK



16-QAM

64-QAM



Non-uniform 16-QAM

Non-uniform 64-QAM

requirements of large-area SFNs. This feasibility is based on work carried out on receiver complexity within the dTTb project, and the development of an 8k FFT chip which can be used for consumer products.

The OFDM signal is transmitted in frames, each of which consists of reference symbols and data-carrying symbols. Each symbol is frequency-interleaved; no time-interleaving is used. This choice was made after due consideration of the User Requirements (only static portable reception is included in these). While time-interleaving could improve the performance for mobile reception, it would impose a considerable increase in memory requirements and thereby add to the cost of the receiver.

The requirements for flexibility in frequency planning, and the possibility to trade bit-rate against coverage, have been fulfilled by using different levels of QAM and different levels of error correction. *Fig. 2* shows the possible constellations: QPSK, 16-QAM, 64-QAM, non-uniform 16-QAM and non-uniform 64-QAM.

The penalty of having a long guard interval is a lower data capacity. To enable a higher data capacity to be available in situations where large SFNs are not required, a flexible guard interval has been specified. The guard interval can have three different values: 1/4, 1/8 and 1/32 of the active symbol duration.

The data container concept had already been adopted for the cable and satellite baseline systems. The same data container can be conveyed via terrestrial transmissions, although the useful data rate may be lower. The input signal is an MPEG-2 transport stream and the same energy dispersal and outer error protection schemes used for the cable and satellite systems are employed in the terrestrial system: Reed-Solomon (204, 188, t = 8). The terrestrial system also uses the inner error protection scheme which has been adapted for the satellite baseline system, i.e. punctured convolutional coding [10].

However, unlike the satellite and cable baseline systems, the transmission containers of the terrestrial system should allow for a two-layer hierarchical system (although no hierarchical source coding is included in the requirements). The transmitter in this case will emit two MPEG-2 transport streams, both of which include programme data and DVB Service Information (SI). The possibility of hierarchical transmission does not imply any additional complexity in the receivers, as only one of the two layers needs to be decoded.

The two MPEG-2 transport streams could contain the same programmes or entirely different programmes. As an example, one transport stream could contain four programmes, each coded at 1.5 Mbit/s, while the other transport stream contains the same four programmes each coded at 4.5 Mbit/s. By using a more rugged transmission scheme for the four 1.5-Mbit/s programmes, these could be received on portable receivers while the four 4.5-Mbit/s programmes might only be received on stationary receivers.

In the case of hierarchical transmission, the more-rugged layer will be carried by a QPSK signal, while the less-rugged layer will be carried by 16- or 64-QAM. The two layers can have different code rates, and it is possible to use non-uniform constellations (multi-resolution QAM) to achieve the desired coverage for each of the two layers.

A signalling channel – Transmission Parameter Signalling (TPS) – has been introduced. It carries information on modulation, code rate(s) and the guard interval length. However, it is not intended that TPS should carry other general-purpose data as this is carried by the MPEG stream; it is transmitted in one symbol of each OFDM frame. As the capacity of a symbol is much larger than that necessary to carry the TPS, the remaining part of this symbol is reserved for future use.

Fig. 3 shows the DVB terrestrial transmitting chain, from the source coders to the transmitter front end. In the case of non-hierarchical transmission, only the white-filled boxes in *Fig. 3* are used; in the case of hierarchical transmissions, the splitter and the other five boxes that are in-filled with grey shading are also used. The splitter separates the incoming MPEG-2 transport stream into two transport streams: the *low-priority* stream and the *high-priority* stream.

Fig. 4 shows the DVB terrestrial receiving chain, from the tuner input to the source decoder. All parts of the system from the inner decoder block onwards are identical to the corresponding parts in a satellite receiver.

4.2. System performance and available bit-rates for the various modes

There is a requirement for various implementation scenarios, implying that the number of different transmission modes will be large. These modes cater for all the foreseeable implementations:

- SFN operation;
- use of on-channel gap-fillers or single transmitter operation;
- operation in free channels or in interference-limited channels;
- desired coverage for portable and fixed receivers;
- hierarchical or non-hierarchical transmission.

Some of the possible modes are less likely to be used in practice. For example, implementation of modes which use code rate 7/8 will be very unlikely, as the performance of this high code rate is rather poor in the case of channels that suffer interference and reflections. Code rate 7/8 is mainly included in the DVB-T specification to provide commonality with the satellite baseline system.

The terrestrial DVB environment has to take account of various receiving conditions. The most demanding condition is portable reception in a situation where the line-of-sight signal is weak, or may even be nonexistent, compared to the reflections arriving at different times and different levels. Less demanding is the situation where a relatively-strong direct signal is present together with reflections; this situation is typical in the case of reception with a directional antenna. Finally, the least demanding receiving condition involves only a line-of-sight signal, disturbed by Gaussian noise.

These three receiving conditions – known as Rayleigh, Ricean and Gaussian – have been simulated by a propagation model. The number of reflections was set at 20, each having a different amplitude, delay time and phase. The model of the Ricean channel had a Rice factor of 10 dB, i.e. the direct signal was 10 dB stronger than the sum of the reflected signals.

The simulations were performed using perfect channel estimation, and the bit error rates (BERs) after convolutional decoding, but before Reed-Solomon (RS) decoding, were derived. A BER of 2.10^{-4} is considered to give quasi-error-free (QEF) reception[8] after RS decoding.

Simulations of a Gaussian, Ricean and Rayleigh channel have been carried out by members of the TFSC and the results are shown in *Table 1* and *Table 2*. These tables also give the useful bit-rates for the various combinations of guard interval, modulation and code rate.

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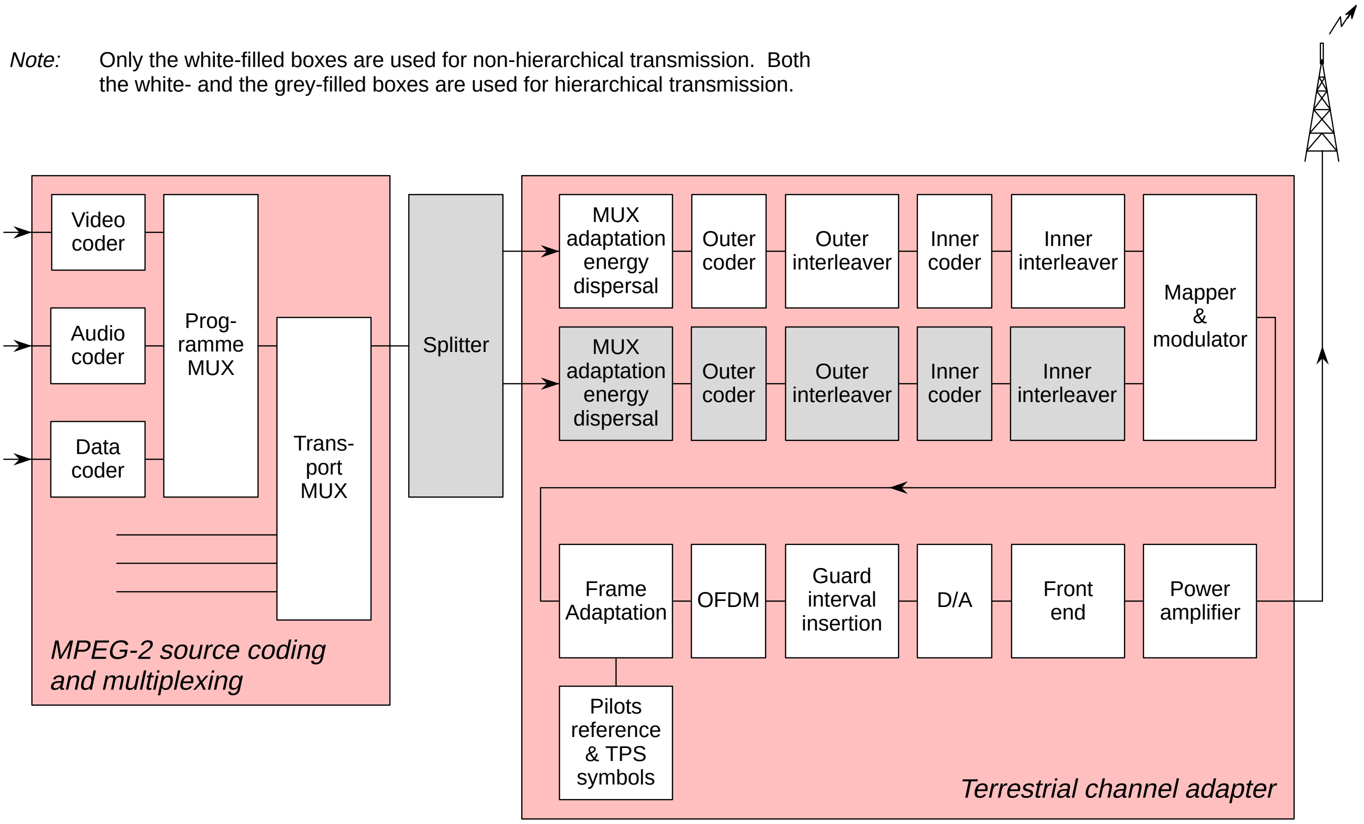
[8] QEF reception means that less than one uncorrected error-event-per-hour should be presented to the MPEG decoder.

Figure 3
DVB terrestrial transmitting chain.

Note: Only the white-filled boxes are used for non-hierarchical transmission. Both the white- and the grey-filled boxes are used for hierarchical transmission.



5. System verification

As mentioned earlier, no hardware implementation available at present is fully in line with the draft specification. Almost all aspects, on the other hand, have been deployed by different OFDM modems. The tests required to verify the specification are being organized by a collaborative group of experts from the various projects. This group has listed the different features which could be verified on individual modems and is now collecting data prior to issuing a report on the tests. One of the main features of the DVB-T specification is the use of 8k OFDM. It has been argued that the carrier spacing of this system would impose too severe requirements on the phase noise of tuners, and the FFT size would not be feasible for consumer receivers.

The phase noise problem has been analyzed theoretically by the BBC [11]. Hardware tests – using the CCETT STERNE modem and the HD-Divine modem, both with a consumer-type tuner developed by Thomson Consumer Electronics in the dTTb project [12] – have confirmed the theoretical results: the phase noise problems are solvable.

The only hardware implemented so far that features “8k OFDM” is the modem developed in the HD-Divine project. This modem, however, is not in accordance with a number of other aspects of the draft specification and, therefore, cannot be used for the full verification. Other modems can “simulate” the 8k system by changing the sampling frequency.

In order to verify other parts of the specification (e.g. hierarchical transmission, synchronization), hardware which has been developed by the $^{\mathrm{H}}\mathrm{DTV}_{\mathrm{T}}$, ITC SPECTRE II, dTTb and CCETT STERNE projects is necessary.

All results of these tests have been reported to the DTTV-SA and the DVB-TM. So far, none of the laboratory or field tests reported have called the viability of the draft specification into question.

Of course the full verification cannot be achieved before a modem which accords with the specification is available, and both the laboratory and the field tests has been completed. Ideally the field tests should include the setting up of an SFN network, with field measurements under various propagation conditions.

Discussions on the cost and complexity of consumer receivers which accord with the draft specification are still in progress.

The dTTb module in charge of complexity evaluations has estimated that the chip size required for

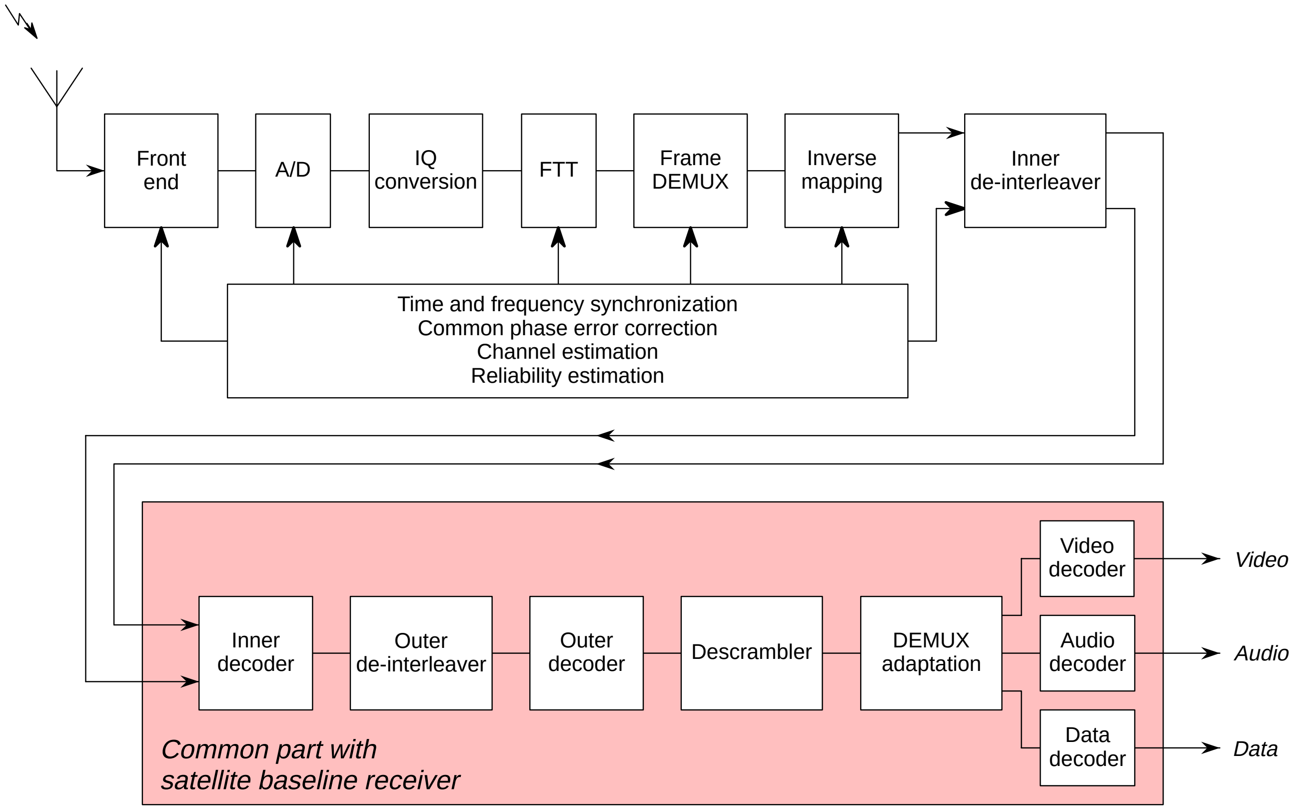


Figure 4
DVB terrestrial receiving chain.

consumer receivers will be feasible to implement in the near future [13].

While the chip area required can be evaluated quite readily, the final cost of the receiver is more difficult to predict as it will mainly be determined by the size of the market.

As few countries in Europe so far have announced their plans to commence digital terrestrial television broadcasting, some manufacturers are unsure of the prospects for a considerable market size.

6. *Prospects for digital terrestrial television*

The future of digital terrestrial television is currently being discussed. It can be argued that digital terrestrial television has very little chance in competition with satellite and cable. This may be the case if the number of channels is the only important factor. However, terrestrial television has certain advantages compared to satellite or cable reception. Some of the most important are the possibilities for portable reception and for the broadcasting of regional and local programmes. Regional programmes can be received on cable – but not on a portable receiver. Furthermore there are areas where cable networks are not feasible, e.g. rural environments.

In all probability, satellite transmission of regional or local programmes will not always be economically feasible, especially for smaller countries where the regions may be very small. In the case of public service broadcasters who have no plans for pay-TV services, the satellite delivery of their television programmes could impose an extra burden – if it became necessary to encrypt these programmes for reasons of programme rights.

The discussion about the complexity of the draft proposal for digital terrestrial television has led to an alternative proposal, based on “2k OFDM”. This will result in less complex receivers, due to the smaller FFT size. A 2k system, however, will not meet the original User Requirements for SFN operation. As SFN operation is required by some countries, the 2k system is unlikely to gain universal acceptance throughout Europe.

Table 1
Required C/N for non-hierarchical transmission to achieve a BER of 2.10^{-4} after the Viterbi decoder, for all combinations of coding rates and modulation types. The net bit-rates after the Reed-Solomon decoder are also listed.

		Required C/N for BER = 2.10^{-4} after Viterbi decoding QEF after Reed-Solomon *(note 1)*			**Bit rate (Mbit/s)** *(note 2)*		
Modulation	**Code Rate**	**Gaussian channel**	**Ricean channel**	**Rayleigh channel**	**$\Delta/T_U = 1/4$ $224\,\mu s$**	**$\Delta/T_U = 1/8$ $112\,\mu s$**	**$\Delta/T_U = 1/8$ $32\,\mu s$**
QPSK	1/2	3.1	3.6	5.4	4.70	5.60	6.10
	2/3	4.9	5.7	8.4	6.27	7.46	8.14
	3/4	5.9	6.8	10.7	7.05	8.39	9.16
	5/6	6.9	8.0	13.1	7.83	9.33	10.17
	7/8	7.7	8.7	16.3	8.23	9.79	10.68
16-QAM	1/2	8.8	9.6	11.2	9.40	11.19	12.21
	2/3	11.1	11.6	14.2	12.53	14.92	16.28
	3/4	12.5	13.0	16.7	14.10	16.79	18.31
	5/6	13.5	14.4	19.3	15.67	18.65	20.35
	7/8	13.9	15.0	22.8	16.45	19.58	21.36
64-QAM	1/2	14.4	14.7	16.0	14.10	16.79	18.31
	2/3	16.5	17.1	19.3	18.80	22.38	24.42
	3/4	18.0	18.6	21.7	21.15	25.18	27.47
	5/6	19.3	20.0	25.3	23.50	27.98	30.52
	7/8	20.1	21.0	27.9	24.68	29.38	32.05

Note 1: Quasi-error-free (QEF) means less than one uncorrected error-event-per-hour, corresponding to a BER of 10^{-11} at the input of the MPEG-2 demultiplexer.

Note 2: Each symbol is transmitted with a duration composed of two parts – a useful part with the duration T_u and a guard interval of duration Δ.

			Required C/N for BER = 2.10^{-4} after Viterbi decoding QEF after Reed-Solomon *(note 1)*			**Bit-rate (Mbit/s)** *(note 2)*		
Modulation	**Code rate**	α *(note 3)*	**Gaussian Channel**	**Ricean Channel**	**Rayleigh Channel**	**$\Delta/T_U = 1/4$ 224 μs**	**$\Delta/T_U = 1/8$ 112 μs**	**$\Delta/T_U = 1/32$ 28 μs**
QPSK in Non-Uniform 16-QAM	1/2	2	4.8	5.4	6.9	4.70	5.60	6.10
	2/3		7.1	7.7	9.8	6.27	7.46	8.14
	3/4		8.4	9.0	11.8	7.05	8.39	9.16
						+		
	1/2		13.0	13.3	14.9	4.70	5.60	6.10
	2/3		15.1	15.3	17.9	6.27	7.46	8.14
	3/4		16.3	16.9	20.0	7.05	8.39	9.16
	5/6		16.9	17.8	22.4	7.83	9.33	10.17
	7/8		17.9	18.7	24.1	8.23	9.79	10.68
QPSK in Non-uniform 16-QAM	1/2	4	3.8	4.4	6.0	4.70	5.60	6.10
	2/3		5.9	6.6	8.6	6.27	7.46	8.14
	3/4		7.1	7.9	10.7	7.05	8.39	9.16
						+		
	1/2		17.3	17.8	19.6	4.70	5.60	6.10
	2/3		19.1	19.6	22.3	6.27	7.46	8.14
	3/4		20.1	20.8	24.2	7.05	8.39	9.16
	5/6		21.1	22.0	26.0	7.83	9.33	10.17
	7/8		21.9	22.8	28.5	8.23	9.79	10.68
QPSK in Uniform 64-QAM	1/2	1	8.9	9.5	11.4	4.70	5.60	6.10
	2/3		12.1	12.7	14.8	6.27	7.46	8.14
	3/4		13.7	14.3	17.5	7.05	8.39	9.16
						+		
	1/2		14.6	14.9	16.4	9.40	11.19	12.21
	2/3		16.9	17.6	19.4	12.53	14.92	16.28
	3/4		18.6	19.1	22.2	14.10	16.79	18.31
	5/6		20.1	20.8	25.8	15.67	18.65	20.35
	7/8		21.1	22.2	27.6	16.45	19.58	21.36
QPSK in Non-uniform 64-QAM	1/2	2	6.5	7.1	8.7	4.70	5.60	6.10
	2/3		9.0	9.9	11.7	6.27	7.46	8.14
	3/4		10.8	11.5	14.5	7.05	8.39	9.16
						+		
	1/2		16.3	16.7	18.2	9.40	11.19	12.21
	2/3		18.9	19.5	21.7	12.53	14.92	16.28
	3/4		21.0	21.6	24.5	14.10	16.79	18.31
	5/6		21.9	22.7	27.3	15.67	18.65	20.35
	7/8		22.9	23.8	29.6	16.45	19.58	21.36

Note 1: Quasi-error-free (QEF) means less than one uncorrected error-event-per-hour, corresponding to a BER of 10^{-11} at the input of the MPEG-2 demultiplexer.

Note 2: Each symbol is transmitted with a duration composed of two parts – a useful part with the duration T_u and a guard interval of duration Δ.

Note 3: α defines the relative distance between clouds (quadrants) and points for non-uniform QAM (see *Fig. 2*).

Table 2
Required C/N for hierarchical transmission to achieve a BER of 2.10^{-4} after Viterbi decoding.

7. Conclusion

The 8k specification for digital terrestrial television has been described in relation to the DVB User Requirements. It can be shown that the performance requirements can be fulfilled with the "8k" specification, but meeting the requirements in terms of price and time-scale is still being debated.

The 8k specification was developed as a collaborative project involving a large number of companies who represented all the areas of broadcasting that are necessary to make terrestrial digital television prosper: broadcasters, the manufacturing industry, operators and research institutes. This collaboration has ensured that necessary consideration has been given to all foreseeable aspects of a terrestrial broadcasting system which should gain wide acceptance both on a short-term and on a long-term basis.

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