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Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television

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Foreword

This European Standard (Telecommunications series) has been produced by Joint Technical Committee (JTC) Broadcast of the European Broadcasting Union (EBU), Comité Européen de Normalisation ELECtrotechnique (CENELEC) and the European Telecommunications Standards Institute (ETSI).

NOTE: The EBU/ETSI JTC Broadcast was established in 1990 to co-ordinate the drafting of standards in the specific field of broadcasting and related fields. Since 1995 the JTC Broadcast became a tripartite body by including in the Memorandum of Understanding also CENELEC, which is responsible for the standardization of radio and television receivers. The EBU is a professional association of broadcasting organizations whose work includes the co-ordination of its members' activities in the technical, legal, programme-making and programme-exchange domains. The EBU has active members in about 60 countries in the European broadcasting area; its headquarters is in Geneva.

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Founded in September 1993, the DVB Project is a market-led consortium of public and private sector organizations in the television industry. Its aim is to establish the framework for the introduction of MPEG-2 based digital television services. Now comprising over 200 organizations from more than 25 countries around the world, DVB fosters market-led systems, which meet the real needs, and economic circumstances, of the consumer electronics and the broadcast industry.

National transposition dates	
Date of adoption of this EN:	22 January 2009
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1 Scope

The present document describes a baseline transmission system for digital terrestrial TeleVision (TV) broadcasting. It specifies the channel coding/modulation system intended for digital multi-programme LDTV/SDTV/EDTV/HDTV terrestrial services.

The scope is as follows:

- it gives a general description of the Baseline System for digital terrestrial TV;
- it identifies the global performance requirements and features of the Baseline System, in order to meet the service quality targets;
- it specifies the digitally modulated signal in order to allow compatibility between pieces of equipment developed by different manufacturers. This is achieved by describing in detail the signal processing at the modulator side, while the processing at the receiver side is left open to different implementation solutions. However, it is necessary in this text to refer to certain aspects of reception.

In order to address Handheld terminals (DVB-H) in annexes are provided:

- an additional 4K Mode offering supplementary options for network planning (annex F);
- an optional in-depth inner interleaver, to mitigate the effects of the high level of man-made noise affecting the reception of DVB-H services (annex F);
- an extension of the Transmission Parameter Signalling (TPS) information for signalling DVB-H Services (annex F);
- the transmission parameters to operate the transmission system in 5 MHz channel bandwidth, even outside of the traditional broadcasting bands (annex G).

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

- For a specific reference, subsequent revisions do not apply.
- Non-specific reference may be made only to a complete document or a part thereof and only in the following cases:
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2.1 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

- [1] ISO/IEC 13818 (Parts 1 to 3): "Information technology - Generic coding of moving pictures and associated audio information".

- [2] ETSI EN 300 421: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services".
- [3] ETSI EN 300 429: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems".
- [4] ETSI EN 300 468: "Digital Video Broadcasting (DVB); Specification for Service Information (SI) in DVB systems".

2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Not applicable.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

constraint length: number of delay elements +1 in the convolutional coder

3.2 Symbols

For the purposes of the present document, the following symbols apply:

$A(e)$	output vector from inner bit interleaver e
$a_{e,w}$	bit number w of inner bit interleaver output stream e
α	constellation ratio which determines the QAM constellation for the modulation for hierarchical transmission
$B(e)$	input vector to inner bit interleaver e
$b_{e,w}$	bit number w of inner bit interleaver input stream e
b_{e,d_0}	output bit number d_0 of demultiplexed bit stream number e of the inner interleaver demultiplexer
b_i	bit number i of the cell identifier
$c_{m,l,k}$	complex cell for frame m in OFDM symbol l at carrier k
C'_k	Complex modulation for a reference signal at carrier k
$C'_{l,k}$	Complex modulation for a TPS signal at carrier k in symbol l
C/N	Carrier-to-Noise ratio
Δ	time duration of the guard interval
d_{free}	convolutional code free distance
f_c	centre frequency of the emitted signal
G_1, G_2	convolutional code Generator polynomials
$g(x)$	Reed-Solomon code generator polynomial
$h(x)$	BCH code generator polynomial
$H(q)$	inner symbol interleaver permutation
$H_e(w)$	inner bit interleaver permutation
i	priority stream index
I	Interleaving depth of the outer convolutional interleaver
$I_0, I_1, I_2, I_3, I_4, I_5$	inner Interleavers
j	branch index of the outer interleaver
k	carrier number index in each OFDM symbol
K	number of active carriers in the OFDM symbol

K_{\min}, K_{\max}	carrier number of the lower and largest active carrier respectively in the OFDM signal
l	OFDM symbol number index in an OFDM frame
m	OFDM frame number index
m'	OFDM super-frame number index
M	convolutional interleaver branch depth for $j = 1, M = N/I$
n	transport stream sync byte number
N	length of error protected packet in bytes
N_{\max}	inner symbol interleaver block size
p	scattered pilot insertion index
$p(x)$	RS code field generator polynomial
$P_k(f)$	Power spectral density for carrier k
$P(n)$	interleaving Pattern of the inner symbol interleaver
r_i	code rate for priority level i
s_i	TPS bit index
t	number of bytes which can be corrected by the Reed-Solomon decoder
T	elementary Time period
T_S	duration of an OFDM symbol
T_F	Time duration of a frame
T_U	Time duration of the useful (orthogonal) part of a symbol, without the guard interval
u	bit numbering index
v	number of bits per modulation symbol
w_k	value of reference PRBS sequence applicable to carrier k
x_{di}	input bit number d_i to the inner interleaver demultiplexer
x'_{di}	high priority input bit number d_i to the inner interleaver demultiplexer
x''_{di}	low priority input bit number d_i to the inner interleaver demultiplexer
Y	output vector from inner symbol interleaver
Y'	intermediate vector of inner symbol interleaver
y_q	bit number q of output from inner symbol interleaver
y'_q	bit number q of intermediate vector of inner symbol interleaver
z	complex modulation symbol
$*$	complex conjugate

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACI	Adjacent Channel Interference
AWGN	Additive White Gaussian Noise
BCH	Bose - Chaudhuri - Hocquenghem code
BER	Bit Error Ratio
CCI	Co-Channel Interference
DBPSK	Differential Binary Phase Shift Keying
DFT	Discrete Fourier Transform
DVB	Digital Video Broadcasting
DVB-H	DVB-Handheld
DVB-T	DVB-Terrestrial
EDTV	Enhanced Definition TeleVision
FFT	Fast Fourier Transform
FIFO	First-In, First-Out shift register
HDTV	High Definition TeleVision
HP	High Priority bit stream
IFFT	Inverse Fast Fourier Transform
LDTV	Limited Definition TeleVision
LP	Low Priority bit stream
MPEG	Moving Picture Experts Group
MSB	Most Significant Bit
MUX	MUltipleX
NICAM	Near-Instantaneous Companded Audio Multiplex

OFDM	Orthogonal Frequency Division Multiplexing
PAL	Phase Alternating Line
PRBS	Pseudo-Random Binary Sequence
QAM	Quadrature Amplitude Modulation
QEF	Quasi Error Free
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
RS	Reed-Solomon
SDTV	Standard Definition TeleVision
SECAM	Système Séquentiel Couleur A Mémoire
SFN	Single Frequency Network
TPS	Transmission Parameter Signalling
TV	TeleVision
UHF	Ultra-High Frequency
VHF	Very-High Frequency

4 Baseline system

4.1 General considerations

The system is defined as the functional block of equipment performing the adaptation of the baseband TV signals from the output of the MPEG-2 transport multiplexer, to the terrestrial channel characteristics. The following processes shall be applied to the data stream (see [1]):

- transport multiplex adaptation and randomization for energy dispersal;
- outer coding (i.e. Reed-Solomon code);
- outer interleaving (i.e. convolutional interleaving);
- inner coding (i.e. punctured convolutional code);
- inner interleaving (either native or in-depth);
- mapping and modulation;
- Orthogonal Frequency Division Multiplexing (OFDM) transmission.

The system is directly compatible with MPEG-2 coded TV signals ISO/IEC 13818 [1].

Since the system is being designed for digital terrestrial television services to operate within the existing VHF and UHF (see note) spectrum allocation for analogue transmissions, it is required that the System provides sufficient protection against high levels of Co-Channel Interference (CCI) and Adjacent Channel Interference (ACI) emanating from existing PAL/SECAM/NTSC services. It is also a requirement that the System allows the maximum spectrum efficiency when used within the VHF and UHF bands; this requirement can be achieved by utilizing Single Frequency Network (SFN) operation.

NOTE: The OFDM system in the present document is specified for 8 MHz, 7 MHz and 6 MHz channel spacing. The basic specification is the same for the three bandwidths except for the parameter *elementary period T*, which is unique for the respective bandwidths. From an implementation point of view the elementary period T can normally be seen as the inverse of the nominal system clock rate. By adjusting the system clock rate the bandwidth and bit rate are modified accordingly. The parameters to operate the transmission system in 5 MHz channel, outside the traditional broadcast bands, are given in the annex G.

To achieve these requirements an OFDM system with concatenated error correcting coding is being specified. To maximize commonality with the Satellite baseline specification (see EN 300 421 [2]) and Cable baseline specifications (see EN 300 429 [3]) the outer coding and outer interleaving are common, and the inner coding is common with the Satellite baseline specification. To allow optimal trade off between network topology and frequency efficiency, a flexible guard interval is specified. This will enable the system to support different network configurations, such as large area SFN and single transmitter, while keeping maximum frequency efficiency.

Two modes of operation, a "2K mode" and an "8K mode", are defined for DVB-T and DVB-H transmissions. The "2K mode" is suitable for single transmitter operation and for small SFN networks with limited transmitter distances. The "8K mode" can be used both for single transmitter operation and for small and large SFN networks.

Exclusively for use in DVB-H systems, a third transmission mode the "4K mode" is defined in annex F, addressing the specific needs of Handheld terminals. The "4K mode" aims to offer an additional trade-off between transmission cell size and mobile reception capabilities, providing an additional degree of flexibility for DVB-H network planning.

The system allows different levels of QAM modulation and different inner code rates to be used to trade bit rate versus ruggedness. The system also allows two level hierarchical channel coding and modulation, including uniform and multi-resolution constellation. In this case the functional block diagram of the system shall be expanded to include the modules shown dashed in figure 1. Two independent MPEG transport streams, referred to as the high-priority and the low-priority stream, are mapped onto the signal constellation by the Mapper and the Modulator which therefore has a corresponding number of inputs.

To guarantee that the signals emitted by such hierarchical systems may be received by a simple receiver the hierarchical nature is restricted to hierarchical channel coding and modulation without the use of hierarchical source coding.

A programme service can thus be "simulcast" as a low-bit-rate, rugged version and another version of higher bit rate and lesser ruggedness. Alternatively, entirely different programmes can be transmitted on the separate streams with different ruggedness. In either case, the receiver requires only one set of the inverse elements: inner de-interleaver, inner decoder, outer de-interleaver, outer decoder and multiplex adaptation. The only additional requirement thus placed on the receiver is the ability for the demodulator/de-mapper to produce one stream selected from those mapped at the sending end.

The price for this receiver economy is that reception can not switch from one layer to another (e.g. to select the more rugged layer in the event of reception becoming degraded) while continuously decoding and presenting pictures and sound. A pause is necessary (e.g. video freeze frame for approximately 0,5 seconds, audio interruption for approximately 0,2 seconds) while the inner decoder and the various source decoders are suitably reconfigured and reacquire lock.

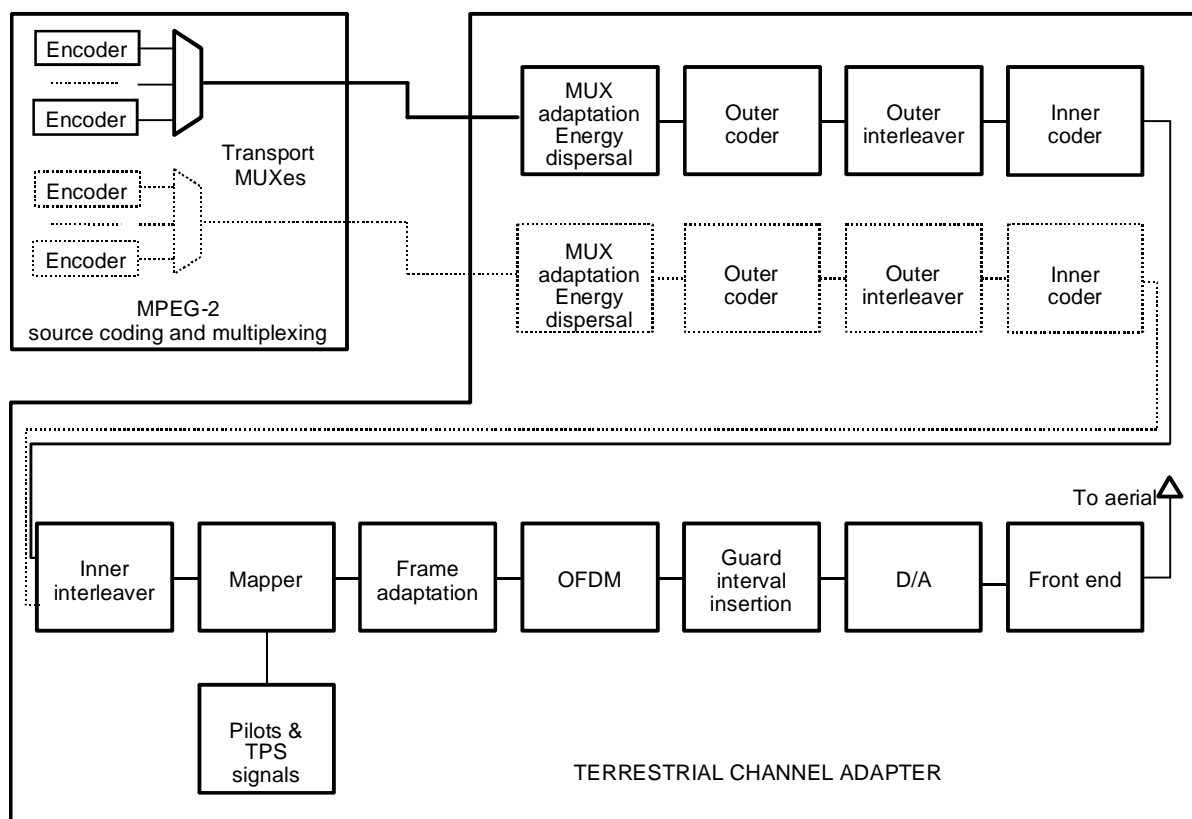


Figure 1: Functional block diagram of the System

4.2 Interfacing

The Baseline System as defined in the present document is delimited by the following interfaces.

Table 1: Interfaces for the Baseline System

Location	Interface	Interface type	Connection
Transmit Station	Input	MPEG-2 transport stream(s) multiplex	from MPEG-2 multiplexer
	Output	RF signal	to aerial
Receive Installation	Input	RF	from aerial
	Output	MPEG-2 transport stream multiplex	to MPEG-2 demultiplexer

4.3 Channel coding and modulation

4.3.1 Transport multiplex adaptation and randomization for energy dispersal

The System input stream shall be organized in fixed length packets (see figure 3), following the MPEG-2 transport multiplexer. The total packet length of the MPEG-2 transport multiplex (MUX) packet is 188 bytes. This includes 1 sync-word byte (i.e. 47_{HEX}). The processing order at the transmitting side shall always start from the MSB (i.e. "0") of the sync-word byte (i.e. 01 000 111). In order to ensure adequate binary transitions, the data of the input MPEG-2 multiplex shall be randomized in accordance with the configurations depicted in figure 2.

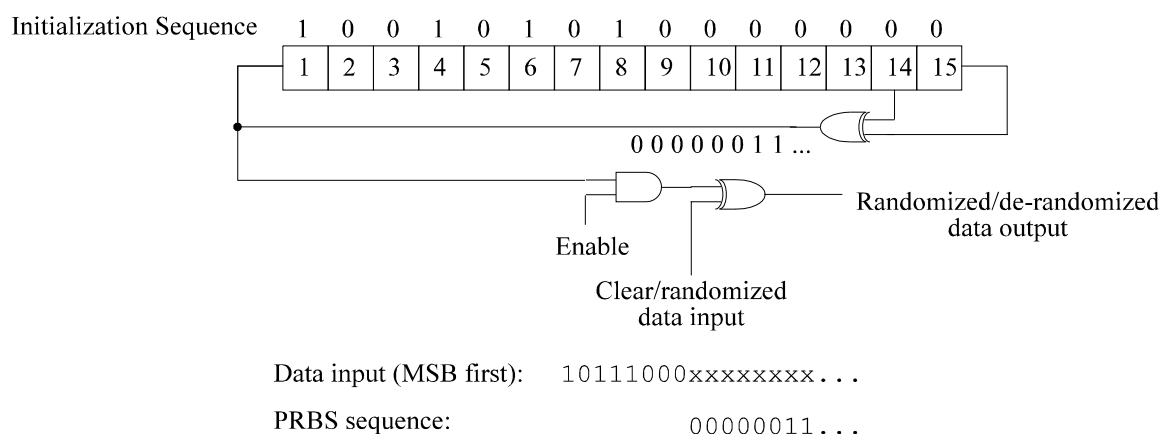


Figure 2: Scrambler/descrambler schematic diagram

The polynomial for the Pseudo Random Binary Sequence (PRBS) generator shall be (see note):

$$1 + X^{14} + X^{15}$$

NOTE: The polynomial description given here is in the form taken from the Satellite baseline specification EN 300 421 [2]. Elsewhere, in both the Satellite baseline specification and in the present document, a different polynomial notation is used which conforms with the standard textbook of Peterson and Weldon (Error correcting codes, second edition, MIT Press, 1972).

Loading of the sequence "100101010000000" into the PRBS registers, as indicated in figure 2, shall be initiated at the start of every eight transport packets. To provide an initialization signal for the descrambler, the MPEG-2 sync byte of the first transport packet in a group of eight packets is bit-wise inverted from 47_{HEX} (SYNC) to B8_{HEX} (SYNC). This process is referred to as "transport multiplex adaptation" (see figure 3b).

The first bit at the output of the PRBS generator shall be applied to the first bit (i.e. MSB) of the first byte following the inverted MPEG-2 sync byte (i.e. B8_{HEX}). To aid other synchronization functions, during the MPEG-2 sync bytes of the subsequent 7 transport packets, the PRBS generation shall continue, but its output shall be disabled, leaving these bytes unrandomized. Thus, the period of the PRBS sequence shall be 1 503 bytes.

The randomization process shall be active also when the modulator input bit-stream is non-existent, or when it is non-compliant with the MPEG-2 transport stream format (i.e. 1 sync byte + 187 packet bytes).

4.3.2 Outer coding and outer interleaving

The outer coding and interleaving shall be performed on the input packet structure (see figure 3a).

Reed-Solomon RS (204,188, t = 8) shortened code (see note 1), derived from the original systematic RS (255,239, t = 8) code, shall be applied to each randomized transport packet (188 byte) of figure 3b to generate an error protected packet (see figure 3c). Reed-Solomon coding shall also be applied to the packet sync byte, either non-inverted (i.e. 47_{HEX}) or inverted (i.e. B8_{HEX}).

NOTE 1: The Reed-Solomon code has length 204 bytes, dimension 188 bytes and allows to correct up to 8 random erroneous bytes in a received word of 204 bytes.

Code Generator Polynomial: $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\dots(x+\lambda^{15})$, where $\lambda = 02_{\text{HEX}}$

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

The shortened Reed-Solomon code may be implemented by adding 51 bytes, all set to zero, before the information bytes at the input of an RS (255,239, t = 8) encoder. After the RS coding procedure these null bytes shall be discarded, leading to a RS code word of N = 204 bytes.

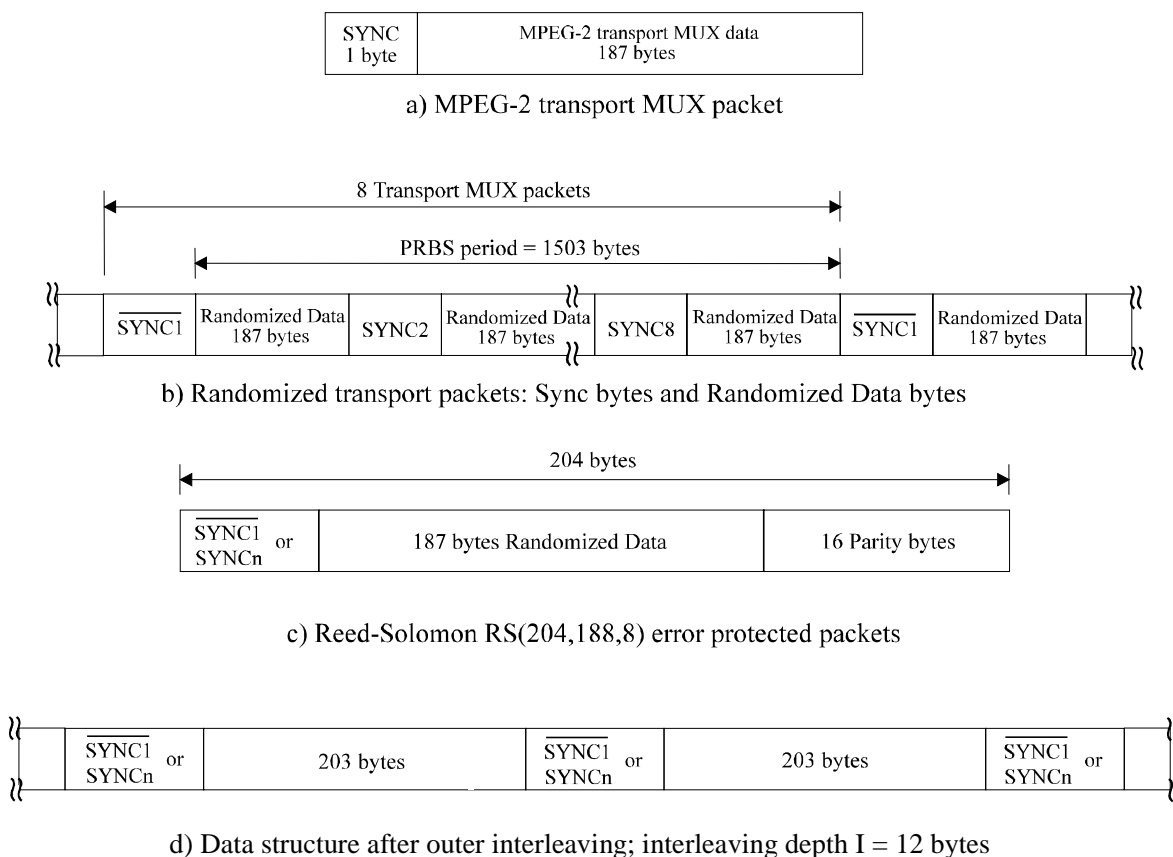
Following the conceptual scheme of figure 4, convolutional byte-wise interleaving with depth I = 12 shall be applied to the error protected packets (see figure 3c). This results in the interleaved data structure (see figure 3d).

The convolutional interleaving process shall be based on the Forney approach which is compatible with the Ramsey type III approach, with I = 12. The interleaved data bytes shall be composed of error protected packets and shall be delimited by inverted or non-inverted MPEG-2 sync bytes (preserving the periodicity of 204 bytes).

The interleaver may be composed of I = 12 branches, cyclically connected to the input byte-stream by the input switch. Each branch j shall be a First-In, First-Out (FIFO) shift register, with depth $j \times M$ cells where $M = 17 = N/I$, N = 204. The cells of the FIFO shall contain 1 byte, and the input and output switches shall be synchronized.

For synchronization purposes, the SYNC bytes and the $\overline{\text{SYNC}}$ bytes shall always be routed in the branch "0" of the interleaver (corresponding to a null delay).

NOTE 2: The deinterleaver is similar in principle, to the interleaver, but the branch indices are reversed (i.e. j = 0 corresponds to the largest delay). The deinterleaver synchronization can be carried out by routing the first recognized sync (SYNC or $\overline{\text{SYNC}}$) byte in the "0" branch.



SYNC1: Non randomized complemented sync byte
 SYNCn: Non randomized sync byte, n = 2, 3, ..., 8

Figure 3: Steps in the process of adaptation, energy dispersal, outer coding and interleaving

SYNC1 is the non randomized complemented sync byte and SYNCn is the non randomized sync byte, n = 2, 3, ..., 8.

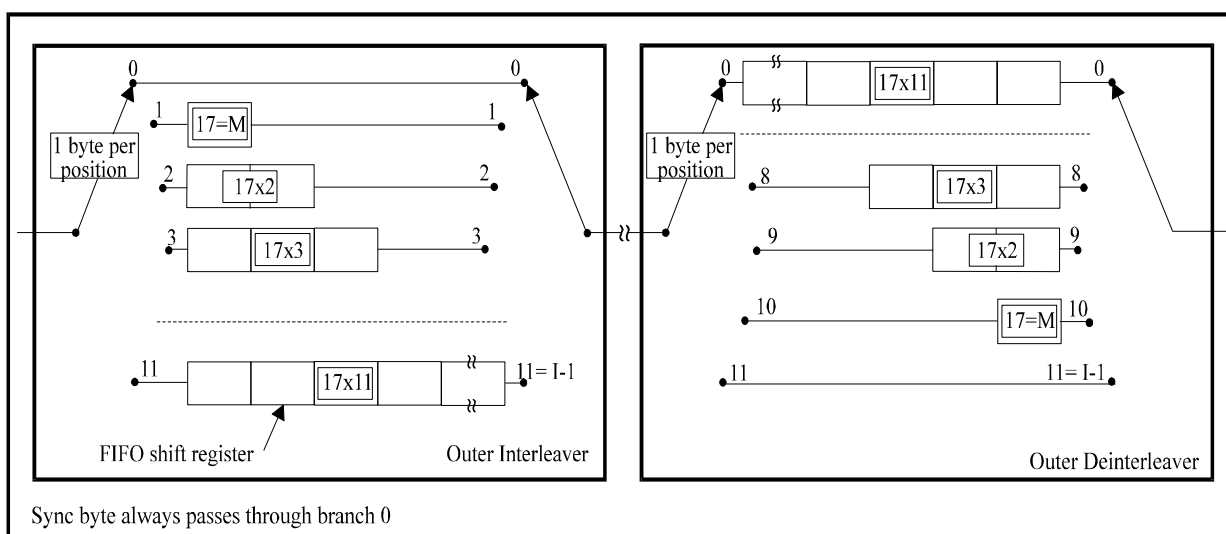


Figure 4: Conceptual diagram of the outer interleaver and deinterleaver

4.3.3 Inner coding

The system shall allow for a range of punctured convolutional codes, based on a mother convolutional code of rate 1/2 with 64 states. This will allow selection of the most appropriate level of error correction for a given service or data rate in either non-hierarchical or hierarchical transmission mode. The generator polynomials of the mother code are $G_1 = 171_{\text{OCT}}$ for X output and $G_2 = 133_{\text{OCT}}$ for Y output (see figure 5).

If two level hierarchical transmission is used, each of the two parallel channel encoders can have its own code rate. In addition to the mother code of rate 1/2 the system shall allow punctured rates of 2/3, 3/4, 5/6 and 7/8.

The punctured convolutional code shall be used as given in table 3. See also figure 5. In this table X and Y refer to the two outputs of the convolutional encoder.

Table 2: Puncturing pattern and transmitted sequence after parallel-to-serial conversion for the possible code rates

Code Rates r	Puncturing pattern	Transmitted sequence (after parallel-to-serial conversion)
1/2	X: 1 Y: 1	$X_1 Y_1$
2/3	X: 1 0 Y: 1 1	$X_1 Y_1 Y_2$
3/4	X: 1 0 1 Y: 1 1 0	$X_1 Y_1 Y_2 X_3$
5/6	X: 1 0 1 0 1 Y: 1 1 0 1 0	$X_1 Y_1 Y_2 X_3 Y_4 X_5$
7/8	X: 1 0 0 0 1 0 1 Y: 1 1 1 1 0 1 0	$X_1 Y_1 Y_2 Y_3 Y_4 X_5 Y_6 X_7$

X_1 is sent first. At the start of a super-frame the MSB of SYNC or $\overline{\text{SYNC}}$ shall lie at the point labelled "data input" in figure 5. The super-frame is defined in clause 4.4.

The first convolutionally encoded bit of a symbol always corresponds to X_1 .

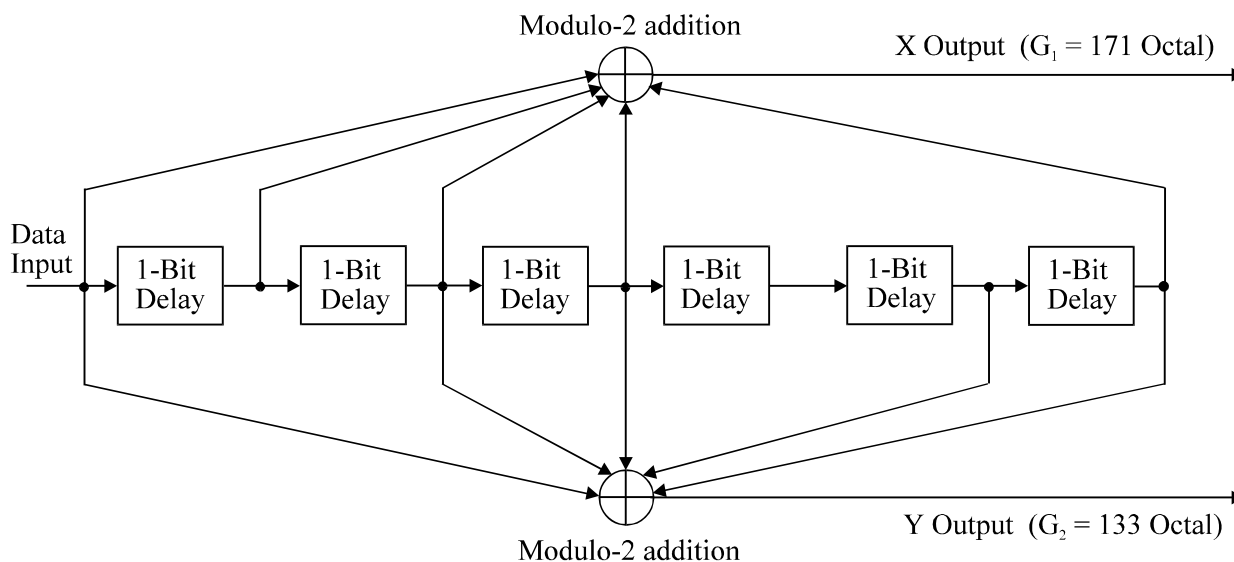


Figure 5: The mother convolutional code of rate 1/2

4.3.4 Inner interleaving

This clause specifies the native inner interleaving processes to be used for 2K and 8K transmission modes. The optional in-depth symbol interleaver for 2K and 4K modes, and the 4K native inner interleaver shall be compliant with the specifications provided in the annex F.

As depicted in figure 6, the inner interleaving consists of bit-wise interleaving followed by symbol interleaving. Both the bit-wise interleaving and the symbol interleaving processes are block-based.

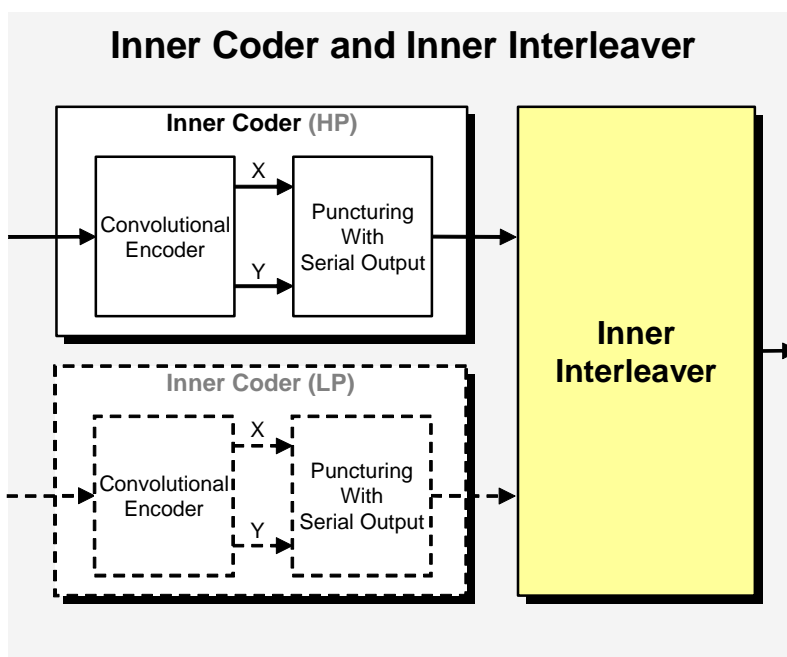


Figure 6: Inner coding and interleaving

4.3.4.1 Bit-wise interleaving

The input, which consists of up to two bit streams, is demultiplexed into v sub-streams, where $v = 2$ for QPSK, $v = 4$ for 16-QAM, and $v = 6$ for 64-QAM. In non-hierarchical mode, the single input stream is demultiplexed into v sub-streams. In hierarchical mode the high priority stream is demultiplexed into two sub-streams and the low priority stream is demultiplexed into $v-2$ sub-streams. This applies in both uniform and non-uniform QAM modes. See figures 7a and 7b.

The demultiplexing is defined as a mapping of the input bits, x_{di} onto the output bits $b_{e,do}$.

In non-hierarchical mode:

$$x_{di} = b_{[di(\text{mod})v](\text{div})(v/2)+2[di(\text{mod})(v/2)],di(\text{div})v}$$

In hierarchical mode:

$$x'_{di} = b_{di(\text{mod})2,di(\text{div})2}$$

$$x''_{di} = b_{[di(\text{mod})(v-2)](\text{div})((v-2)/2)+2[di(\text{mod})((v-2)/2)]+2,di(\text{div})(v-2)}$$

Where: x_{di} is the input to the demultiplexer in non-hierarchical mode;

x'_{di} is the high priority input to the demultiplexer;

x''_{di} is the low priority input, in hierarchical mode;

di is the input bit number;

$b_{e,do}$ is the output from the demultiplexer;

e is the demultiplexed bit stream number ($0 \leq e < v$);

do is the bit number of a given stream at the output of the demultiplexer;

mod is the integer modulo operator;

div is the integer division operator.

The demultiplexing results in the following mapping:

QPSK: x_0 maps to $b_{0,0}$

x_1 maps to $b_{1,0}$

16-QAM non-hierarchical transmission:

x_0 maps to $b_{0,0}$

x_1 maps to $b_{2,0}$

x_2 maps to $b_{1,0}$

x_3 maps to $b_{3,0}$

16-QAM hierarchical transmission:

x'_0 maps to $b_{0,0}$

x'_1 maps to $b_{1,0}$

x''_0 maps to $b_{2,0}$

x''_1 maps to $b_{3,0}$

64-QAM non-hierarchical transmission:

x_0 maps to $b_{0,0}$

x_1 maps to $b_{2,0}$

x_2 maps to $b_{4,0}$

x_3 maps to $b_{1,0}$

x_4 maps to $b_{3,0}$

x_5 maps to $b_{5,0}$

64-QAM hierarchical transmission:

x'_0 maps to $b_{0,0}$

x'_1 maps to $b_{1,0}$

x''_0 maps to $b_{2,0}$

x''_1 maps to $b_{4,0}$

x''_2 maps to $b_{3,0}$

x''_3 maps to $b_{5,0}$

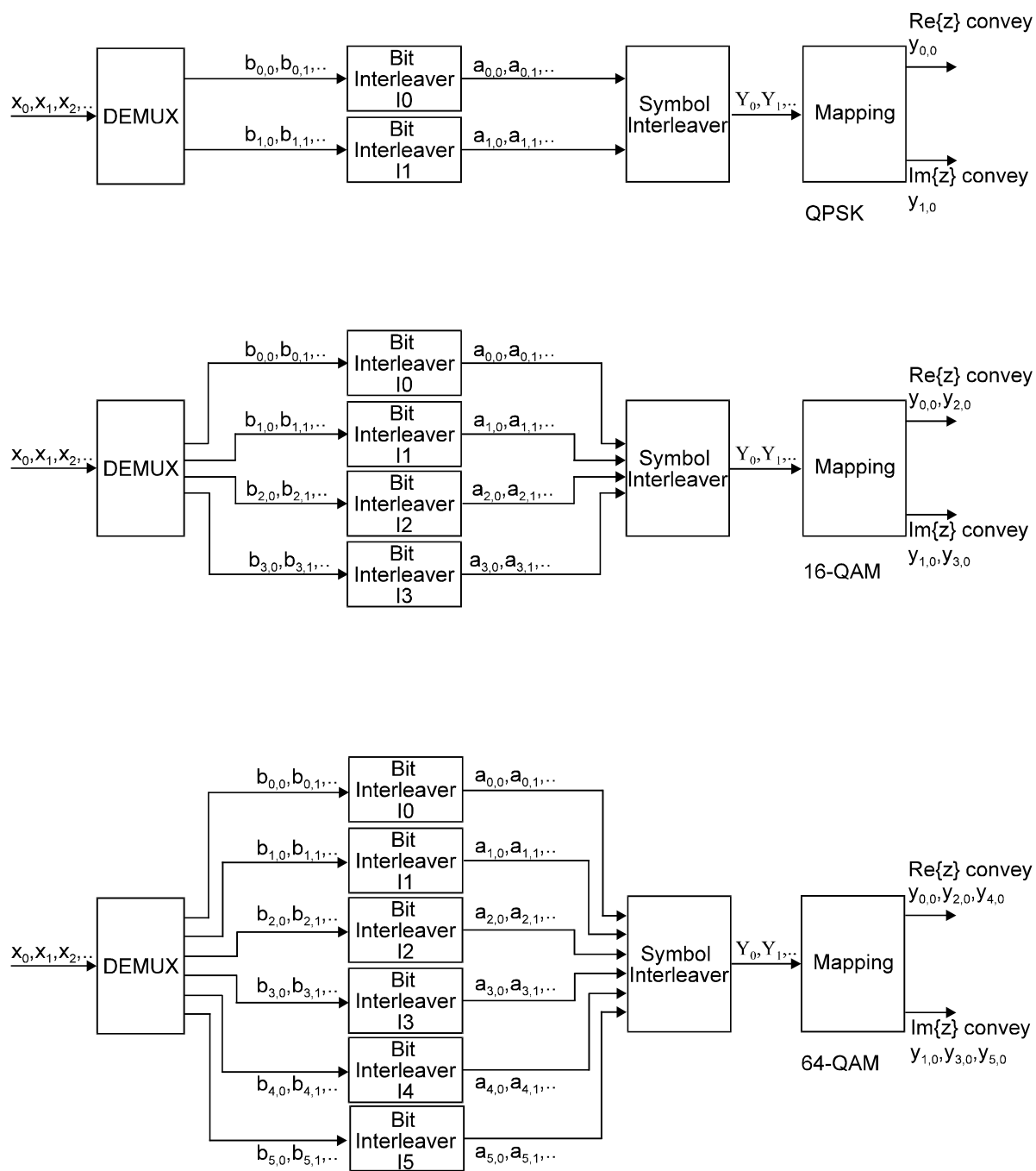


Figure 7a: Mapping of input bits onto output modulation symbols, for non-hierarchical transmission modes

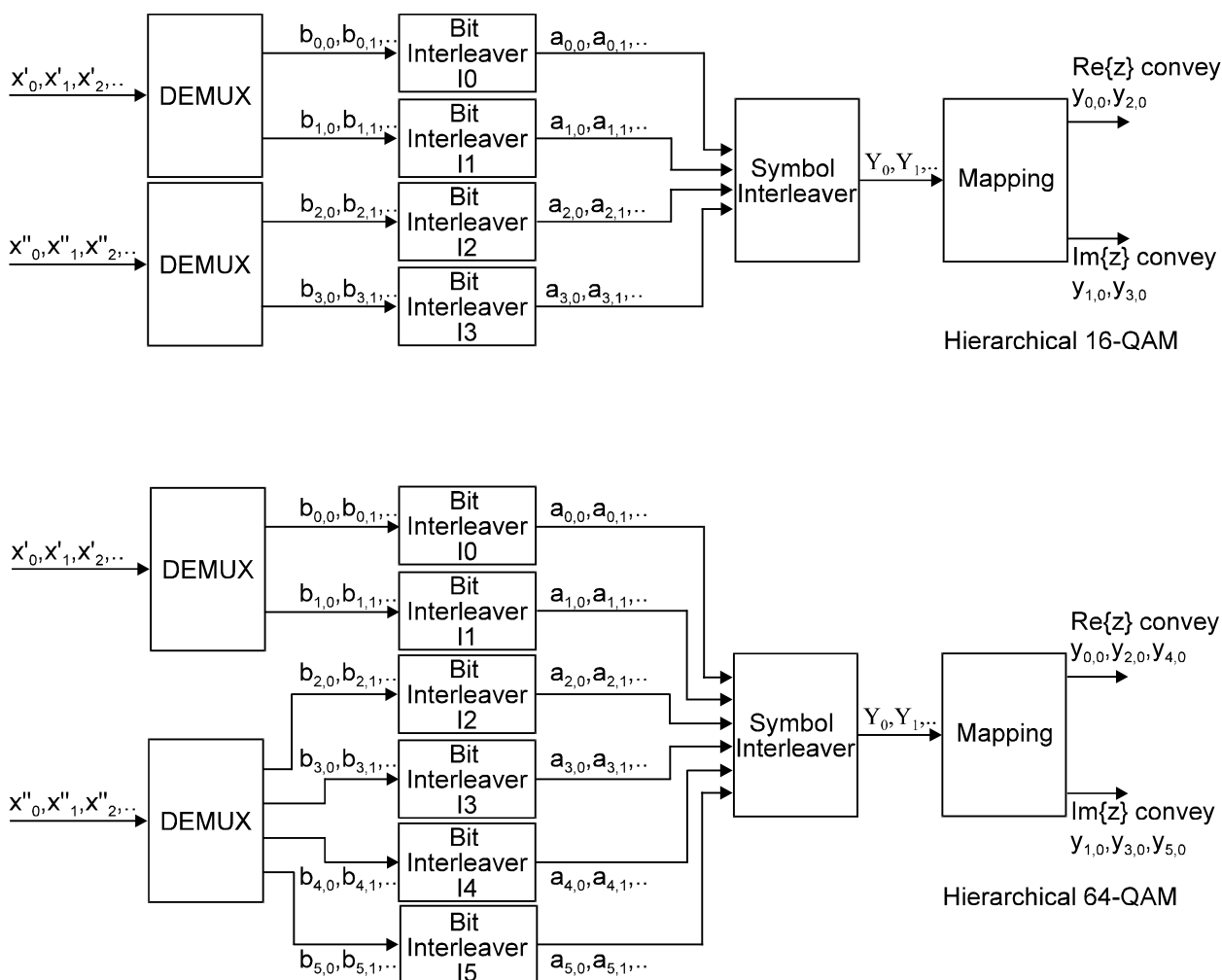


Figure 7b: Mapping of input bits onto output modulation symbols, for hierarchical transmission modes

Each sub-stream from the demultiplexer is processed by a separate bit interleaver. There are therefore up to six interleavers depending on v , labelled I0 to I5. I0 and I1 are used for QPSK, I0 to I3 for 16-QAM and I0 to I5 for 64-QAM.

Bit interleaving is performed only on the useful data. The block size is the same for each interleaver, but the interleaving sequence is different in each case. The bit interleaving block size is 126 bits. The block interleaving process is therefore repeated exactly twelve times per OFDM symbol of useful data in the 2K mode and forty-eight times per symbol in the 8K mode. Regarding the number of repetitions for the 4K mode and the use of the in-depth interleaver, see clause F.3.1.1.1.

For each bit interleaver, the input bit vector is defined by:

$$B(e) = (b_{e,0}, b_{e,1}, b_{e,2}, \dots, b_{e,125})$$

where e ranges from 0 to $v-1$.

The interleaved output vector $A(e) = (a_{e,0}, a_{e,1}, a_{e,2}, \dots, a_{e,125})$ is defined by:

$$a_{e,w} = b_{e, H_e(w)} \quad w = 0, 1, 2, \dots, 125$$

where $H_e(w)$ is a permutation function which is different for each interleaver.

$H_e(w)$ is defined as follows for each interleaver:

$$I0: H_0(w) = w$$

$$I1: H_1(w) = (w + 63) \bmod 126$$

$$I2: H_2(w) = (w + 105) \bmod 126$$

$$I3: H_3(w) = (w + 42) \bmod 126$$

$$I4: H_4(w) = (w + 21) \bmod 126$$

$$I5: H_5(w) = (w + 84) \bmod 126$$

The outputs of the v bit interleavers are grouped to form the digital data symbols, such that each symbol of v bits will consist of exactly one bit from each of the v interleavers. Hence, the output from the bit-wise interleaver is a v bit word y' that has the output of I0 as its most significant bit, i.e.:

$$y'_w = (a_{0,w}, a_{1,w}, \dots, a_{v-1,w})$$

4.3.4.2 Symbol interleaver

The purpose of the symbol interleaver is to map v bit words onto the 1 512 (2K mode) or 6 048 (8K mode) active carriers per OFDM symbol. The symbol interleaver acts on blocks of 1 512 (2K mode) or 6 048 (8K mode) data symbols.

Thus in the 2K mode, 12 groups of 126 data words from the bit interleaver are read sequentially into a vector $Y' = (y'_0, y'_1, y'_2, \dots, y'_{1511})$. Similarly in the 8K mode, a vector $Y' = (y'_0, y'_1, y'_2, \dots, y'_{6047})$ is assembled from 48 groups of 126 data words.

The interleaved vector $Y = (y_0, y_1, y_2, \dots, y_{N_{\max}-1})$ is defined by:

$$y_{H(q)} = y'_q \text{ for even symbols for } q = 0, \dots, N_{\max}-1$$

$$y_q = y'_{H(q)} \text{ for odd symbols for } q = 0, \dots, N_{\max}-1$$

where $N_{\max} = 1\,512$ in the 2K mode and $N_{\max} = 6\,048$ in the 8K mode.

The symbol index, defining the position of the current OFDM symbol in the OFDM frame, is defined in clause 4.4.

$H(q)$ is a permutation function defined by the following.

An $(N_r - 1)$ bit binary word R'_i is defined, with $N_r = \log_2 M_{\max}$, where $M_{\max} = 2\,048$ in the 2K mode and $M_{\max} = 8\,192$ in the 8K mode, where R'_i takes the following values:

$$i = 0,1: \quad R'_i [N_r-2, N_r-3, \dots, 1, 0] = 0, 0, \dots, 0, 0$$

$$i = 2: \quad R'_i [N_r-2, N_r-3, \dots, 1, 0] = 0, 0, \dots, 0, 1$$

$$2 < i < M_{\max}: \quad \{ R'_i [N_r-3, N_r-4, \dots, 1, 0] = R'_{i-1} [N_r-2, N_r-3, \dots, 2, 1];$$

$$\text{in the 2K mode: } R'_i [9] = R'_{i-1} [0] \oplus R'_{i-1} [3]$$

$$\text{in the 8K mode: } R'_i [11] = R'_{i-1} [0] \oplus R'_{i-1} [1] \oplus R'_{i-1} [4] \oplus R'_{i-1} [6] \}$$

A vector R_i is derived from the vector R'_i by the bit permutations given in tables 3a and 3b.

Table 3a: Bit permutations for the 2K mode

R _i ' bit positions	9	8	7	6	5	4	3	2	1	0
R _i bit positions	0	7	5	1	8	2	6	9	3	4

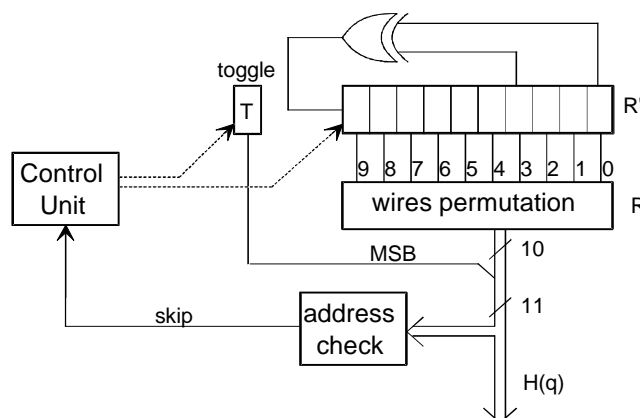
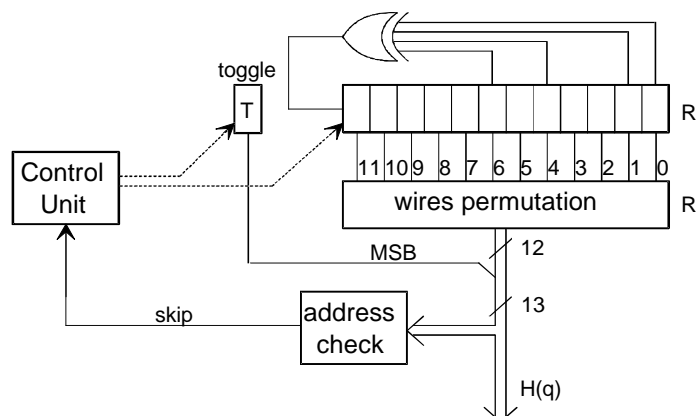
Table 3b: Bit permutations for the 8K mode

R _i ' bit positions	11	10	9	8	7	6	5	4	3	2	1	0
R _i bit positions	5	11	3	0	10	8	6	9	2	4	1	7

The permutation function H(q) is defined by the following algorithm:

$$\begin{aligned}
 & q = 0; \\
 & \text{for } (i = 0; i < M_{\max}; i = i + 1) \\
 & \{ H(q) = (i \bmod 2) \cdot 2^{N_r-1} + \sum_{j=0}^{N_r-2} R_i(j) \cdot 2^j; \\
 & \quad \text{if } (H(q) < N_{\max}) \ q = q + 1; \}
 \end{aligned}$$

A schematic block diagram of the algorithm used to generate the permutation function is represented in figure 8a for the 2K mode and in figure 8b for the 8K mode.

**Figure 8a: Symbol interleaver address generation scheme for the 2K mode****Figure 8b: Symbol interleaver address generation scheme for the 8K mode**

In a similar way to y' , y is made up of v bits:

$$y_{q'} = (y_{0,q'}, y_{1,q'}, \dots, y_{v-1,q'})$$

where q' is the symbol number at the output of the symbol interleaver.

These values of y are used to map the data into the signal constellation, as described in clause 4.3.5.

4.3.5 Signal constellations and mapping

The system uses Orthogonal Frequency Division Multiplex (OFDM) transmission. All data carriers in one OFDM frame are modulated using either QPSK, 16-QAM, 64-QAM, non-uniform 16-QAM or non-uniform 64-QAM constellations. The constellations, and the details of the Gray mapping applied to them, are illustrated in figure 9.

The exact proportions of the constellations depend on a parameter α , which can take the three values 1, 2 or 4, thereby giving rise to the three diagrams figures 9a to 9c. α is the minimum distance separating two constellation points carrying different HP-bit values divided by the minimum distance separating any two constellation points.

Non-hierarchical transmission uses the same uniform constellation as the case with $\alpha = 1$, i.e. figure 9a.

The exact values of the constellation points are $z \in \{n + j m\}$ with values of n , m given below for the various constellations:

QPSK

$$n \in \{-1, 1\}, m \in \{-1, 1\}$$

16-QAM (non-hierarchical and hierarchical with $\alpha = 1$)

$$n \in \{-3, -1, 1, 3\}, m \in \{-3, -1, 1, 3\}$$

Non-uniform 16-QAM with $\alpha = 2$

$$n \in \{-4, -2, 2, 4\}, m \in \{-4, -2, 2, 4\}$$

Non-uniform 16-QAM with $\alpha = 4$

$$n \in \{-6, -4, 4, 6\}, m \in \{-6, -4, 4, 6\}$$

64-QAM (non-hierarchical and hierarchical with $\alpha = 1$)

$$n \in \{-7, -5, -3, -1, 1, 3, 5, 7\}, m \in \{-7, -5, -3, -1, 1, 3, 5, 7\}$$

Non-uniform 64-QAM with $\alpha = 2$

$$n \in \{-8, -6, -4, -2, 2, 4, 6, 8\}, m \in \{-8, -6, -4, -2, 2, 4, 6, 8\}$$

Non-uniform 64-QAM with $\alpha = 4$

$$n \in \{-10, -8, -6, -4, 4, 6, 8, 10\}, m \in \{-10, -8, -6, -4, 4, 6, 8, 10\}$$

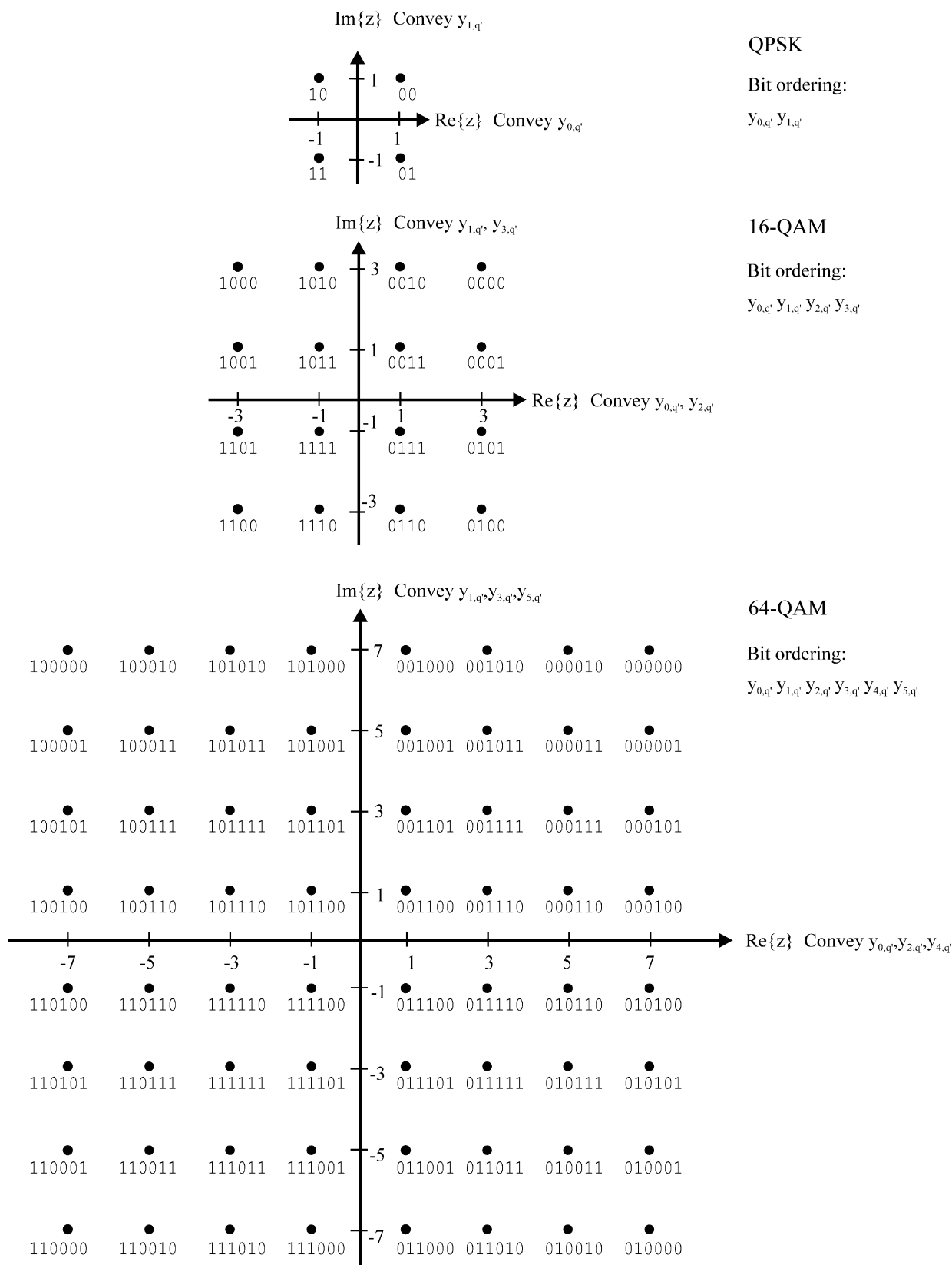


Figure 9a: The QPSK, 16-QAM and 64-QAM mappings and the corresponding bit patterns (non-hierarchical, and hierarchical with $\alpha = 1$)

The $y_{u,q}$ denote the bits representing a complex modulation symbol z .

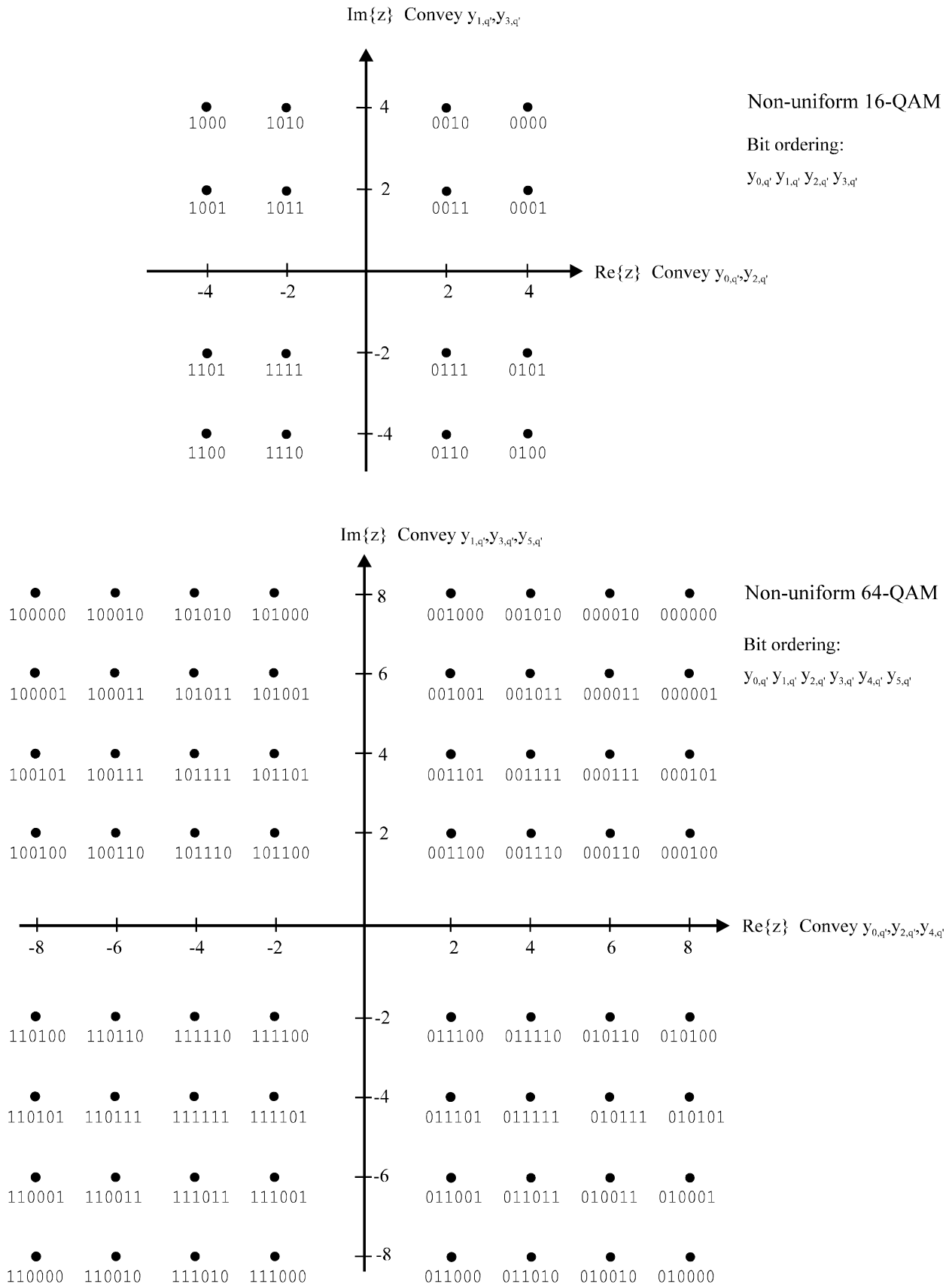


Figure 9b: Non-uniform 16-QAM and 64-QAM mappings with $\alpha = 2$

The $y_{u,q}$ denote the bits representing a complex modulation symbol z .

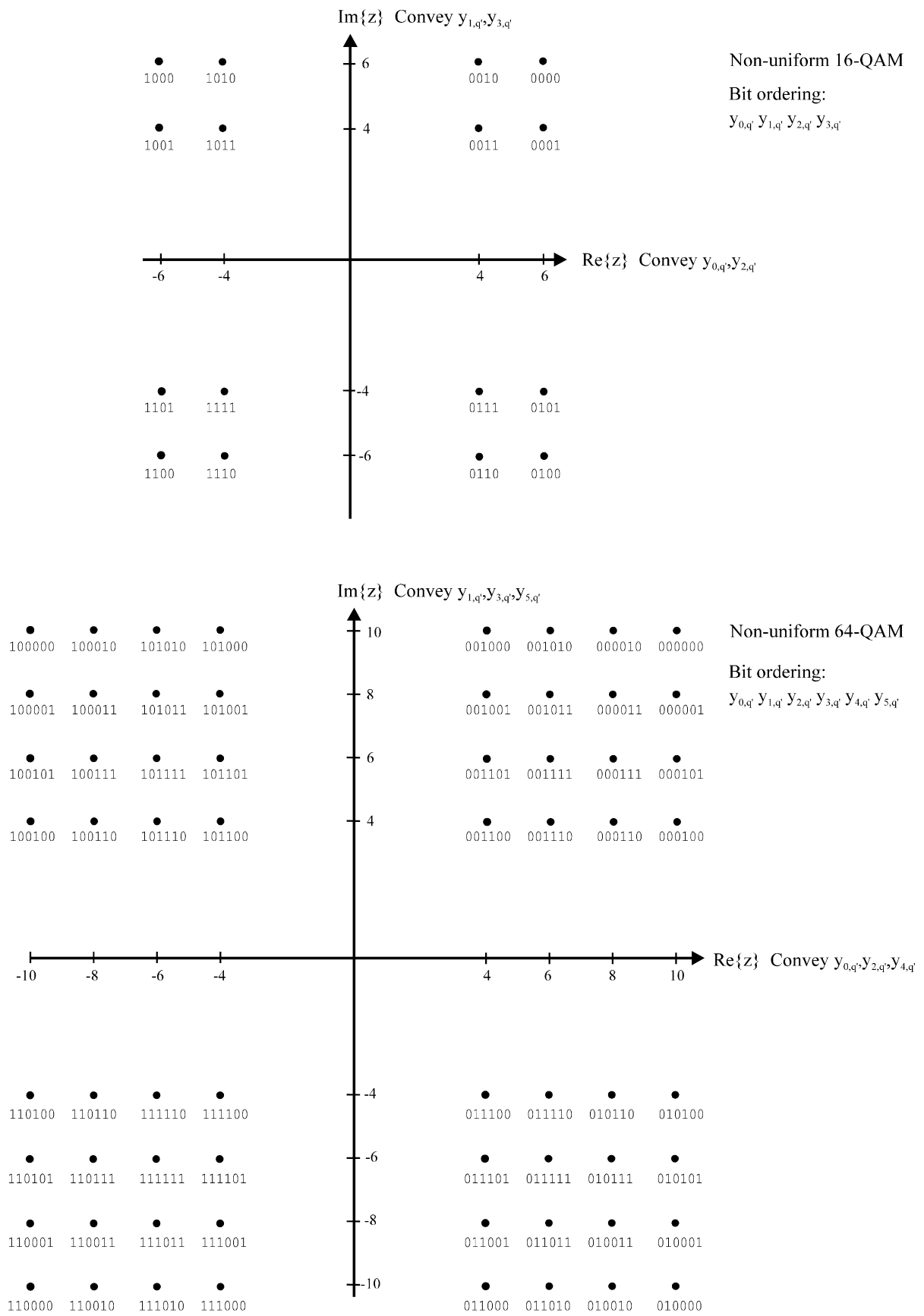


Figure 9c: Non-uniform 16-QAM and 64-QAM mappings with $\alpha = 4$

The $y_{u,q}$ denote the bits representing a complex modulation symbol z .

Non-hierarchical transmission:

The data stream at the output of the inner interleaver consists of v bit words. These are mapped onto a complex number z , according to figure 9a.

Hierarchical transmission:

In the case of hierarchical transmission, the data streams are formatted as shown in figure 7b, and then the mappings as shown in figures 9a, 9b, or 9c are applied, as appropriate.

For hierarchical 16-QAM:

The high priority bits are the $y_{0,q}$ and $y_{1,q}$ bits of the inner interleaver output words. The low priority bits are the $y_{2,q}$ and $y_{3,q}$ bits of the inner interleaver output words. The mappings of figures 9a, 9b or 9c are applied, as appropriate. For example, the top left constellation point, corresponding to 1 000 represents $y_{0,q} = 1$, $y_{1,q} = y_{2,q} = y_{3,q} = 0$. If this constellation is decoded as if it were QPSK, the high priority bits, $y_{0,q}$, $y_{1,q}$ will be deduced. To decode the low priority bits, the full constellation shall be examined and the appropriate bits ($y_{2,q}$, $y_{3,q}$) extracted from $y_{0,q}$, $y_{1,q}$, $y_{2,q}$, $y_{3,q}$.

For hierarchical 64-QAM:

The high priority bits are the $y_{0,q}$ and $y_{1,q}$ bits of the inner interleaver output words. The low priority bits are the $y_{2,q}$, $y_{3,q}$, $y_{4,q}$ and $y_{5,q}$ bits of the inner interleaver output words. The mappings of figures 9a, 9b or 9c are applied, as appropriate. If this constellation is decoded as if it were QPSK, the high priority bits, $y_{0,q}$, $y_{1,q}$ will be deduced. To decode the low priority bits, the full constellation shall be examined and the appropriate bits ($y_{2,q}$, $y_{3,q}$, $y_{4,q}$, $y_{5,q}$) extracted from $y_{0,q}$, $y_{1,q}$, $y_{2,q}$, $y_{3,q}$, $y_{4,q}$, $y_{5,q}$.

4.4 OFDM frame structure

Clause 4.4 specifies the OFDM frame structure to use for the 2K and 8K transmission modes. The OFDM frame structure parameters for the 4K transmission mode shall be compliant with the specifications provided in the annex F.

The transmitted signal is organized in frames. Each frame has a duration of T_F , and consists of 68 OFDM symbols. Four frames constitute one super-frame. Each symbol is constituted by a set of $K = 6\,817$ carriers in the 8K mode and $K = 1\,705$ carriers in the 2K mode and transmitted with a duration T_S . It is composed of two parts: a useful part with duration T_U and a guard interval with a duration Δ . The guard interval consists in a cyclic continuation of the useful part, T_U , and is inserted before it. Four values of guard intervals may be used according to table 5.

The symbols in an OFDM frame are numbered from 0 to 67. All symbols contain data and reference information.

Since the OFDM signal comprises many separately-modulated carriers, each symbol can in turn be considered to be divided into cells, each corresponding to the modulation carried on one carrier during one symbol.

In addition to the transmitted data an OFDM frame contains:

- scattered pilot cells;
- continual pilot carriers;
- TPS carriers.

The pilots can be used for frame synchronization, frequency synchronization, time synchronization, channel estimation, transmission mode identification and can also be used to follow the phase noise.

The carriers are indexed by $k \in [K_{\min}; K_{\max}]$ and determined by $K_{\min} = 0$ and $K_{\max} = 1\,704$ in 2K mode and $6\,816$ in 8K mode respectively. The spacing between adjacent carriers is $1/T_U$ while the spacing between carriers K_{\min} and K_{\max} are determined by $(K-1)/T_U$.

The numerical values for the OFDM parameters for the 8K and 2K modes are given in tables 4 and 5 for 8 MHz channels, in annex E for 6 MHz and 7 MHz channels, and in annex G for 5 MHz channels.

The values for the various time-related parameters are given in multiples of the elementary period T and in microseconds.

The elementary period T is 7/64 μ s for 8 MHz channels, 1/8 μ s for 7 MHz channels, 7/48 μ s for 6 MHz channels and 7/40 μ s for 5 MHz channels.

Table 4: Numerical values for the OFDM parameters for the 8K and 2K modes for 8 MHz channels

Parameter	8K mode	2K mode
Number of carriers K	6 817	1 705
Value of carrier number K_{\min}	0	0
Value of carrier number K_{\max}	6 816	1 704
Duration T_U (see note 2)	896 μ s	224 μ s
Carrier spacing $1/T_U$ (see notes 1 and 2)	<i>1 116 Hz</i>	<i>4 464 Hz</i>
Spacing between carriers K_{\min} and K_{\max} $(K-1)/T_U$ (see note 2)	<i>7,61 MHz</i>	<i>7,61 MHz</i>
NOTE 1: Values in italics are approximate values.		
NOTE 2: Values for 8 MHz channels. Values for 6 MHz and 7 MHz channels are given in tables E.1 and E.2.		

The emitted signal is described by the following expression:

$$s(t) = \text{Re} \left\{ e^{j2\pi f_c t} \sum_{m=0}^{\infty} \sum_{l=0}^{67} \sum_{k=K_{\min}}^{K_{\max}} c_{m,l,k} \times \psi_{m,l,k}(t) \right\}$$

$$\text{where } \psi_{m,l,k}(t) = \begin{cases} e^{j2\pi \frac{k'}{T_U}(t - \Delta - l \times T_s - 68 \times m \times T_s)} & (l + 68 \times m) \times T_s \leq t \leq (l + 68 \times m + 1) \times T_s \\ 0 & \text{else} \end{cases}$$

where:

- k denotes the carrier number;
- l denotes the OFDM symbol number;
- m denotes the transmission frame number;
- K is the number of transmitted carriers;
- T_S is the symbol duration;
- T_U is the inverse of the carrier spacing;
- Δ is the duration of the guard interval;
- f_c is the central frequency of the RF signal;
- k' is the carrier index relative to the centre frequency, $k' = k - (K_{\max} + K_{\min}) / 2$;
- $c_{m,0,k}$ complex symbol for carrier k of the Data symbol no. 1 in frame number m;
- $c_{m,1,k}$ complex symbol for carrier k of the Data symbol no. 2 in frame number m;
- ...
- $c_{m,67,k}$ complex symbol for carrier k of the Data symbol no. 68 in frame number m.

Table 5: Duration of symbol part for the allowed guard intervals for 8 MHz channels

Mode	8K mode				2K mode			
Guard interval Δ / T_U	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Duration of symbol part T_U	8 192 × T 896 μs (see note)				2 048 × T 224 μs (see note)			
Duration of guard interval Δ	2 048 × T 224 μs	1 024 × T 112 μs	512 × T 56 μs	256 × T 28 μs	512 × T 56 μs	256 × T 28 μs	128 × T 14 μs	64 × T 7 μs
Symbol duration $T_S = \Delta + T_U$	10 240 × T 1 120 μs	9 216 × T 1 008 μs	8 704 × T 952 μs	8 448 × T 924 μs	2 560 × T 280 μs	2 304 × T 252 μs	2 176 × T 238 μs	2 112 × T 231 μs

NOTE: Values for 8 MHz channels. Values for 6 MHz and 7 MHz channels are given in tables E.3 and E.4.

The $c_{m,l,k}$ values are normalized modulation values of the constellation point z (see figure 9) according to the modulation alphabet used for the data. The normalization factors yield $E[c \times c^*] = 1$ and are shown in table 6.

Table 6: Normalization factors for data symbols

Modulation scheme		Normalization factor
QPSK		$c = z/\sqrt{2}$
16-QAM	$\alpha = 1$	$c = z/\sqrt{10}$
	$\alpha = 2$	$c = z/\sqrt{20}$
	$\alpha = 4$	$c = z/\sqrt{52}$
64-QAM	$\alpha = 1$	$c = z/\sqrt{42}$
	$\alpha = 2$	$c = z/\sqrt{60}$
	$\alpha = 4$	$c = z/\sqrt{108}$

4.5 Reference signals

This clause specifies the mode independent Reference signals processes and the parameters to use for the 2K and 8K transmission modes; parameters for the 4K mode are specified in annex F.

4.5.1 Functions and derivation

Various cells within the OFDM frame are modulated with reference information whose transmitted value is known to the receiver. Cells containing reference information are transmitted at "boosted" power level (see clause 4.5.5). The information transmitted in these cells are scattered or continual pilot cells.

Each continual pilot coincides with a scattered pilot every fourth symbol; the number of useful data carriers is constant from symbol to symbol: 1 512 useful carriers in 2K mode and 6 048 useful carriers in 8K mode.

The value of the scattered or continual pilot information is derived from a Pseudo-Random Binary Sequence (PRBS) which is a series of values, one for each of the transmitted carriers (see clause 4.5.2).

4.5.2 Definition of reference sequence

The continual and scattered pilots are modulated according to a PRBS sequence, w_k , corresponding to their respective carrier index k . This sequence also governs the starting phase of the TPS information (described in clause 4.6).

The PRBS sequence is generated according to figure 10.

The PRBS is initialized so that the first output bit from the PRBS coincides with the first active carrier. A new value is generated by the PRBS on every used carrier (whether or not it is a pilot).

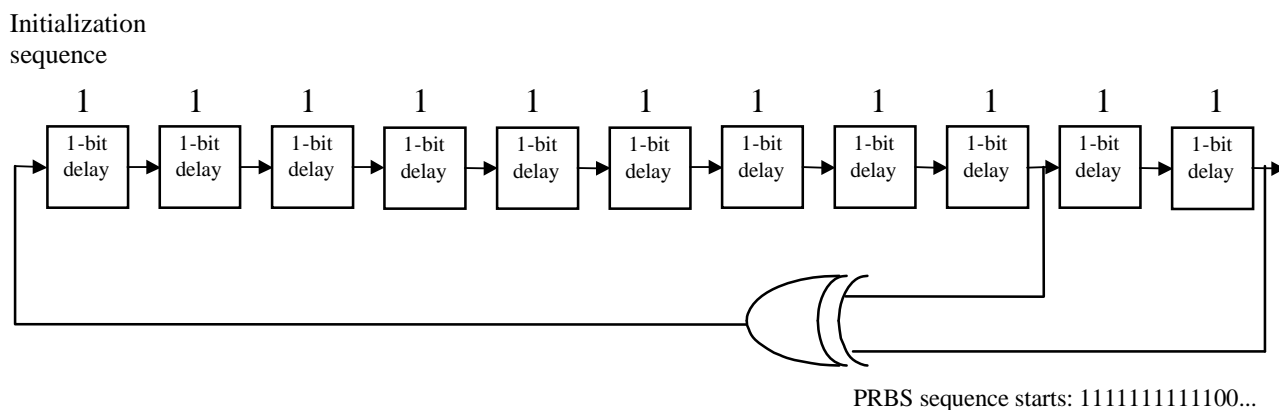


Figure 10: Generation of PRBS sequence

The polynomial for the Pseudo Random Binary Sequence (PRBS) generator shall be:

$$X^{11} + X^2 + 1 \text{ (see figure 10)}$$

4.5.3 Location of scattered pilot cells

Reference information, taken from the reference sequence, is transmitted in scattered pilot cells in every symbol. Scattered pilot cells are always transmitted at the "boosted" power level (see clause 4.5.5). Thus the corresponding modulation is given by:

$$\text{Re}\{c_{m,l,k}\} = 4 / 3 \times 2 (1/2 - w_k)$$

$$\text{Im}\{c_{m,l,k}\} = 0$$

Where m is the frame index, k is the frequency index of the carriers and l is the time index of the symbols.

For the symbol of index l (ranging from 0 to 67), carriers for which index k belongs to the subset $\{k = K_{\min} + 3 \times (l \bmod 4) + 12p \mid p \text{ integer, } p \geq 0, k \in [K_{\min}; K_{\max}]\}$ are scattered pilots.

Where p is an integer that takes all possible values greater than or equal to zero, provided that the resulting value for k does not exceed the valid range $[K_{\min}; K_{\max}]$.

The pilot insertion pattern is shown in figure 11.

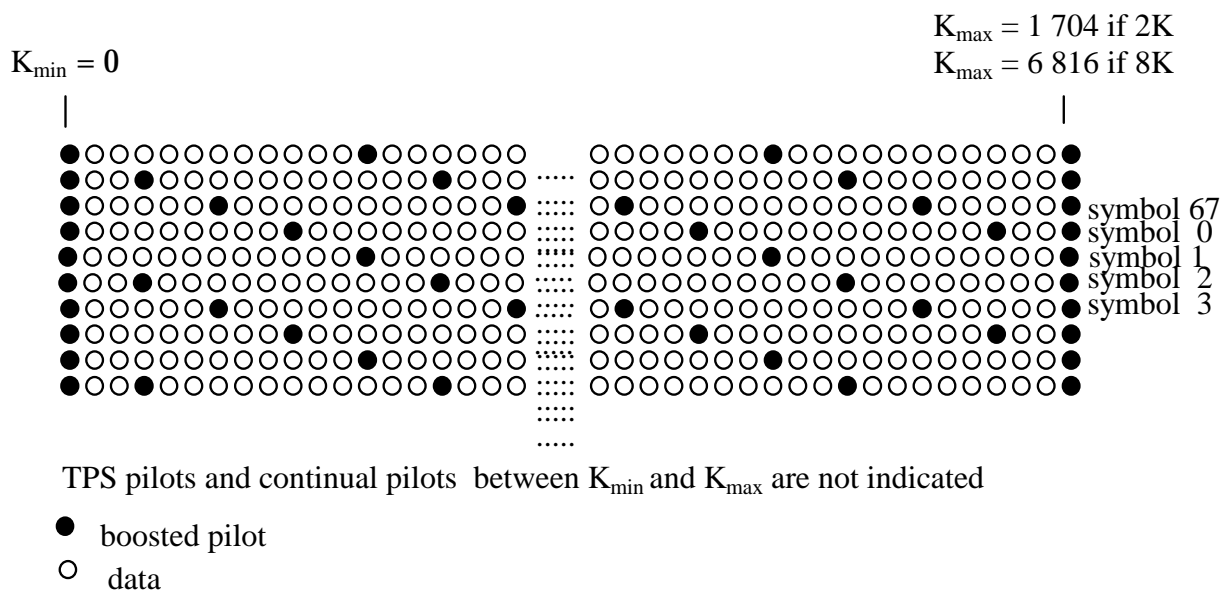


Figure 11: Frame structure

4.5.4 Location of continual pilot carriers

In addition to the scattered pilots described above, 177 continual (see note) pilots in the 8K mode and 45 in the 2K mode, are inserted according to table 7.

NOTE: Where "continual" means that they occur on all symbols.

Table 7: Carrier indices for continual pilot carriers

Continual pilot carrier positions (index number k)													
2K mode							8K mode						
0	48	54	87	141	156	192	0	48	54	87	141	156	192
201	255	279	282	333	432	450	201	255	279	282	333	432	450
483	525	531	618	636	714	759	483	525	531	618	636	714	759
765	780	804	873	888	918	939	765	780	804	873	888	918	939
942	969	984	1 050	1 101	1 107	1 110	942	969	984	1 050	1 101	1 107	1 110
1 137	1 140	1 146	1 206	1 269	1 323	1 377	1 137	1 140	1 146	1 206	1 269	1 323	1 377
1 491	1 683	1 704					1 491	1 683	1 704	1 752	1 758	1 791	1 845
							1 860	1 896	1 905	1 959	1 983	1 986	2 037
							2 136	2 154	2 187	2 229	2 235	2 322	2 340
							2 418	2 463	2 469	2 484	2 508	2 577	2 592
							2 622	2 643	2 646	2 673	2 688	2 754	2 805
							2 811	2 814	2 841	2 844	2 850	2 910	2 973
							3 027	3 081	3 195	3 387	3 408	3 456	3 462
							3 495	3 549	3 564	3 600	3 609	3 663	3 687
							3 690	3 741	3 840	3 858	3 891	3 933	3 939
							4 026	4 044	4 122	4 167	4 173	4 188	4 212
							4 281	4 296	4 326	4 347	4 350	4 377	4 392
							4 458	4 509	4 515	4 518	4 545	4 548	4 554
							4 614	4 677	4 731	4 785	4 899	5 091	5 112
							5 160	5 166	5 199	5 253	5 268	5 304	5 313
							5 367	5 391	5 394	5 445	5 544	5 562	5 595
							5 637	5 643	5 730	5 748	5 826	5 871	5 877
							5 892	5 916	5 985	6 000	6 030	6 051	6 054
							6 081	6 096	6 162	6 213	6 219	6 222	6 249
							6 252	6 258	6 318	6 381	6 435	6 489	6 603
							6 795	6 816					

All continual pilots are modulated according to the reference sequence, see clause 4.5.2.

The continual pilots are transmitted at "boosted" power level.

Thus the corresponding modulation is given by:

$$\text{Re}\{c_{m,l,k}\} = 4 / 3 \times 2 (1/2 - w_k)$$

$$\text{Im}\{c_{m,l,k}\} = 0$$

4.5.5 Amplitudes of all reference information

As explained in clause 4.4 the modulation of all data cells is normalized so that $E[c \times c^*] = 1$.

All cells which are continual or scattered pilots, i.e. they are members of the sets defined in clauses 4.5.3 or 4.5.4, are transmitted at boosted power so that for these $E[c \times c^*] = 16/9$.

4.6 Transmission Parameter Signalling (TPS)

This clause specifies the Transmission Parameter Signalling (TPS). Options covering 4K, in-depth inner interleaver, time-slicing and MPE-FEC bits for DVB-H signalling are specified in annex F.

The TPS carriers are used for the purpose of signalling parameters related to the transmission scheme, i.e. to channel coding and modulation. The TPS is transmitted in parallel on 17 TPS carriers for the 2K mode and on 68 carriers for the 8K mode. Every TPS carrier in the same symbol conveys the same differentially encoded information bit. The following carrier indices contain TPS carriers:

Table 8: Carrier indices for TPS carriers

2K mode					8K mode							
34	50	209	346	413	34	50	209	346	413	569	595	688
569	595	688	790	901	790	901	1 073	1 219	1 262	1 286	1 469	1 594
1 073	1 219	1 262	1 286	1 469	1 687	1 738	1 754	1 913	2 050	2 117	2 273	2 299
1 594	1 687				2 392	2 494	2 605	2 777	2 923	2 966	2 990	3 173
					3 298	3 391	3 442	3 458	3 617	3 754	3 821	3 977
					4 003	4 096	4 198	4 309	4 481	4 627	4 670	4 694
					4 877	5 002	5 095	5 146	5 162	5 321	5 458	5 525
					5 681	5 707	5 800	5 902	6 013	6 185	6 331	6 374
					6 398	6 581	6 706	6 799				

The TPS carriers convey information on:

- modulation including the α value of the QAM constellation pattern (see note);
- hierarchy information;
- guard interval (not for initial acquisition but for supporting initial response of the receiver in case of reconfiguration);
- inner code rates;
- transmission mode (2K or 8K, not for the initial acquisition but for supporting initial response of the receiver in case of reconfiguration);
- frame number in a super-frame;
- cell identification.

NOTE: The α value defines the modulation based on the cloud spacing of a generalized QAM constellation. It allows specification of uniform and non-uniform modulation schemes, covering QPSK, 16-QAM, and 64-QAM.

4.6.1 Scope of the TPS

The TPS is defined over 68 consecutive OFDM symbols, referred to as one OFDM frame. Four consecutive frames correspond to one OFDM super-frame.

The reference sequence corresponding to the TPS carriers of the first symbol of each OFDM frame are used to initialize the TPS modulation on each TPS carrier (see clause 4.6.3).

Each OFDM symbol conveys one TPS bit. Each TPS block (corresponding to one OFDM frame) contains 68 bits, defined as follows:

- 1 initialization bit;
- 16 synchronization bits;
- 37 information bits;
- 14 redundancy bits for error protection.

Of the 37 information bits, 31 are used. The remaining 6 bits shall be set to zero.

4.6.2 TPS transmission format

The transmission parameter information shall be transmitted as shown in table 9.

The mapping of each of the transmission parameters: constellation characteristics, α value, code rate(s), super-frame indicator and guard interval onto the bit combinations is performed according to clauses 4.6.2.1 to 4.6.2.8. The left most bit is sent first.

Table 9: TPS signalling information and format

Bit number	Format	Purpose/Content
s_0	see clause 4.6.2.1	Initialization
s_1 to s_{16}	0011010111101110 or 1100101000010001	Synchronization word
s_{17} to s_{22}	see clause 4.6.2.3	Length indicator (see annex F)
s_{23} , s_{24}	see table 10	Frame number
s_{25} , s_{26}	see table 11	Constellation
s_{27} , s_{28} , s_{29}	see table 12	Hierarchy information (see annex F)
s_{30} , s_{31} , s_{32}	see table 13	Code rate, HP stream
s_{33} , s_{34} , s_{35}	see table 13	Code rate, LP stream
s_{36} , s_{37}	see table 14	Guard interval
s_{38} , s_{39}	see table 15	Transmission mode (see annex F)
s_{40} to s_{47}	see clause 4.6.2.10	Cell identifier
s_{48} to s_{53}	all set to "0"	See annex F
s_{54} to s_{67}	BCH code	Error protection

The TPS information transmitted in super-frame m' bits s_{25} - s_{39} always apply to super-frame $m' + 1$, whereas all other bits refer to super-frame m' .

4.6.2.1 Initialization

The first bit, s_0 , is an initialization bit for the differential 2-PSK modulation. The modulation of the TPS initialization bit is derived from the PRBS sequence defined in clause 4.5.2. This process is described in clause 4.6.3.

4.6.2.2 Synchronization

Bits 1 to 16 of the TPS is a synchronization word.

The first and third TPS block in each super-frame have the following synchronization word:

$$s_1 - s_{16} = 0011010111101110.$$

The second and fourth TPS block have the following synchronization word:

$$s_1 - s_{16} = 1100101000010001.$$

4.6.2.3 TPS length indicator

The first 6 bits of the TPS information is used as a TPS length indicator (binary count starting from and including bit s_{17}) to signal the number of used bits of the TPS.

The transmission of the Cell Identification (see clause 4.6.2.10) is optional. The TPS length indicator carries then the values:

- "010111" when Cell Identification information is not transmitted (23 TPS bits in use);
- "011111" when Cell Identification information is transmitted (31 TPS bits in use).

4.6.2.4 Frame number

Four frames constitute one super-frame. The frames inside the super-frame are numbered from 1 to 4. The mapping from bits s_{23} , s_{24} to the frame number is given in table 10.

Table 10: Signalling format for frame number

Bits s_{23} , s_{24}	Frame number
00	Frame number 1 in the super-frame
01	Frame number 2 in the super-frame
10	Frame number 3 in the super-frame
11	Frame number 4 in the super-frame

4.6.2.5 Constellation

The constellation shall be signalled by 2 bits according to table 11. In order to determine the modulation scheme, the receiver shall also decode the hierarchy information given in table 12.

Table 11: Signalling format for the possible constellation patterns

Bits s_{25} , s_{26}	Constellation characteristics
00	QPSK
01	16-QAM
10	64-QAM
11	Reserved

4.6.2.6 Hierarchy information

The hierarchy information specifies whether the transmission is hierarchical and, if so, what the α value is. The QAM constellation diagrams which correspond to various α values are shown in figures 9a/b/c. Where α is signalled by three bits according to table 12.

Table 12: Signalling format for the α values

Bits s_{27} , s_{28} , s_{29}	α value
000	Non hierarchical
001	$\alpha = 1$
010	$\alpha = 2$
011	$\alpha = 4$
100	see annex F
101	see annex F
110	see annex F
111	see annex F

4.6.2.7 Code rates

Non-hierarchical channel coding and modulation requires signalling of one code rate r . In this case, three bits specifying the code rate according to table 13 are followed by another three bits of value 000.

Two different code rates may be applied to two different levels of the modulation with the aim of achieving hierarchy. Transmission then starts with the code rate for the HP level (r_1) of the modulation and ends with the one for the LP level (r_2). Each code rate shall be signalled according to table 13.

Table 13: Signalling format for each of the code rates

Bits s_{30}, s_{31}, s_{32} (HP stream) s_{33}, s_{34}, s_{35} (LP stream)	Code rate
000	1/2
001	2/3
010	3/4
011	5/6
100	7/8
101	reserved
110	reserved
111	reserved

4.6.2.8 Guard Intervals

The value of the guard interval is signalled according to table 14.

Table 14: Signalling format for each of the guard interval values

Bits s_{36}, s_{37}	Guard interval values (ΔT_U)
00	1/32
01	1/16
10	1/8
11	1/4

4.6.2.9 Transmission mode

Two bits are used to signal the transmission mode (2K mode or 8K mode).

Table 15: Signalling format for transmission mode

Bits s_{38}, s_{39}	Transmission mode
00	2K mode
01	8K mode
10	see annex F
11	Reserved

4.6.2.10 Cell identifier

The eight bits s_{40} to s_{47} are used to identify the cell from which the signal comes from. The most significant byte of the cell_id [4], i.e. $b_{15} - b_8$, shall be transmitted in super-frames with the frame number 1 and 3. The least significant byte of the cell_id, i.e. $b_7 - b_0$, shall be transmitted in super-frames with the frame number 2 and 4. The mapping of bits is according to table 18. If the provision of the cell_id is not foreseen the eight bits shall be set to zero.

Table 15a: Mapping of the cell_id on the TPS bits

TPS bit number	Frame number 1 or 3	Frame number 2 or 4
s ₄₀	cell_id b ₁₅	cell_id b ₇
s ₄₁	cell_id b ₁₄	cell_id b ₆
s ₄₂	cell_id b ₁₃	cell_id b ₅
s ₄₃	cell_id b ₁₂	cell_id b ₄
s ₄₄	cell_id b ₁₁	cell_id b ₃
s ₄₅	cell_id b ₁₀	cell_id b ₂
s ₄₆	cell_id b ₉	cell_id b ₁
s ₄₇	cell_id b ₈	cell_id b ₀

4.6.2.11 Error protection of TPS

The 53 bits containing the TPS synchronization and information (bits s₁ - s₅₃) are extended with 14 parity bits of the BCH (67,53, t = 2) shortened code, derived from the original systematic BCH (127,113, t = 2) code.

Code generator polynomial:

$$h(x) = x^{14} + x^9 + x^8 + x^6 + x^5 + x^4 + x^2 + x + 1.$$

The shortened BCH code may be implemented by adding 60 bits, all set to zero, before the information bits input of an BCH(127,113, t = 2) encoder. After the BCH encoding these null bits shall be discarded, leading to a BCH code word of 67 bits.

4.6.3 TPS modulation

TPS cells are transmitted at the "normal" power level, i.e. they are transmitted with energy equal to that of the mean of all data cells, i.e. $E[c \times c^*] = 1$.

Every TPS carrier is DBPSK modulated and conveys the same message. The DBPSK is initialized at the beginning of each TPS block.

The following rule applies for the differential modulation of carrier k of symbol l (l > 0) in frame m:

- if s_l = 0, then $\text{Re}\{c_{m,l,k}\} = \text{Re}\{c_{m,l-1,k}\}$; $\text{Im}\{c_{m,l,k}\} = 0$;
- if s_l = 1, then $\text{Re}\{c_{m,l,k}\} = -\text{Re}\{c_{m,l-1,k}\}$; $\text{Im}\{c_{m,l,k}\} = 0$.

The absolute modulation of the TPS carriers in the first symbol in a frame is derived from the reference sequence w_k as follows:

$$\text{Re}\{c_{m,l,k}\} = 2 (1/2 - w_k)$$

$$\text{Im}\{c_{m,l,k}\} = 0$$

4.7 Number of RS-packets per OFDM super-frame

This clause gives the number of RS-packets per OFDM super-frame for the 2K and 8K transmission modes. The information for the 4K transmission mode is given in the annex F. The useful bitrate is independent of the transmission mode.

The OFDM frame structure allows for an integer number of Reed-Solomon 204 byte packets to be transmitted in an OFDM super-frame, and therefore avoids the need for any stuffing, whatever the constellation, the guard interval length, the coding rate or the channel bandwidth may be. See table 16.

The first data byte transmitted in an OFDM super-frame shall be one of the SYNC/SYNC bytes.

Table 16: Number of Reed-Solomon packets per OFDM super-frame for all combinations of code rates and modulation forms

Code rate	QPSK		16-QAM		64-QAM	
	2K mode	8K mode	2K mode	8K mode	2K mode	8K mode
1/2	252	1 008	504	2 016	756	3 024
2/3	336	1 344	672	2 688	1 008	4 032
3/4	378	1 512	756	3 024	1 134	4 536
5/6	420	1 680	840	3 360	1 260	5 040
7/8	441	1 764	882	3 528	1 323	5 292

Table 17: Useful bitrate (Mbit/s) for all combinations of guard interval, constellation and code rate for non-hierarchical systems for 8 MHz channels (irrespective of the transmission modes)

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	4,98	5,53	5,85	6,03
	2/3	6,64	7,37	7,81	8,04
	3/4	7,46	8,29	8,78	9,05
	5/6	8,29	9,22	9,76	10,05
	7/8	8,71	9,68	10,25	10,56
16-QAM	1/2	9,95	11,06	11,71	12,06
	2/3	13,27	14,75	15,61	16,09
	3/4	14,93	16,59	17,56	18,10
	5/6	16,59	18,43	19,52	20,11
	7/8	17,42	19,35	20,49	21,11
64-QAM	1/2	14,93	16,59	17,56	18,10
	2/3	19,91	22,12	23,42	24,13
	3/4	22,39	24,88	26,35	27,14
	5/6	24,88	27,65	29,27	30,16
	7/8	26,13	29,03	30,74	31,67

NOTE: Figures in italics are approximate values for 8 MHz channels. Values for 6 MHz and 7 MHz channels are given in annex E. Values for 5 MHz channels are given in annex G.

For the hierarchical schemes the useful bit rates can be obtained from table 17 as follows:

- HP stream: figures from QPSK columns;
- LP stream, 16-QAM: figures from QPSK columns;
- LP stream, 64-QAM: figures from 16-QAM columns.

4.8 Spectrum characteristics and spectrum mask

4.8.1 Spectrum characteristics

The OFDM symbols constitute a juxtaposition of equally-spaced orthogonal carriers. The amplitudes and phases of the data cell carriers are varying symbol by symbol according to the mapping process described in clause 4.3.5.

The power spectral density $P_k(f)$ of each carrier at frequency:

$$f_k = f_c + \frac{k}{T_u}; \left(-\frac{K-1}{2} \leq k \leq \frac{K-1}{2}\right)$$

is defined by the following expression:

$$P_k(f) = \left[\frac{\sin \pi(f - f_k)T_s}{\pi(f - f_k)T_s} \right]^2$$

The overall power spectral density of the modulated data cell carriers is the sum of the power spectral densities of all these carriers. A theoretical DVB transmission signal spectrum is illustrated in figure 12 (for 8 MHz channels). Because the OFDM symbol duration is larger than the inverse of the carrier spacing, the main lobe of the power spectral density of each carrier is narrower than twice the carrier spacing. Therefore the spectral density is not constant within the nominal bandwidth of *7,608 259 MHz* for the 8K mode *or 7,611 607 MHz* for the 2K mode (see note). For the 4K mode, see annex F.

NOTE: Values in italics are approximate values.

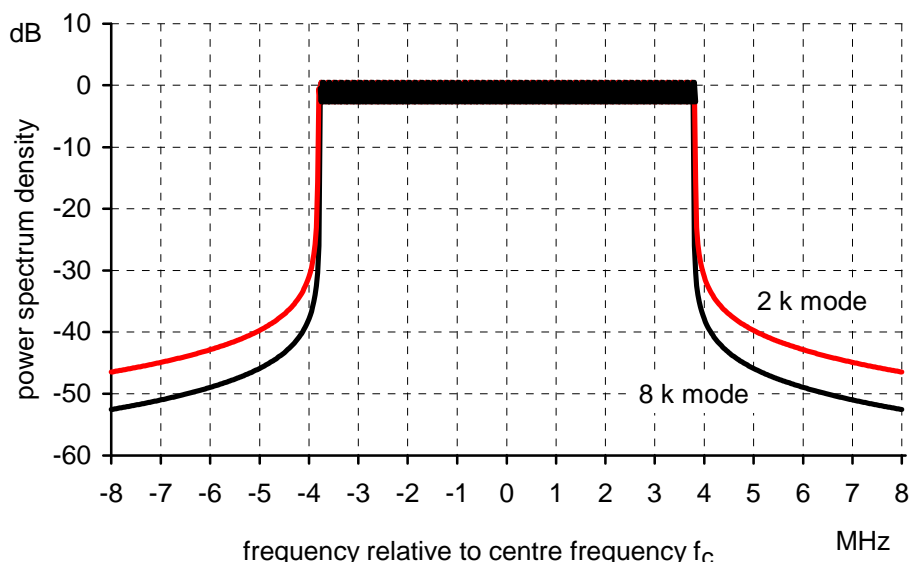


Figure 12: Theoretical DVB transmission signal spectrum for guard interval $\Delta = T_u/4$ (for 8 MHz channels)

4.8.2 Out-of-band spectrum mask (for 8 MHz channels)

The level of the spectrum at frequencies outside the nominal bandwidth can be reduced by applying appropriate filtering.

Spectrum masks for cases where a transmitter for digital terrestrial television is co-sited with, and operating on a channel adjacent to, a transmitter for analogue television are given in figure 13 and table 18 for the following analogue television systems:

- G/PAL/A2 and G/PAL/NICAM;
- I/PAL/NICAM;
- K/SECAM and K/PAL;
- L/SECAM/NICAM.

The masks shown in figure 13 cover the minimum protection needed for analogue television where the analogue and the digital television transmitters are co-sited and are applicable for cases where:

- no polarization discrimination between digital and analogue television is used; and
- the radiated power from both transmitters is the same (analogue sync-peak power equal to total power from the digital television transmitter).

If the radiated powers from the two transmitters are not identical, proportional correction can be applied as follows:

$$\text{correction} = \text{minimum analogue erp} - \text{maximum digital erp.}$$

Corrected breakpoints equal reference breakpoints plus correction (dB).

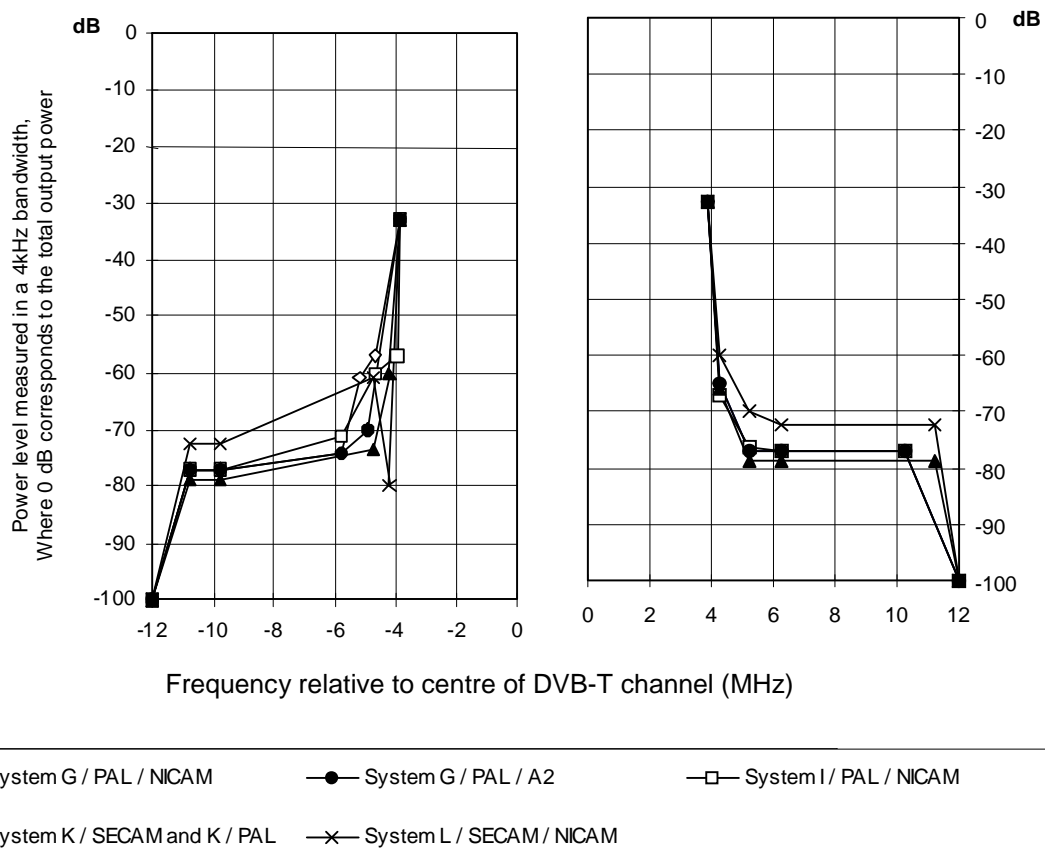


Figure 13: Spectrum masks for a digital terrestrial television transmitter operating on a lower or higher adjacent channel to a co-sited analogue television transmitter

Table 18: Breakpoints for spectrum mask

Breakpoints										
see notes below	G/PAL / NICAM		G/PAL / A2		I/PAL / NICAM		K/SECAM K/PAL		L/SECAM / NICAM	
	rel. freq. (MHz)	rel. level (dB)	rel. freq. (MHz)	rel. level (dB)	rel. freq. (MHz)	rel. level (dB)	rel. freq. (MHz)	rel. level (dB)	rel. freq. (MHz)	rel. level (dB)
1	-12	-100	-12	-100	-12	-100	-12	-100	-12	-100
2	-10,75	-76,9	-10,75	-76,9	-10,75	-76,9	-10,75	-78,7	-10,75	-72,4
3	-9,75	-76,9	-9,75	-76,9	-9,75	-76,9	-9,75	-78,7	-9,75	-72,4
4	-5,75	-74,2	-5,75	-74,2	-5,75	-70,9	-4,75	-73,6	-4,75	-60,9
5	-5,185	-60,9	-5,185	n.a.	-4,685	-59,9	-4,185	-59,9	-4,185	-79,9
6	n.a.	n.a.	-4,94	-69,9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
7	-4,65	-56,9	n.a.	n.a.	-3,925	-56,9	n.a.	n.a.	-4,65	n.a.
8	-3,9	-32,8	-3,9	-32,8	-3,9	-32,8	-3,9	-32,8	-3,9	-32,8
9	+3,9	-32,8	+3,9	-32,8	+3,9	-32,8	+3,9	-32,8	+3,9	-32,8
10	+4,25	-64,9	+4,25	-64,9	+4,25	-66,9	+4,25	-66,1	+4,25	-59,9
11	+5,25	-76,9	+5,25	-76,9	+5,25	-76,2	+5,25	-78,7	+5,25	-69,9
12	+6,25	-76,9	+6,25	-76,9	+6,25	-76,9	+6,25	-78,7	+6,25	-72,4
13	+10,25	-76,9	+10,25	-76,9	+10,25	-76,9	+11,25	-78,7	+11,25	-72,4
14	+12	-100	+12	-100	+12	-100	+12	-100	+12	-100

NOTE 1: Lower end of lower adjacent channel.
NOTE 2: Vision carrier in lower adjacent channel.
NOTE 3: Vision carrier + 1 MHz in lower adjacent channel.
NOTE 4: Upper end of video sideband in lower adjacent channel.
NOTE 5: Upper end of the RF bandwidth of the first soundcarrier in lower adjacent channel.
NOTE 6: Upper end of the RF bandwidth of the A2 second soundcarrier in lower adjacent channel.
NOTE 7: Upper end of the RF bandwidth of the NICAM signal in the lower adjacent channel.
NOTE 8: Lower end of the RF bandwidth of the DVB-T signal.
NOTE 9: Upper end of the RF bandwidth of the DVB-T signal.
NOTE 10: Lower video sideband (vision carrier - 1 MHz) in upper adjacent channel.
NOTE 11: Vision carrier in upper adjacent channel.
NOTE 12: Vision carrier + 1 MHz in upper adjacent channel.
NOTE 13: Upper end of video sideband in upper adjacent channel.
NOTE 14: Upper end of upper adjacent channel.

Cells marked "n.a." in table 18 indicates that this part of the analogue television signal does not exist or has no influence on the shape of the spectrum mask.

For critical cases such as television channels adjacent to other services (low power or receive only) a spectrum mask with higher of out-of-channel attenuation may be needed. A spectrum mask for critical cases is shown in figure 14. Breakpoints for the critical mask are given in table 19.

Power level measured in a 4 kHz bandwidth,
where 0 dB corresponds to the total output power.

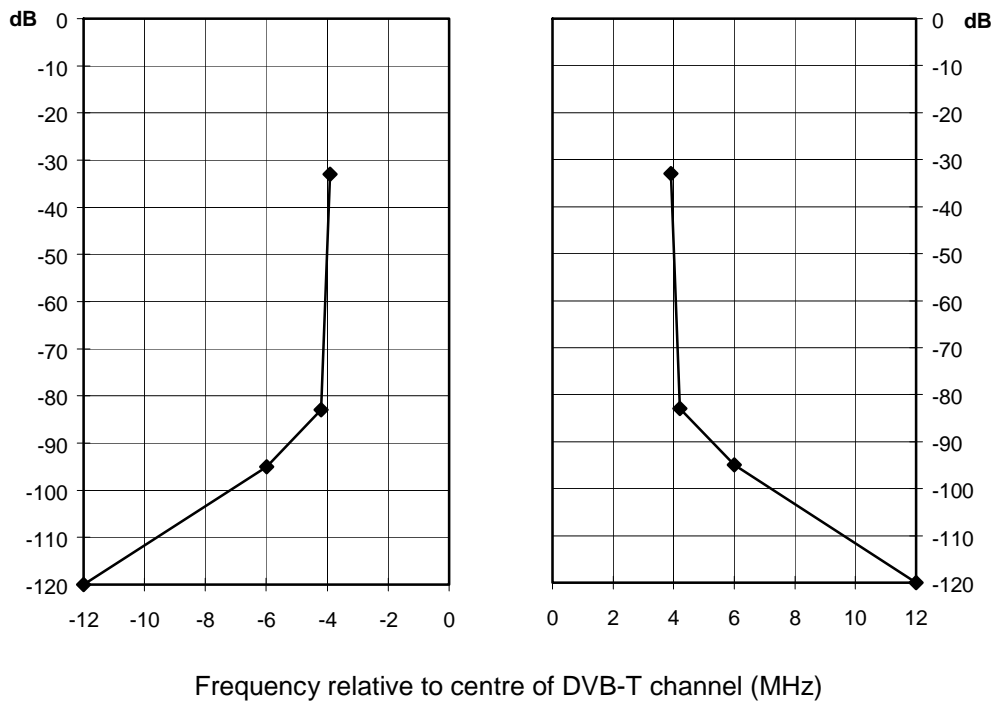


Figure 14: Spectrum mask for critical cases

Table 19: Breakpoints for spectrum mask for critical cases

Breakpoints	
relative frequency (MHz)	relative level (dB)
-12	-120
-6	-95
-4,2	-83
-3,8	-32,8
+3,8	-32,8
+4,2	-83
+6	-95
+12	-120

4.8.3 Centre frequency of RF signal (for 8 MHz UHF channels)

The nominal centre frequency f_c of the RF signal is given by:

$$470 \text{ MHz} + 4 \text{ MHz} + i_1 \times 8 \text{ MHz}, i_1 = 0, 1, 2, 3, \dots$$

This is exactly the centre frequency of the UHF channel in use. This centre frequency may be offset to improve spectrum sharing.

Annex A (informative): Simulated system performance for 8 MHz channels

Tables A.1 to A.3 show the simulated performance of the system assuming an ideal transmission chain with "perfect channel estimation without phase noise". C/N figures are provided for channel coding and modulation combinations in the 8K mode, calculated over the transmitted 6 817 OFDM carriers.

These results are given for a Gaussian channel (AWGN), a Ricean channel (F_1) and a Rayleigh channel (P_1) when the centre carrier of the DVB-T signal is positioned at 32/7 MHz. The Ricean channel (F_1) and Rayleigh channel (P_1) are described in annex B.

Associated useful bit rates available after Reed-Solomon decoder are also indicated for the four values of guard interval.

**Table A.1: Required C/N for Non-Hierarchical transmission
to achieve a BER = 2×10^{-4} after the Viterbi decoder**

Constellation	Code rate	Required C/N (dB) for BER = 2×10^{-4} after Viterbi QEF after Reed-Solomon (see note 2)			Bitrate (Mbit/s) (see note 3)			
		Gaussian Channel (AWGN)	Ricean channel (F_1)	Rayleigh channel (P_1)	$\Delta/T_U = 1/4$	$\Delta/T_U = 1/8$	$\Delta/T_U = 1/16$	$\Delta/T_U = 1/32$
QPSK	1/2	3,5	4,1	5,9	4,98	5,53	5,85	6,03
QPSK	2/3	5,3	6,1	9,6	6,64	7,37	7,81	8,04
QPSK	3/4	6,3	7,2	12,4	7,46	8,29	8,78	9,05
QPSK	5/6	7,3	8,5	15,6	8,29	9,22	9,76	10,05
QPSK	7/8	7,9	9,2	17,5	8,71	9,68	10,25	10,56
<hr/>								
16-QAM	1/2	9,3	9,8	11,8	9,95	11,06	11,71	12,06
16-QAM	2/3	11,4	12,1	15,3	13,27	14,75	15,61	16,09
16-QAM	3/4	12,6	13,4	18,1	14,93	16,59	17,56	18,10
16-QAM	5/6	13,8	14,8	21,3	16,59	18,43	19,52	20,11
16-QAM	7/8	14,4	15,7	23,6	17,42	19,35	20,49	21,11
<hr/>								
64-QAM	1/2	13,8	14,3	16,4	14,93	16,59	17,56	18,10
64-QAM	2/3	16,7	17,3	20,3	19,91	22,12	23,42	24,13
64-QAM	3/4	18,2	18,9	23,0	22,39	24,88	26,35	27,14
64-QAM	5/6	19,4	20,4	26,2	24,88	27,65	29,27	30,16
64-QAM	7/8	20,2	21,3	28,6	26,13	29,03	30,74	31,67

NOTE 1: Figures in italics are approximate values.
NOTE 2: Quasi Error Free (QEF) means less than one uncorrected error event per hour, corresponding to BER = 10^{-11} at the input of the MPEG-2 demultiplexer.
NOTE 3: Net bit rates are given after the Reed-Solomon decoder.

Table A.2: Required C/N for Hierarchical transmission using 16QAM constellations to achieve a BER = 2×10^{-4} after Viterbi decoder

Constellation	Code Rate	α	Required C/N (dB) for BER = 2×10^{-4} after Viterbi QEF after Reed-Solomon (see note 2)			Bitrate (Mbit/s) (see note 3)				
			Gaussian Channel (AWGN)	Ricean Channel (F_1)	Rayleigh Channel (P_1)	$\Delta/T_U = 1/4$	$\Delta/T_U = 1/8$	$\Delta/T_U = 1/16$	$\Delta/T_U = 1/32$	
QPSK in non-uniform 16-QAM	1/2	2	<i>5,1</i>	<i>5,6</i>	<i>7,7</i>	<i>4,98</i>	<i>5,53</i>	<i>5,85</i>	<i>6,03</i>	
	2/3		<i>7,3</i>	<i>8,0</i>	<i>11,4</i>	<i>6,64</i>	<i>7,37</i>	<i>7,81</i>	<i>8,04</i>	
	3/4		<i>8,6</i>	<i>9,5</i>	<i>14,2</i>	<i>7,46</i>	<i>8,29</i>	<i>8,78</i>	<i>9,05</i>	
	+									
	1/2		<i>13,5</i>	<i>14,1</i>	<i>15,9</i>	<i>4,98</i>	<i>5,53</i>	<i>5,85</i>	<i>6,03</i>	
	2/3		<i>15,3</i>	<i>16,1</i>	<i>19,5</i>	<i>6,64</i>	<i>7,37</i>	<i>7,81</i>	<i>8,04</i>	
	3/4		<i>16,3</i>	<i>17,2</i>	<i>22,4</i>	<i>7,46</i>	<i>8,29</i>	<i>8,78</i>	<i>9,05</i>	
	5/6		<i>17,3</i>	<i>18,5</i>	<i>25,5</i>	<i>8,29</i>	<i>9,22</i>	<i>9,76</i>	<i>10,05</i>	
7/8	<i>17,9</i>	<i>19,2</i>	<i>28,2</i>	<i>8,71</i>	<i>9,68</i>	<i>10,25</i>	<i>10,56</i>			
QPSK in non-uniform 16-QAM	1/2	4	<i>4,1</i>	<i>4,6</i>	<i>6,6</i>	<i>4,98</i>	<i>5,53</i>	<i>5,85</i>	<i>6,03</i>	
	2/3		<i>6,0</i>	<i>6,8</i>	<i>10,3</i>	<i>6,64</i>	<i>7,37</i>	<i>7,81</i>	<i>8,04</i>	
	3/4		<i>7,1</i>	<i>8,1</i>	<i>13,1</i>	<i>7,46</i>	<i>8,29</i>	<i>8,78</i>	<i>9,05</i>	
	+									
	1/2		<i>17,7</i>	<i>18,2</i>	<i>20,1</i>	<i>4,98</i>	<i>5,53</i>	<i>5,85</i>	<i>6,03</i>	
	2/3		<i>19,4</i>	<i>20,2</i>	<i>23,6</i>	<i>6,64</i>	<i>7,37</i>	<i>7,81</i>	<i>8,04</i>	
	3/4		<i>20,4</i>	<i>21,4</i>	<i>26,5</i>	<i>7,46</i>	<i>8,29</i>	<i>8,78</i>	<i>9,05</i>	
	5/6		<i>21,4</i>	<i>22,6</i>	<i>29,7</i>	<i>8,29</i>	<i>9,22</i>	<i>9,76</i>	<i>10,05</i>	
7/8	<i>22,0</i>	<i>23,4</i>	<i>32,3</i>	<i>8,71</i>	<i>9,68</i>	<i>10,25</i>	<i>10,56</i>			

NOTE 1: Figures in italics are approximate values.
NOTE 2: Quasi Error Free (QEF) means less than one uncorrected error event per hour, corresponding to BER = 10^{-11} at the input of the MPEG-2 demultiplexer.
NOTE 3: Net bit rates are given after the Reed-Solomon decoder.

Table A.3: Required C/N for Hierarchical transmission using 64QAM constellation to achieve a BER = 2×10^{-4} after Viterbi decoder

Constellation	Code Rate	α	Required C/N (dB) for BER = 2×10^{-4} after Viterbi QEF after Reed-Solomon (see note 2)			Bitrate (Mbit/s) (see note 3)				
			Gaussian Channel (AWGN)	Ricean Channel (F_1)	Rayleigh Channel (P_1)	$\Delta/T_U = 1/4$	$\Delta/T_U = 1/8$	$\Delta/T_U = 1/16$	$\Delta/T_U = 1/32$	
QPSK in uniform 64-QAM	1/2	1	8,5	9,1	11,8	4,98	5,53	5,85	6,03	
	2/3		12,5	13,1	16,4	6,64	7,37	7,81	8,04	
	3/4		15,0	15,6	19,3	7,46	8,29	8,78	9,05	
	1/2		15,5	16,0	18,1	9,95	11,06	11,71	12,06	
	2/3		17,6	18,3	21,6	13,27	14,75	15,61	16,09	
	3/4		18,8	19,7	24,4	14,93	16,59	17,56	18,10	
5/6	20,0	21,1	27,6	16,59	18,43	19,52	20,11			
7/8	20,7	21,9	29,7	17,42	19,35	20,49	21,11			
QPSK in non- uniform 64-QAM	1/2	2	6,5	7,1	9,4	4,98	5,53	5,85	6,03	
	2/3		9,3	10,1	13,5	6,64	7,37	7,81	8,04	
	3/4		11,1	11,9	16,3	7,46	8,29	8,78	9,05	
	1/2		17,1	17,6	19,6	9,95	11,06	11,71	12,06	
	2/3		19,2	19,9	23,1	13,27	14,75	15,61	16,09	
	3/4		20,4	21,2	25,9	14,93	16,59	17,56	18,10	
5/6	21,6	22,6	29,1	16,59	18,43	19,52	20,11			
7/8	22,2	23,4	31,2	17,42	19,35	20,49	21,11			

NOTE 1: Figures in italics are approximate values.
NOTE 2: Quasi Error Free (QEF) means less than one uncorrected error event per hour, corresponding to BER = 10^{-11} at the input of the MPEG-2 demultiplexer.
NOTE 3: Net bit rates are given after the Reed-Solomon decoder.
NOTE 4: Results for QPSK in non-uniform 64-QAM with $\alpha = 4$ are not included due to the poor performance of the 64-QAM signal.

Annex B (informative): Definition of P_1 and F_1

The performance of the system has been simulated with two channel models for fixed reception - F_1 and portable reception - P_1 , respectively.

The channel models have been generated from the following equations where $x(t)$ and $y(t)$ are input and output signals respectively:

a) Fixed reception F_1 :

$$y(t) = \frac{\rho_0 x(t) + \sum_{i=1}^N \rho_i e^{-j\theta_i} x(t - \tau_i)}{\sqrt{\sum_{i=0}^N \rho_i^2}}$$

where:

- the first term before the sum represents the line of sight ray;
- N is the number of echoes equals to 20;
- θ_i is the phase shift from scattering of the i 'th path - listed in table B.1;
- ρ_i is the attenuation of the i 'th path - listed in table B.1;
- τ_i is the relative delay of the i 'th path - listed in table B.1.

The Ricean factor K (the ratio of the power of the direct path (the line of sight ray) to the reflected paths) is given as:

$$K = \frac{\rho_0^2}{\sum_{i=1}^N \rho_i^2}$$

In the simulations a Ricean factor $K = 10$ dB has been used. In this case:

$$\rho_0 = \sqrt{10 \sum_{i=1}^N \rho_i^2}$$

b) Portable reception, Rayleigh fading (P_1):

$$y(t) = k \sum_{i=1}^N \rho_i e^{-j\theta_i} x(t - \tau_i) \quad \text{where } k = \frac{1}{\sqrt{\sum_{i=1}^N \rho_i^2}}$$

θ_i , ρ_i and τ_i are given in table B.1.

Table B.1: Relative power, phase and delay values for F_1 and P_1

i	ρ_i	τ_i [μs]	θ_i [rad]
1	0,057 662	1,003 019	4,855 121
2	0,176 809	5,422 091	3,419 109
3	0,407 163	0,518 650	5,864 470
4	0,303 585	2,751 772	2,215 894
5	0,258 782	0,602 895	3,758 058
6	0,061 831	1,016 585	5,430 202
7	0,150 340	0,143 556	3,952 093
8	0,051 534	0,153 832	1,093 586
9	0,185 074	3,324 866	5,775 198
10	0,400 967	1,935 570	0,154 459
11	0,295 723	0,429 948	5,928 383
12	0,350 825	3,228 872	3,053 023
13	0,262 909	0,848 831	0,628 578
14	0,225 894	0,073 883	2,128 544
15	0,170 996	0,203 952	1,099 463
16	0,149 723	0,194 207	3,462 951
17	0,240 140	0,924 450	3,664 773
18	0,116 587	1,381 320	2,833 799
19	0,221 155	0,640 512	3,334 290
20	0,259 730	1,368 671	0,393 889

Annex C (informative): Interleaving example

The bit interleaving and symbol interleaving rules and the corresponding mapping onto carriers are illustrated in table C.1 for the first symbol in a superframe (i.e. even symbol), 2K mode, 64-QAM, non-hierarchical transmission.

Table C.1 shows the input bit indices to the mapping block, shown in figure 7a, when the input bits to the bit interleaver are numbered 0 to 9 071, and the corresponding carrier number. The indices corresponds to the interleaver input bit numbers.

Table C.1: Mapping of input bits

Input to mapping block $y_{q'} = y_{0q'}, y_{1q'}, y_{2q'}, y_{3q'}, y_{4q'}, y_{5q'}$	Carrier number k
pilot	0
0, 381, 631, 256, 128, 509	1
4 602, 4 983, 5 233, 4 858, 4 730, 5 111	2
36, 417, 667, 292, 164, 545	3
4 656, 5 037, 5 287, 4 912, 4 784, 5 165	4
48, 429, 679, 304, 176, 557	5
2 376, 2 757, 3 007, 2 632, 2 504, 2 885	6
780, 1 161, 1 411, 1 036, 908, 1 289	7
6 906, 7 287, 7 537, 7 162, 7 034, 7 415	8
4 590, 4 971, 5 221, 4 846, 4 718, 5 099	9
5 286, 4 911, 5 161, 4 786, 4 658, 5 039	10
2 364, 2 745, 2 995, 2 620, 2 492, 2 873	11
pilot	12
4 788, 5 169, 4 663, 5 044, 4 916, 4 541	13
.....	
4 194, 3 819, 4 069, 4 450, 4 322, 3 947	1 691
pilot	1 692
7 782, 8 163, 7 657, 8 038, 7 910, 8 291	1 693
6 624, 6 249, 6 499, 6 124, 6 752, 6 377	1 694
3 402, 3 027, 3 277, 3 658, 3 530, 3 155	1 695
546, 171, 421, 46, 674, 299	1 696
8 574, 8 955, 8 449, 8 830, 8 702, 8 327	1 697
8 376, 8 757, 9 007, 8 632, 8 504, 8 885	1 698
1 680, 2 061, 1 555, 1 936, 1 808, 2 189	1 699
7 620, 8 001, 8 251, 7 876, 7 748, 8 129	1 700
5 700, 5 325, 5 575, 5 956, 5 828, 5 453	1 701
8 826, 8 451, 8 701, 8 326, 8 954, 8 579	1 702
8 724, 8 349, 8 599, 8 980, 8 852, 8 477	1 703
pilot	1 704

Annex D (informative): Guidelines to implementation of the emitted signal

The present document serves to define only the *emitted signal* (which is all that needs to be standardized) and thus does not consider aspects of implementation. In particular, no mention is made of the Fast Fourier Transform (FFT) which is the expected means of generating and demodulating an OFDM signal. This informative annex explains how to avoid certain pitfalls which may be encountered when the FFT is used.

D.1 Use of the FFT

The emitted signal is unambiguously specified, for every OFDM symbol of every transmission frame, by the equations of clause 4.4. The apparent complexity of these equations can be simplified if it is noted that the waveform emitted during each transmitted symbol period depends solely on the K complex values $c_{m,l,k}$ which define the complex amplitude of the K active carriers for that period. Each symbol can thus be considered in isolation; for example, the signal for the period from $t = 0$ to $t = T_S$ is given by:

$$s(t) = \operatorname{Re} \left\{ e^{j2\pi f_C t} \sum_{k=K_{\min}}^{K_{\max}} c_{0,0,k} e^{j2\pi k'(t-\Delta)/T_U} \right\},$$

with $k' = k - (K_{\max} + K_{\min})/2$

There is a clear resemblance between this and the inverse Discrete Fourier Transform (DFT) (see note 1):

$$x_n = \frac{1}{N} \sum_{q=0}^{N-1} X_q e^{j2\pi n q/N}$$

NOTE 1: This is the definition of the *inverse* DFT in common use in the Engineering Sciences.

The corresponding *forward* DFT has $-j$ in the exponent.

Mathematicians, however, sometimes use the opposite notation, so that their forward transform has $-j$, and their inverse transform has $+j$, in the exponent.

Symbols used in this formula follow common nomenclature in engineering and mathematics.

They do not represent the symbols used elsewhere in the present document.

Since various efficient Fast Fourier Transform algorithms exist to perform the DFT and its inverse, it is a convenient form of implementation to use the inverse FFT (IFFT) in a DVB-T modulator (see note 2) to generate N samples x_n corresponding to the useful part, T_U long, of each symbol. The guard interval is added by taking copies of the last $N\Delta/T_U$ of these samples and appending them in front. This process is then repeated for each symbol in turn, producing a continuous stream of samples which constitute a complex baseband representation of the DVB-T signal. A subsequent up-conversion process then gives the real signal $s(t)$ centred on the frequency f_C .

However, care is needed in mapping the K values $c_{m,l,k}$ to the N IFFT coefficients X_q .

NOTE 2: The forward FFT may similarly be used in a demodulator.

D.2 Choice of "baseband" centre frequency

The basis function for the middle emitted carrier ($k' = 0$) is constant throughout each symbol,

$$\psi_{m,l,(K_{\max}+K_{\min})/2} = 1.$$

This carrier is therefore emitted at the centre frequency f_C and has no phase discontinuities when modulated with the same value in every symbol.

It follows that the data for this middle carrier should be mapped to an IFFT coefficient X_q of index q such that the corresponding inverse DFT basis function $e^{j2\pi nq/N}$ has a whole number of cycles within the guard interval, regardless of which of the possible guard-interval lengths (1/32, 1/16, 1/8 or 1/4 of the "useful" symbol period T_U) may be in use. The index q chosen for the middle carrier should therefore be a multiple of 32.

In particular, either of the following alternatives is recommended as they satisfy this requirement while leading to a simple implementation:

- a) assign the middle carrier to the half-way index $q = N/2$, i.e. the half-sampling-frequency term; or
- b) assign the middle carrier to index $q = 0$, i.e. the DC or zero-frequency term.

D.3 Other potential difficulties

The conversion process by which the complex baseband signal produced by the IFFT is translated to a real signal centred on the desired centre frequency similarly requires care to ensure that the result complies with the specification.

In particular:

- a) The spectrum of the emitted signal should not be inverted compared with the specification, i.e. the highest-frequency radiated carrier should convey the modulation $c_{m,l,K_{\max}}$.
- b) The emitted signal should not have an "inverted imaginary axis" compared with the specification. This would happen if, in the expression for the emitted signal $s(t)$, the $c_{m,l,k}$ were replaced by the complex-conjugate values $c_{m,l,k}^*$.

Some possible causes of such error are:

- c) Incorrect complex-to-real conversion may cause inversion of both the spectrum and the imaginary axis.
- d) Using a forward FFT instead of the inverse FFT will cause inversion of the imaginary axis.
- e) If the signal is shifted in frequency by some heterodyning process that causes inversion of the spectrum, then inversion of the imaginary axis will also occur.
If such a process is repeated, the resulting signal will comply with the specification.

If case e) occurs as a natural consequence of the choices of intermediate frequency(ies), it may be compensated for in the detail of the complex-to-real conversion, or by using a forward FFT to correct for the inversion of the imaginary axis while feeding it with the coefficients in reverse order to correct for inversion of the spectrum.

Annex E (normative): Values for 6 MHz and 7 MHz channels

The system can be scaled to 6 MHz and 7 MHz channels by changing the elementary period to $T = 7/48 \mu\text{s}$ for 6 MHz channels and $T = 1/8 \mu\text{s}$ for 7 MHz channels.

In a practical implementation this corresponds to a change of clock frequency from 64/7 MHz for 8 MHz channels to 48/7 MHz for 6 MHz channels and 8 MHz for 7 MHz channels.

The frame structure and the rules for coding, mapping and interleaving are kept. The change of elementary period results in change of the carrier spacing, the symbol length, the guard interval length and the useful bit rate as given in tables E.1 to E.6.

Table E.1: Numerical values for the OFDM parameters for the 8K and 2K modes for 6 MHz channels

Parameter	8K mode	2K mode
Number of carriers K	6 817	1 705
Value of carrier number K_{\min}	0	0
Value of carrier number K_{\max}	6 816	1 704
Duration T_U	<i>1 194,667 μs</i>	<i>298,6667 μs</i>
Carrier spacing $1/T_U$	<i>0,837054 kHz</i>	<i>3,348214 kHz</i>
Spacing between carriers K_{\min} and K_{\max} : $(K-1)/T_U$	<i>5,71 MHz</i>	<i>5,71 MHz</i>
NOTE: Values in italics are approximate values.		

Table E.2: Duration of symbol part for the allowed guard intervals for 6 MHz channels

Mode	8K mode				2K mode			
	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Guard interval Δ / T_U								
Duration of symbol part T_U	$8\,192 \times T$ <i>1 194,667 μs</i>				$2\,048 \times T$ <i>298,667 μs</i>			
Duration of guard interval Δ	$2\,048 \times T$ <i>298,667 μs</i>	$1\,024 \times T$ <i>149,333 μs</i>	$512 \times T$ <i>74,667 μs</i>	$256 \times T$ <i>37,333 μs</i>	$512 \times T$ <i>74,667 μs</i>	$256 \times T$ <i>37,333 μs</i>	$128 \times T$ <i>18,667 μs</i>	$64 \times T$ <i>9,333 μs</i>
Symbol duration $T_S = \Delta + T_U$	$10\,240 \times T$ <i>1 493,3 μs</i>	$9\,216 \times T$ <i>1 344 μs</i>	$8\,704 \times T$ <i>1 269,3 μs</i>	$8\,448 \times T$ <i>1 232 μs</i>	$2\,560 \times T$ <i>373,3 μs</i>	$2\,304 \times T$ <i>336 μs</i>	$2\,176 \times T$ <i>317,3 μs</i>	$2\,112 \times T$ <i>308 μs</i>
NOTE: Values in italics are approximate values.								

Table E.3: Useful bitrate (Mbit/s) for all combinations of guard interval, constellation and code rate for non-hierarchical systems for 6 MHz channels

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	3,732	4,147	4,391	4,524
	2/3	4,976	5,529	5,855	6,032
	3/4	5,599	6,221	6,587	6,786
	5/6	6,221	6,912	7,318	7,540
	7/8	6,532	7,257	7,684	7,917
16-QAM	1/2	7,465	8,294	8,782	9,048
	2/3	9,953	11,059	11,709	12,064
	3/4	11,197	12,441	13,173	13,572
	5/6	12,441	13,824	14,637	15,080
	7/8	13,063	14,515	15,369	15,834
64-QAM	1/2	11,197	12,441	13,173	13,572
	2/3	14,929	16,588	17,564	18,096
	3/4	16,796	18,662	19,760	20,358
	5/6	18,662	20,735	21,955	22,620
	7/8	19,595	21,772	23,053	23,751

NOTE: Figures in italics are approximate values.
 For the hierarchical schemes the useful bit rates can be obtained from table E.5 as follows:
 - HP stream: figures from QPSK columns;
 - LP stream, 16-QAM: figures from QPSK columns;
 - LP stream, 64-QAM: figures from 16-QAM columns.

Table E.4: Numerical values for the OFDM parameters for the 8K and 2K modes for 7 MHz channels

Parameter	8K mode	2K mode
Number of carriers K	6 817	1 705
Value of carrier number K_{\min}	0	0
Value of carrier number K_{\max}	6 816	1 704
Duration T_U	1 024 μ s	256 μ s
Carrier spacing $1/T_U$	0,976563 kHz	3,90625 kHz
Spacing between carriers K_{\min} and K_{\max} : $(K-1)/T_U$	6,66 MHz	6,66 MHz

NOTE: Values in italics are approximate values.

Table E.5: Duration of symbol part for the allowed guard intervals for 7 MHz channels

Mode	8K mode				2K mode			
	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Guard interval Δ / T_U	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Duration of symbol part T_U	8 192 \times T 1 024 μ s				2 048 \times T 256 μ s			
Duration of guard interval Δ	2 048 \times T 256 μ s	1 024 \times T 128 μ s	512 \times T 64 μ s	256 \times T 32 μ s	512 \times T 64 μ s	256 \times T 32 μ s	128 \times T 16 μ s	64 \times T 8 μ s
Symbol duration $T_S = \Delta + T_U$	10 240 \times T 1 280 μ s	9 216 \times T 1 152 μ s	8 704 \times T 1 088 μ s	8 448 \times T 1 056 μ s	2 560 \times T 320 μ s	2 304 \times T 288 μ s	2 176 \times T 272 μ s	2 112 \times T 264 μ s

Table E.6: Useful bitrate (Mbit/s) for all combinations of guard interval, constellation and code rate for non-hierarchical systems for 7 MHz channels

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	4,354	4,838	5,123	5,278
	2/3	5,806	6,451	6,830	7,037
	3/4	6,532	7,257	7,684	7,917
	5/6	7,257	8,064	8,538	8,797
	7/8	7,620	8,467	8,965	9,237
16-QAM	1/2	8,709	9,676	10,246	10,556
	2/3	11,612	12,902	13,661	14,075
	3/4	13,063	14,515	15,369	15,834
	5/6	14,515	16,127	17,076	17,594
	7/8	15,240	16,934	17,930	18,473
64-QAM	1/2	13,063	14,515	15,369	15,834
	2/3	17,418	19,353	20,491	21,112
	3/4	19,595	21,772	23,053	23,751
	5/6	21,772	24,191	25,614	26,390
	7/8	22,861	25,401	26,895	27,710

NOTE: Figures in italics are approximate values.
 For the hierarchical schemes the useful bit rates can be obtained from table E.6 as follows:

- HP stream: figures from QPSK columns;
- LP stream, 16-QAM: figures from QPSK columns;
- LP stream, 64-QAM: figures from 16-QAM columns.

Annex F (normative): Additional features for DVB Handheld terminals (DVB-H)

Annex F specifies features addressing only DVB Handheld terminals (DVB-H). Annex F features shall be used exclusively for DVB-H transmissions, notwithstanding that DVB-H transmissions could use DVB-T transmission modes (i.e. 2K and 8K).

The annex F scope is as follows:

- it describes an additional 4K mode providing supplementary options for DVB-H network planning;
- it describes an optional in-depth inner interleaver, usable either for the 2K or 4K transmission modes;
- it defines an extended Transmission Parameter Signalling (TPS) information to be use for signalling DVB-H services.

F.1 General Considerations

Although the DVB-T transmission system has proven its ability to serve fixed, portable and mobile terminals, Handheld terminals (defined as a light battery powered apparatus) require specific features from the transmission system serving them:

- as battery powered, the transmission system shall offer them the possibility to repeatedly power off some part of the reception chain to increase the battery usage duration,
- as targeting nomadic users, the transmission system shall ease access to the DVB-H services when receivers leave a given transmission cell and enter a new one,
- as expected to serve various situations of use (indoor and outdoor, pedestrian and inside moving vehicle), the transmission system shall offer sufficient flexibility / scalability to allow reception of DVB-H services at various speeds, while optimizing transmitter coverage,
- as DVB-H services are expected to be delivered in an environment suffering high levels of man-made noise, the transmission system shall offer the means to mitigate their effects on the receiving capabilities,
- as DVB-H aims to provide a generic way to serve handheld terminals, in various part of the world, the transmission system shall offer the flexibility to be used in various transmission bands and channel bandwidths.

These items have driven the standardization of the DVB-H system. This annex provides additional features to DVB-T to support Handheld terminals transmitting DVB-H services.

F.2 Additional features overview

As depicted in figure F.1, this annex provides the following processes variant:

- Orthogonal Frequency Division Multiplexing (OFDM) transmission: an additional 4K mode is provided with the implied reference signals and Transmission Parameter Signalling (TPS).
- Inner interleaving: a native inner interleaver for the 4K transmission mode is provided as well as an in-depth symbol interleaver to be used with the 2K or 4K modes. Also, the implied Transmission Parameter Signalling (TPS) is defined.
- Signalling information: Transmission Parameter Signalling bits are defined to signal to the receivers the use of Time-Slicing and / or MPE-FEC in the DVB-H transmission.

The additional "4K" transmission mode is an interpolation of the parameters defined for the "2K" and "8K" transmission modes. It aims to offer an additional trade-off between transmission cell size and mobile reception capabilities, providing an additional degree of flexibility for network planning.

Terms of the trade-off can be expressed as follows:

- The DVB-T "8K mode" can be used both for single transmitter operation and for small, medium and large SFNs. It provides a Doppler tolerance allowing high speed reception.
- The DVB-T "4K mode" can be used both for single transmitter operation and for small and medium SFNs. It provides a Doppler tolerance allowing very high speed reception.
- The DVB-T "2K mode" is suitable for single transmitter operation and for small SFNs with limited transmitter distances. It provides a Doppler tolerance allowing extremely high speed reception.

The additional features affect the blocks shaded in figure F.1.

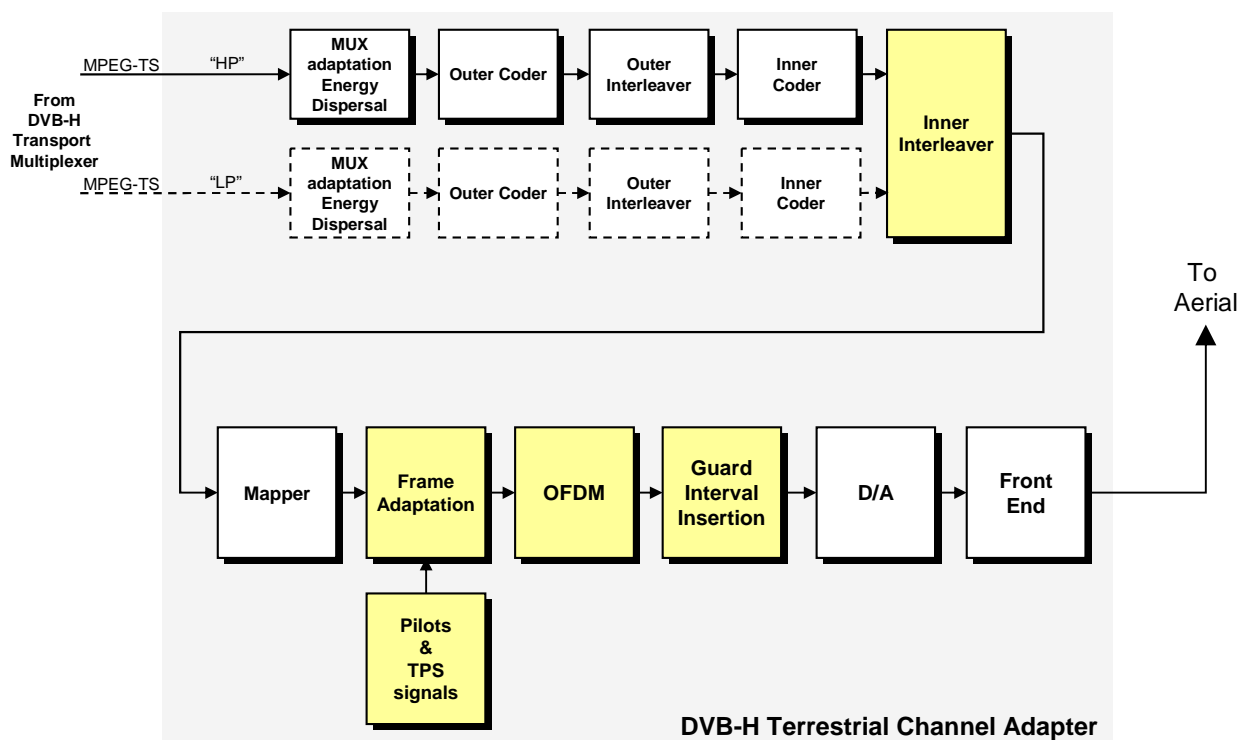


Figure F.1: Functional block diagram of the additional features

F.3 Additional baseline features

The following clauses make reference to specific normative elements in clause 4. Where a specific subsection in clause 4 is referenced, it is included in the sentence below the title.

F.3.1 Channel coding and modulation

Related to clause 4.3.

F.3.1.1 Inner interleaving

Related to clause 4.3.4.

A native inner interleaver for the "4K" mode as well as the option to use the 8K inner interleaver onto the encoded bit-flows produced for the 2K and 4K modes are specified.

As illustrated in figure F.2, this option enlarge the depth of the inner interleaving to four consecutives OFDM symbols (2K) or two consecutives OFDM symbols (4K).

When the in-depth interleaver is used, it shall be signalled within the Transmission Parameter Signalling bits defined in clause F.3.1.1.2.2.

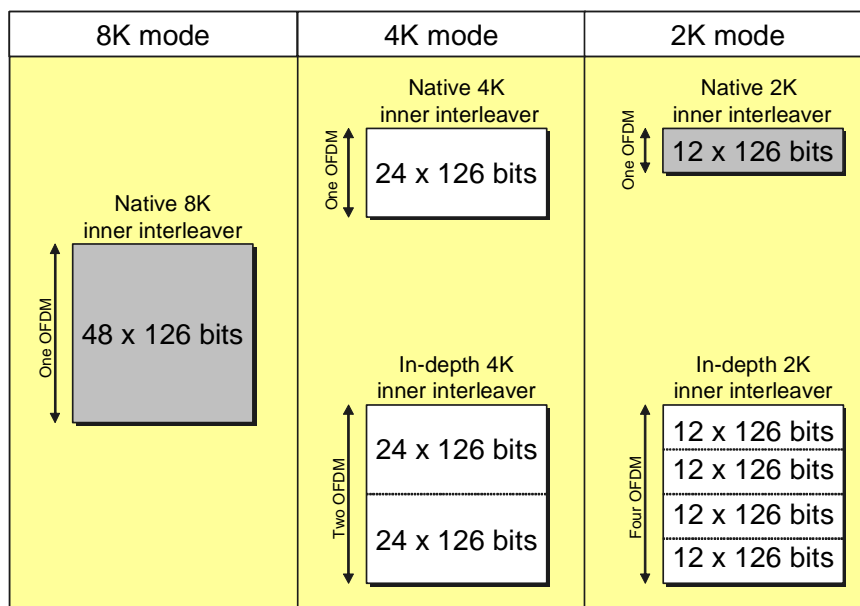


Figure F.2: In-depth inner interleaver for 2K and 4K modes

The inner interleaving consists of bit-wise interleaving followed by symbol interleaving. Both the bit-wise interleaving and the symbol interleaving processes are block-based.

F.3.1.1.1 Bit-wise interleaving

Related to clause 4.3.4.1.

The block interleaving process defined in clause 4.3.4.1, shall be repeated twenty-four times per OFDM symbol in the 4K mode.

When the in-depth interleaving is applied in the 2K or 4K modes, either hierarchical or non-hierarchical, the block interleaving process is repeated forty-eight times, thus providing the symbol interleaver with the blocks of useful data needed to produce four consecutive "2K OFDM symbols" and two consecutive "4K OFDM symbols".

F.3.1.1.2 Symbol interleaver

Related to clause 4.3.4.2.

In the 4K mode, the purpose of the symbol interleaver is to map v bit words onto the 3 024 active carriers per OFDM symbol.

F.3.1.1.2.1 Native symbol interleaver

Related to clause 4.3.4.2.1.

When the native 4K mode interleaver is implemented, the symbol interleaver acts on blocks of 3 024 data symbols.

Thus in the in the 4K mode, 24 groups of 126 data words from the bit interleaver are read sequentially into a vector $Y' = (y'_0, y'_1, y'_2, \dots, y'_{3\,023})$.

The interleaved vector $Y = (y_0, y_1, y_2, \dots, y_{N_{\max}-1})$ is defined by:

$$y_{H(q)} = y'_q \text{ for even symbols for } q = 0, \dots, N_{\max}-1$$

$$y_q = y'_{H(q)} \text{ for odd symbols for } q = 0, \dots, N_{\max}-1$$

where, in case of native interleaver, $N_{\max} = 3\,024$ in the 4K mode.

F.3.1.1.2.2 In-depth symbol interleavers

Related to clause 4.3.4.2.2.

When the in-depth interleaver is selected in the 2K mode or 4K mode contexts, the symbol interleaver acts on blocks of 6 048 data symbols, whatever the mode. Thus, a vector $Y' = (y'_0, y'_1, y'_2, \dots, y'_{6\,047})$ is assembled from 48 groups of 126 data words.

The interleaved vector $Y = (y_0, y_1, y_2, \dots, y_{N_{\max}-1})$ is defined by:

$$y_{H(q)} = y'_q \text{ for even interleaved vectors for } q = 0, \dots, N_{\max}-1$$

$$y_q = y'_{H(q)} \text{ for odd interleaved vectors for } q = 0, \dots, N_{\max}-1$$

Where, $N_{\max} = 6\,048$ always for in-depth interleavers, whatever the mode 2K or 4K.

In the 2K mode, interleaved vectors shall be mapped onto four consecutive OFDM symbols. For even interleaved vectors these shall start with symbols 0, 8, 16, 24, etc. and for odd interleaved vectors these shall start with symbols 4, 12, 20, 28, etc. in every super-frame.

In the 4K mode, interleaved vectors shall be mapped onto two consecutive OFDM symbols. For even interleaved vectors these shall start with symbols 0, 4, 8, 12, etc. and for odd interleaved vectors these shall start with symbols 2, 6, 10, 14, etc. in every super-frame.

F.3.1.1.2.3 Permutation function

Related to clause 4.3.4.2.

$H(q)$ is a permutation function defined by the following: an $(N_r - 1)$ bit binary word R'_i is defined, with $N_r = \log_2 M_{\max}$. For the 4K mode, $M_{\max} = 4\,096$ and R'_i takes the following values:

$$\begin{aligned} i = 0,1: & \quad R'_i [N_r-2, N_r-3, \dots, 1, 0] = 0, 0, \dots, 0, 0 \\ i = 2: & \quad R'_i [N_r-2, N_r-3, \dots, 1, 0] = 0, 0, \dots, 0, 1 \\ 2 < i < M_{\max}: & \quad \{ R'_i [N_r-3, N_r-4, \dots, 1, 0] = R'_{i-1} [N_r-2, N_r-3, \dots, 2, 1]; \\ & \quad \text{in the 4K mode: } R'_i [10] = R'_{i-1} [0] \oplus R'_{i-1} [2] \} \end{aligned}$$

For the 4K mode, a vector R_i is derived from the vector R'_i by the bit permutations given in table F.1.

Table F.1: Bit permutations for the 4K mode

R'_i bit positions	10	9	8	7	6	5	4	3	2	1	0
R_i bit positions	7	10	5	8	1	2	4	9	0	3	6

A schematic block diagram of the algorithm used to generate the permutation function is represented in figure F.3 for the 4K mode.

When, instead of the native mode, the in-depth interleaver is selected for the 2K or 4K modes, the permutation function defined for native 8K mode in table 3b and in figure 8b shall be used.

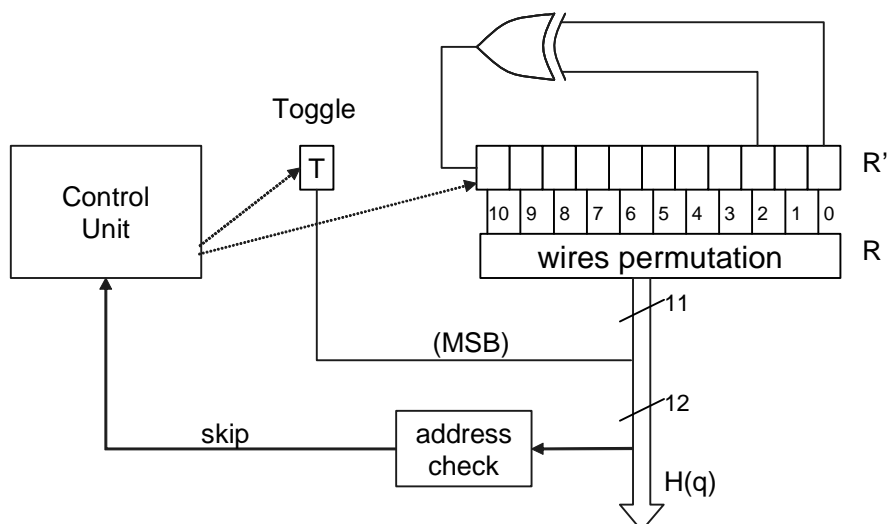


Figure F.3: Symbol interleaver address generation scheme for the 4K mode

F.3.2 OFDM frame structure

Related to clause 4.4.

For the 4K mode, each symbol is constituted by a set of $K = 3\,409$ carriers and transmitted with a duration T_S .

For the 4K mode, four values of guard intervals may be used, in relation with the channel bandwidth, according to table F.3.

For the 4K mode, the carriers are indexed by $k \in [K_{\min}; K_{\max}]$ and determined by $K_{\min} = 0$ and $K_{\max} = 3\,408$.

For the 4K mode, the numerical values for the OFDM parameters in 8 MHz, 7 MHz and 6 MHz channels are given in tables F.2 and F.3.

Table F.2: Frequency Domain parameters for 4K mode in 8 MHz, 7 MHz and 6 MHz channels

Frequency domain parameters for the 4K mode	8 MHz channel	7 MHz channel	6 MHz channel
Number of carriers K	3 409	3 409	3 409
Value of carrier number K_{\min}	0	0	0
Value of carrier number K_{\max}	3 408	3 408	3 408
Elementary period T	<i>7/64</i>	<i>7/56</i>	<i>7/48</i>
Duration T_U	448 μ s	512 μ s	597,333 μ s
Carrier spacing $1 / T_U$	<i>2 232,143 Hz</i>	<i>1 953,125 Hz</i>	<i>1 674,107 Hz</i>
Spacing between carriers K_{\min} and K_{\max} $(K - 1) / T_U$	<i>7,61 MHz</i>	<i>6,66 MHz</i>	<i>5,71 MHz</i>
NOTE: Values in italics are approximate values.			

Table F.3: Time Domain parameters for 4K mode in 8 MHz, 7 MHz and 6 MHz channels

Time domain parameters for the 4K mode	8 MHz channel				7 MHz channel				6 MHz channel			
Useful symbol part T_u	4 096 T 448 μ s				4 096 T 512 μ s				4 096 T 597,333 μ s			
Guard interval part Δ / T_u	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Guard interval duration T_g	1 024 T 112 μ s	512 T 56 μ s	256 T 28 μ s	128 T 14 μ s	1 024 T 128 μ s	512 T 64 μ s	256 T 32 μ s	128 T 16 μ s	1 024 T 149,33 μ s	512 T 74,67 μ s	256 T 37,33 μ s	128 T 18,67 μ s
Total symbol duration $T_S = \Delta + T_u$	5 120 T 560 μ s	4 608 T 504 μ s	4 352 T 476 μ s	4 224 T 462 μ s	5 120 T 640 μ s	4 608 T 576 μ s	4 352 T 544 μ s	4 224 T 528 μ s	5 120 T 746,67 μ s	4 608 T 672,00 μ s	4 352 T 634,67 μ s	4 224 T 616,00 μ s

F.3.3 Reference signals

Related to clause 4.5.

For the 4K mode, the number of useful data carriers, constant from symbol to symbol, shall be 3 024 useful carriers.

F.3.3.1 Location of continual pilot carriers

Related to clause 4.5.4.

For the 4K mode, 89 continual pilots (where "continual" means that they occur on all symbols) shall be inserted according to table F.4.

Table F.4: Carrier indices for continual pilot carriers

Continual pilots carrier positions for 4K mode (index number k)											
0	48	54	87	141	156	192	201	255	279	282	333
432	450	483	525	531	618	636	714	759	765	780	804
873	888	918	939	942	969	984	1 050	1 101	1 107	1 110	1 137
1 140	1 146	1 206	1 269	1 323	1 377	1 491	1 683	1 704	1 752	1 758	1 791
1 845	1 860	1 896	1 905	1 959	1 983	1 986	2 037	2 136	2 154	2 187	2 229
2 235	2 322	2 340	2 418	2 463	2 469	2 484	2 508	2 577	2 592	2 622	2 643
2 646	2 673	2 688	2 754	2 805	2 811	2 814	2 841	2 844	2 850	2 910	2 973
3 027	3 081	3 195	3 387	3 408							

F.3.4 Transmission Parameter Signalling (TPS)

Related to clause 4.6.

For the 4K Mode, the TPS shall be transmitted in parallel on 34 TPS carriers and shall be carried on the carrier having the indices presented in table F.5.

Table F.5: Carrier indices for TPS carriers in 4K mode

TPS carrier indices for 4K mode											
34	50	209	346	413	569	595	688	790	901	1 073	1 219
1 262	1 286	1 469	1 594	1 687	1 738	1 754	1 913	2 050	2 117	2 273	2 299
2 392	2 494	2 605	2 777	2 923	2 966	2 990	3 173	3 298	3 391		

F.3.4.1 Scope of the TPS

Related to clause 4.6.1.

When DVB-H signalling is performed, of the 37 information bits, 33 are used. The remaining 4 bits shall be set to zero.

F.3.4.2 TPS transmission format

Related to clause 4.6.2.

Options covering 4K, in-depth inner interleaver, time-slicing and MPE-FEC bits for DVB-H signalling are specified in this annex. The definitions for the other signalling bits are given in the clause 4.6.2.

The mapping of each of the transmission parameters related to Cell identifier and DVB-H signalling onto the bit combinations shall be performed according to clauses 4.6.2.10 and F.3.4.2.4 respectively and shall be transmitted as shown in table F.6.

Table F.6: TPS signalling information and format

Bit number	Format	Purpose/Content
S ₁₇ - S ₂₂	see clause F.3.4.2.1	Length indicator
S ₂₇ , S ₂₈ , S ₂₉	see clause F.3.4.2.2	Hierarchy information
S ₃₈ , S ₃₉	see clause F.3.4.2.3	Transmission mode
S ₄₈ , S ₄₉	see clause F.3.4.2.4	DVB-H signalling
S ₅₀ - S ₅₃	all set to "0"	Reserved for future use

F.3.4.2.1 TPS length indicator

Related to clause 4.6.2.3.

When DVB-H signalling (see clause F.3.4.2.4) is in use, valid Cell Identification information shall be transmitted and the value of the TPS length indicator shall be set to "100001" (33 TPS bits in use).

F.3.4.2.2 Hierarchy and Interleaving information

Related to clause 4.6.2.6.

Bits S₂₇, S₂₈ and S₂₉ shall be used to signal if the in-depth interleaver is in use and if the transmission is hierarchical.

The use of the in-depth interleaver for 2K or 4K transmission mode, as defined in clause F.3.1.1, shall be signalled using bit S₂₇ as indicated in table F.7. When an 8K signal is transmitted only the native interleaver shall be used.

Table F.7: Signalling format for in-depth inner interleaver

Bit s ₂₇	In-depth inner interleaver information
0	native interleaver
1	in-depth interleaver

The QAM constellation diagrams, which correspond to the various α values, are specified in clause 4.3.5 and depicted in figure 9a/b/c. Hierarchical transmission and, if so, the value of the α factor shall be signalled, using bits S₂₈ and S₂₉, in compliance with table F.8.

Table F.8: Signalling format for Hierarchy information

Bits s ₂₈ , s ₂₉	Hierarchy information
00	Non hierarchical
01	$\alpha = 1$
10	$\alpha = 2$
11	$\alpha = 4$

F.3.4.2.3 Transmission mode

Related to clause 4.6.2.9.

The transmission mode shall be signalled according to table F.9.

Table F.9: Signalling format for transmission mode

Bits s ₃₈ , s ₃₉	Transmission mode
00	2K mode
01	8K mode
10	4K mode
11	reserved

F.3.4.2.4 DVB-H signalling

Related to clause 4.6.2.11.

Bits s_{48} and s_{49} shall be used to indicate to the receivers the transmission of DVB-H services in compliance with table F.10.

In case of Hierarchical transmission, the signification of bits s_{48} and s_{49} varies with the parity of the OFDM frame transmitted, as follows:

- When received during OFDM frame number 1 and 3 of each super frame, DVB-H signalling shall be interpreted as in relation with the High Priority stream (HP) and in compliance with table F.10.
- When received during OFDM frame number 2 and 4 of each super frame, DVB-H signalling shall be interpreted in relation with the Low Priority stream (LP) in compliance with table F.10.

In case of non-Hierarchical transmission, every frame in the super-frame carries the same information, which shall be interpreted in compliance with table F.10.

Table F.10: DVB-H service indication

s_{48}	s_{49}	DVB-H signalling
0	x	Time Slicing is not used
1	x	At least one elementary stream uses Time Slicing
x	0	MPE-FEC not used
x	1	At least one elementary stream uses MPE-FEC
NOTE: "x" means whatever bit state.		

F.3.5 Transmission Capacities

Related to clause 4.7.

F.3.5.1 Number of RS-packets per Super Frame

Related to clause 4.7.1.

For the 4K mode, the number of RS-packets per super-frame is given in table F.11.

Table F.11: Number of Reed-Solomon 204 bytes packets per OFDM super-frame for all combinations of code rates and modulation forms

Code rate	QPSK			16-QAM			64-QAM		
	2K mode	4K mode	8K mode	2K mode	4K mode	8K mode	2K mode	4K mode	8K mode
1/2	252	504	1 008	504	1 008	2 016	756	1 512	3 024
2/3	336	672	1 344	672	1 344	2 688	1 008	2 016	4 032
3/4	378	756	1 512	756	1 512	3 024	1 134	2 268	4 536
5/6	420	840	1 680	840	1 680	3 360	1 260	2 520	5 040
7/8	441	882	1 764	882	1 764	3 528	1 323	2 646	5 292

F.3.5.2 Useful Bitrate

Related to clause 4.7.2.

Useful bitrates are given for the 4K mode in the following tables and cover the 8 MHz, 7 MHz and 6 MHz channels.

In the following tables, the values in italics are approximate values for the given channel bandwidth.

For the hierarchical transmission schemes the useful bit rates can be obtained as follows:

- HP stream: values from QPSK columns;
- LP stream, 16-QAM: figures from QPSK columns;
- LP stream, 64-QAM: figures from 16-QAM columns.

Table F.12: Useful bitrate (Mbit/s) for non-hierarchical systems in 8 MHz channels

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	4,98	5,53	5,85	6,03
	2/3	6,64	7,37	7,81	8,04
	3/4	7,46	8,29	8,78	9,05
	5/6	8,29	9,22	9,76	10,05
	7/8	8,71	9,68	10,25	10,56
16-QAM	1/2	9,95	11,06	11,71	12,06
	2/3	13,27	14,75	15,61	16,09
	3/4	14,93	16,59	17,56	18,10
	5/6	16,59	18,43	19,52	20,11
	7/8	17,42	19,35	20,49	21,11
64-QAM	1/2	14,93	16,59	17,56	18,10
	2/3	19,91	22,12	23,42	24,13
	3/4	22,39	24,88	26,35	27,14
	5/6	24,88	27,65	29,27	30,16
	7/8	26,13	29,03	30,74	31,67

Table F.13: Useful bitrate (Mbit/s) for non-hierarchical systems in 7 MHz channels

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	4,354	4,838	5,123	5,278
	2/3	5,806	6,451	6,830	7,037
	3/4	6,532	7,257	7,684	7,917
	5/6	7,257	8,064	8,538	8,797
	7/8	7,620	8,467	8,965	9,237
16-QAM	1/2	8,709	9,676	10,246	10,556
	2/3	11,612	12,902	13,661	14,075
	3/4	13,063	14,515	15,369	15,834
	5/6	14,515	16,127	17,076	17,594
	7/8	15,240	16,934	17,930	18,473
64-QAM	1/2	13,063	14,515	15,369	15,834
	2/3	17,418	19,353	20,491	21,112
	3/4	19,595	21,772	23,053	23,751
	5/6	21,772	24,191	25,614	26,390
	7/8	22,861	25,401	26,895	27,710

Table F.14: Useful bitrate (Mbit/s) for non-hierarchical systems for 6 MHz channels

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	3,732	4,147	4,391	4,524
	2/3	4,976	5,529	5,855	6,032
	3/4	5,599	6,221	6,587	6,786
	5/6	6,221	6,912	7,318	7,540
	7/8	6,532	7,257	7,684	7,917
16-QAM	1/2	7,465	8,294	8,782	9,048
	2/3	9,953	11,059	11,709	12,064
	3/4	11,197	12,441	13,173	13,572
	5/6	12,441	13,824	14,637	15,080
	7/8	13,063	14,515	15,369	15,834
64-QAM	1/2	11,197	12,441	13,173	13,572
	2/3	14,929	16,588	17,564	18,096
	3/4	16,796	18,662	19,760	20,358
	5/6	18,662	20,735	21,955	22,620
	7/8	19,595	21,772	23,053	23,751

F.3.6 Spectrum characteristics and spectrum mask

Related to clause 4.8.

F.3.6.1 Spectrum characteristics

Related to clause 4.8.1.

The spectral density is not constant within the nominal bandwidth of approximately 7,609 375 MHz for the 4K mode.

A theoretical DVB transmission signal spectrum is illustrated in figure F.4 (for 8 MHz channels).

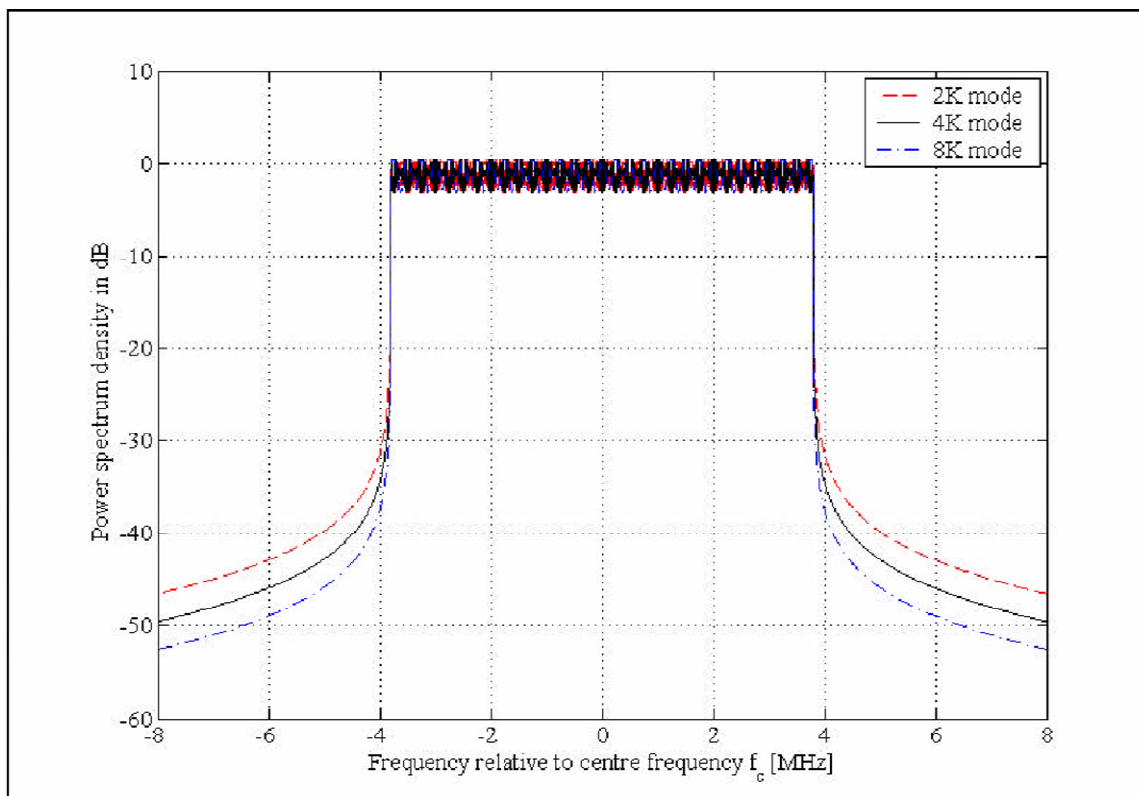


Figure F.4: Theoretical DVB transmission signal spectrum for guard interval $\Delta = T_u / 4$ (for 8 MHz channels)

Annex G (normative):

5 MHz channel bandwidth operation

The OFDM system presented in the present document is specified for use in 8 MHz, 7 MHz and 6 MHz channel spacing. Nevertheless, in some parts of the world, it could be wished to use it with other channel bandwidth in non-broadcasting frequency bands.

As far as the RF transmission chain is concerned, precaution and additional studies shall be performed to define proper spectrum masks (in-band and out-of-band) for the emitted signal, as the tuner characteristics for the receiver (sensitivity, phase noise, etc.).

As far as the base-band processing is concerned, the transmission system can be tailored changing only the parameter *elementary period T*, which is unique for each given channel bandwidth. From an implementation point of view the elementary period T can normally be seen as the inverse of the nominal system clock rate. By adjusting the system clock rate the bandwidth and the transmission capacity are modified accordingly.

For 5 MHz channel operation the parameters and figures given here-after shall be used.

Table G.1: Frequency domain Parameters for 5 MHz channel

Frequency domain parameters for the 4K mode	8K mode	4K mode	2K mode
Number of carriers K	6 817	3 409	1 705
Value of carrier number K_{\min}	0	0	0
Value of carrier number K_{\max}	6 816	3 408	1 704
Elementary period T	<i>7/40</i>	<i>7/40</i>	<i>7/40</i>
Duration T_u	1 433,60 μ s	716,80 μ s	358,40 μ s
Carrier spacing $1 / T_u$	<i>697,545 Hz</i>	<i>1 395,089 Hz</i>	<i>2 790,179 Hz</i>
Spacing between carriers K_{\min} and K_{\max} $(K - 1) / T_u$	<i>4,75 MHz</i>	<i>4,75 MHz</i>	<i>4,75 MHz</i>
NOTE: Values in italics are approximate values.			

Table G.2: Time domain Parameters for 5 MHz channel

Time domain parameters for the 4K mode	8K mode				4K mode				2K mode			
Useful symbol part T_U	8 192 T 1 433,60 μ s				4 096 T 716,80 μ s				2 048 T 358,40 μ s			
Guard interval part Δ / T_U	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Guard interval duration T_g	2 048 T 358,40 μ s	1 024 T 179,20 μ s	512 T 89,60 μ s	256 T 44,80 μ s	1 024 T 179,20 μ s	512 T 89,60 μ s	256 T 44,80 μ s	128 T 22,40 μ s	512 T 89,60 μ s	256 T 44,80 μ s	128 T 22,40 μ s	64 T 11,20 μ s
Total symbol duration $T_S = \Delta + T_U$	10 240 T 1 792,00 μ s	9 216 T 1 612,80 μ s	8 704 T 1 523,20 μ s	8 448 T 1 478,40 μ s	5 120 T 896,00 μ s	4 608 T 806,40 μ s	4 352 T 761,60 μ s	4 224 T 739,20 μ s	2 560 T 448,00 μ s	2 304 T 403,20 μ s	2 176 T 380,80 μ s	2 112 T 369,60 μ s

From the Time Domain parameters presented in table G.2, it appears that operating the transmission system in 5 MHz channels provides slightly longer symbol duration (i.e.: in the ratio 8/5) than in traditional broadcast channel bandwidths. As the guard interval duration is also increased, it will allow the transmission system to have an augmented robustness to long delay echoes, meaning the possibility to deploy wider transmission cells (if compared with traditional broadcast channels from each given mode 2K, 4K, 8K).

The Frequency Domain parameters presented in table G.1, highlights an inter-carrier spacing slightly smaller, for each given mode, than that offered by the traditional broadcast channel bandwidths. Accordingly, the robustness of the transmission system against Doppler effects, occurring while receiving the signal in motion, will be slightly worse than in broadcast channels bandwidths. This will probably limit the ability to receive the signal at very high speed.

The non-hierarchical transmission capacity offered by the system operated in 5 MHz channel bandwidth is given in table G.3.

For the hierarchical transmission schemes the useful bit rates can be obtained as follows:

- HP stream: values from QPSK columns;
- LP stream, 16-QAM: figures from QPSK columns;
- LP stream, 64-QAM: figures from 16-QAM columns.

Table G.3: Useful bitrate (Mbit/s) for non-hierarchical systems in 5 MHz channel

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	3,110	3,456	3,659	3,770
	2/3	4,147	4,608	4,879	5,027
	3/4	4,665	5,184	5,489	5,655
	5/6	5,184	5,760	6,099	6,283
	7/8	5,443	6,048	6,404	6,598
16-QAM	1/2	6,221	6,912	7,318	7,540
	2/3	8,294	9,216	9,758	10,053
	3/4	9,331	10,368	10,978	11,310
	5/6	10,368	11,520	12,197	12,567
	7/8	10,886	12,096	12,807	13,195
64-QAM	1/2	9,331	10,368	10,978	11,310
	2/3	12,441	13,824	14,637	15,080
	3/4	13,996	15,551	16,466	16,965
	5/6	15,551	17,279	18,296	18,850
	7/8	16,329	18,143	19,211	19,793

Spectrum efficiency of the transmission system remaining unaltered by the modification of the channel bandwidth, the useful bitrate offered by the system is slightly less than in traditional broadcast channel bandwidths.

But as the system offers an absolute duration of symbol slightly larger, the smallest guard interval values can be selected without limiting the transmission performance while providing usability of the higher bitrate ranges.

History

Document history		
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V1.2.1	July 1999	Publication
V1.4.1	January 2001	Publication
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V1.6.1	September 2008	One-step Approval Procedure OAP 20090122: 2008-09-24 to 2009-01-22
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