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European Broadcasting Union — Union Européenne de Radio-Télévision

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

ETSI

European Telecommunications Standards Institute

ETSI Secretariat

Postal address: F-06921 Sophia Antipolis CEDEX - FRANCE
Office address: 650 Route des Lucioles - Sophia Antipolis - Valbonne - FRANCE
X.400: c=fr, a=atlas, p=etsi, s=secretariat - **Internet:** secretariat@etsi.fr

Tel.: +33 4 92 94 42 00 - Fax: +33 4 93 65 47 16

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Foreword

This final draft European Telecommunication Standard (ETS) has been produced by the Joint Technical Committee (JTC) of the European Broadcasting Union (EBU), Comité Européen de Normalisation ELECtrotechnique (CENELEC) and the European Telecommunications Standards Institute (ETSI), and is now submitted for the Voting phase of the ETSI standards approval procedure.

NOTE: The JTC was established in 1990 to co-ordinate the drafting of ETSs in the specific field of broadcasting and related fields. Since 1995 the JTC 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 organisations 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 *.

* European Broadcasting Union
Case Postale 67
CH-1218 GRAND SACONNEX (Geneva)
Switzerland

Tel: +41 22 717 21 11
Fax: +41 22 717 24 81

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Date of latest publication of new National Standard or endorsement of this ETS (dop/e):	6 months after doa
Date of withdrawal of any conflicting National Standard (dow):	6 months after doa

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1 Scope

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

The scope of the specification 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.

2 Normative references

This ETS incorporates by dated and undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this ETS only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

[1] ISO/IEC 13 818 Part 1, 2 , 3 (November 1994): "Coding of moving pictures and associated audio".

[2] ETS 300 421: "Digital broadcasting systems for television, sound and data services; framing structure, channel coding and modulation for 11/12 GHz satellite services".

[3] ETS 300 429: "Digital broadcasting systems for television, sound and data services. Framing structure, channel coding and modulation for cable systems".

3 Symbols, abbreviations and definition

3.1 Symbols

For the purposes of this ETS, 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 steam e
$b_{e,do}$	output bit number do of demultiplexed bit stream number e of the inner interleaver demultiplexer
$c_{m,l,k}$	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
I0,I1,I2,I3,I4,I5	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 di to the inner interleaver demultiplexer
x'_{di}	High priority input bit number di to the inner interleaver demultiplexer
x''_{di}	Low priority input bit number di 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

3.2 Abbreviations

For the purposes of this ETS, the following abbreviations apply:

ACI	Adjacent Channel Interference
AFC	Automatic Frequency Control
BCH	Bose - Chaudhuri - Hocquenghem code
BER	Bit Error Ratio
D/A	Digital-to-Analogue converter
DBPSK	Differential Binary Phase Shift Keying
DVB	Digital Video Broadcasting
DVB-T	DVB-Terrestrial
EDTV	Enhanced Definition Television
ETS	European Telecommunication Standard
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FIFO	First-In, First-Out shift register
HDTV	High Definition Television
HEX	Hexadecimal notation
HP	High Priority bit stream
IF	Intermediate Frequency
LDTV	Limited Definition Television
LO	Local Oscillator
LP	Low Priority bit stream
LSB	Least Significant Bit
MPEG	Moving Picture Experts Group
MSB	Most Significant Bit
MUX	Multiplex
NICAM	Near-Instantaneous companded Audio Multiplex
OCT	Octal notation
OFDM	Orthogonal Frequency Division Multiplexing
PAL	Phase Alternating Line
PCR	Program Clock Reference
PID	Program Identifier
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 Sequentiel Couleur A Mémoire
SFN	Single Frequency Network
TPS	Transmission Parameter Signalling
TV	Television
UHF	Ultra-High Frequency
VHF	Very-High Frequency

3.3 Definition

For the purposes of this ETS, the following definition applies:

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

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 figure 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;
- mapping and modulation;
- OFDM transmission.

The system is directly compatible with MPEG-2 coded TV signals ISO/IEC 13 818 [1].

Since the system is being designed for digital terrestrial television services to operate within the existing 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 services. It is also a requirement that the System allows the maximum spectrum efficiency when used within the UHF bands; this requirement can be achieved by utilising Single Frequency Network (SFN) operation.

NOTE: I.e. 8 MHz channel spacing. An adaptation of this specification for 7 MHz channels can be achieved by scaling down all system parameters according to a change of the system clock rate from 64/7 MHz to exactly 8,0 MHz. The frame structure and the rules for coding, mapping and interleaving are kept, only the data capacity of the system is reduced by a factor 7/8 due to the respective reduction of signal bandwidth.

To achieve these requirements an OFDM system with concatenated error correcting coding is being specified. To maximise commonality with the Satellite baseline specification (see ETS 300 421 [2]) and Cable baseline specifications (see ETS 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 are defined: a "2k mode" and an "8k mode". 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.

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. The splitter separates the incoming transport stream into two independent MPEG transport streams, referred to as the high-priority and the low-priority stream. These two bitstreams are mapped onto the signal constellation by the Mapper and 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 s, audio interruption for approximately 0,2 s) while the inner decoder and the various source decoders are suitably reconfigured and reacquire lock.

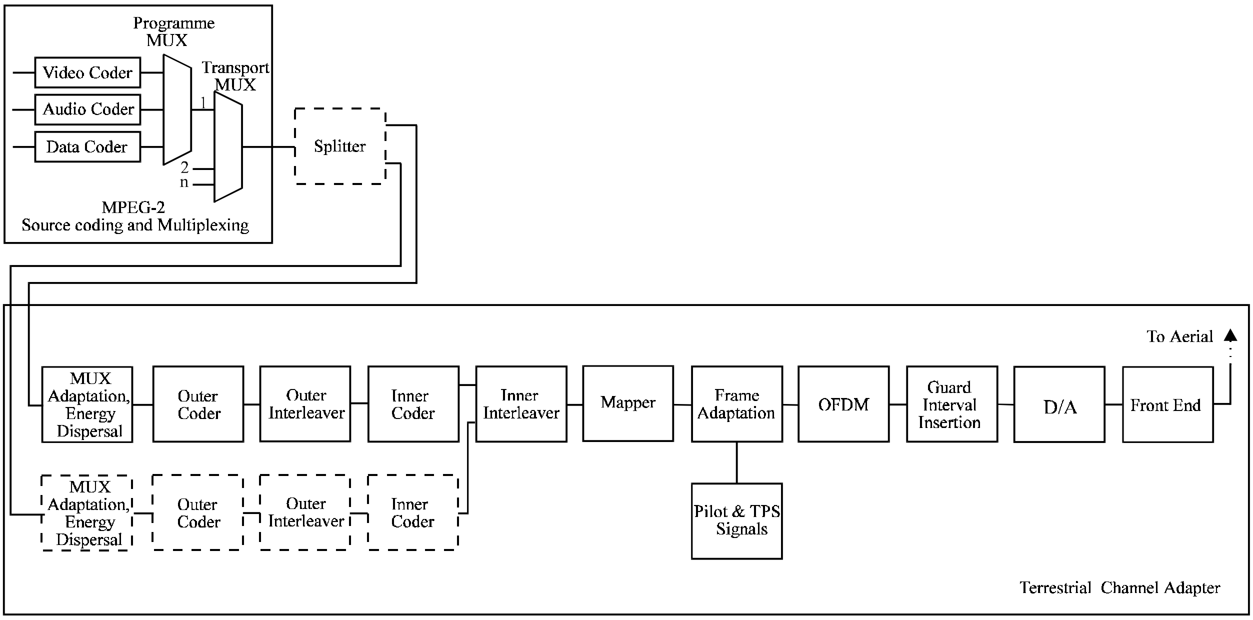


Figure 1: Functional block diagram of the System

4.2 Interfacing

The Baseline System as defined in this specification 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 organised 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 randomised in accordance with the configurations depicted in figure 2.

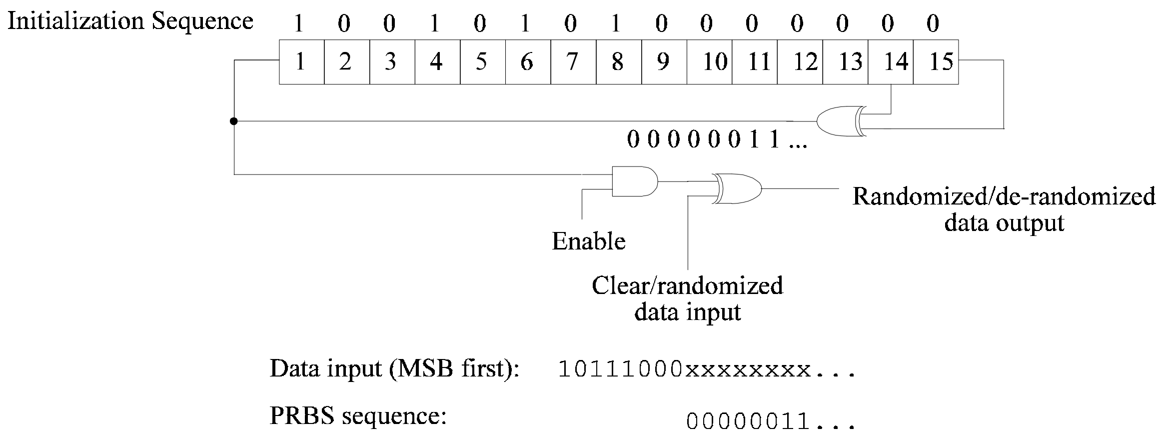


Figure 2: Scrambler/Descrambler schematic diagram

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 ETS 300 421 [2]. Elsewhere, in both the Satellite baseline specification and in this specification, 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 $B8_{HEX}$ ($\overline{\text{SYNC}}$). 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), derived from the original systematic RS (255,239, t = 8) code, shall be applied to each randomised 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: $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)...(x+\lambda^{15})$, where $\lambda = 02_{HEX}$

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 × 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 synchronised.

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 synchronisation can be carried out by routing the first recognised sync (SYNC or $\overline{\text{SYNC}}$) byte in the "0" branch.

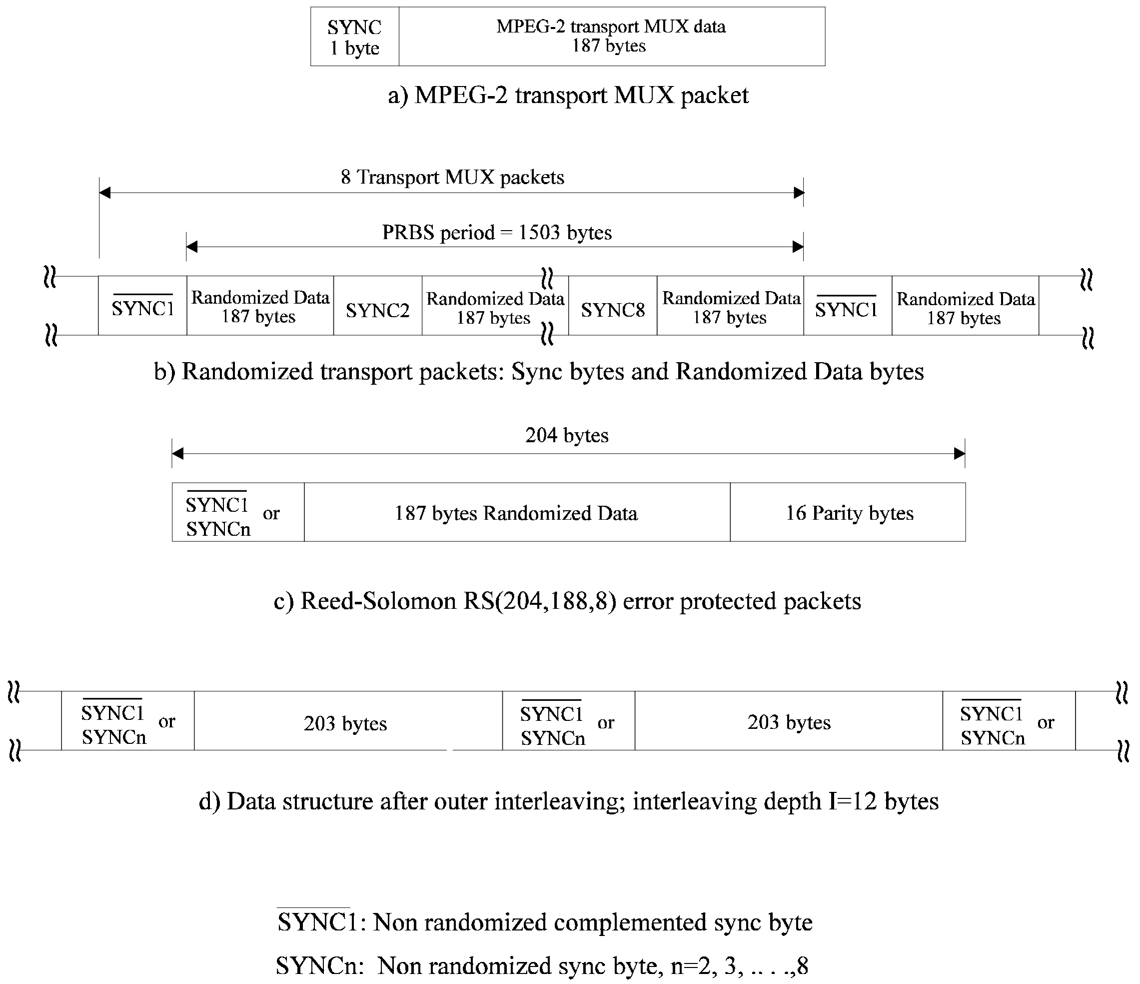


Figure 3: Steps in the process of adaptation, energy dispersal, outer coding and interleaving

$\overline{\text{SYNC1}}$ is the non randomised complemented sync byte and SYNCn is the non randomised sync byte, n = 2,3,..,8

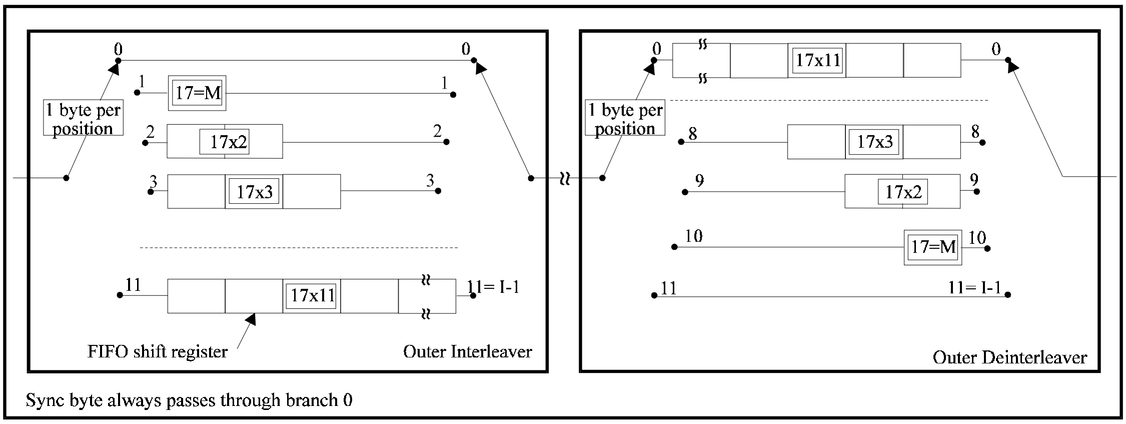


Figure 4: Conceptual diagram of the outer interleaver and deinterleaver

4.3.3 Inner coding

The system shall allow for a range of punctured convolutional codes, based on a mother convolutional code of rate ½ 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 $G_1 = 171_{OCT}$ for X output and $G_2 = 133_{OCT}$ 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 ½ 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 below. 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 subclause 4.4.

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

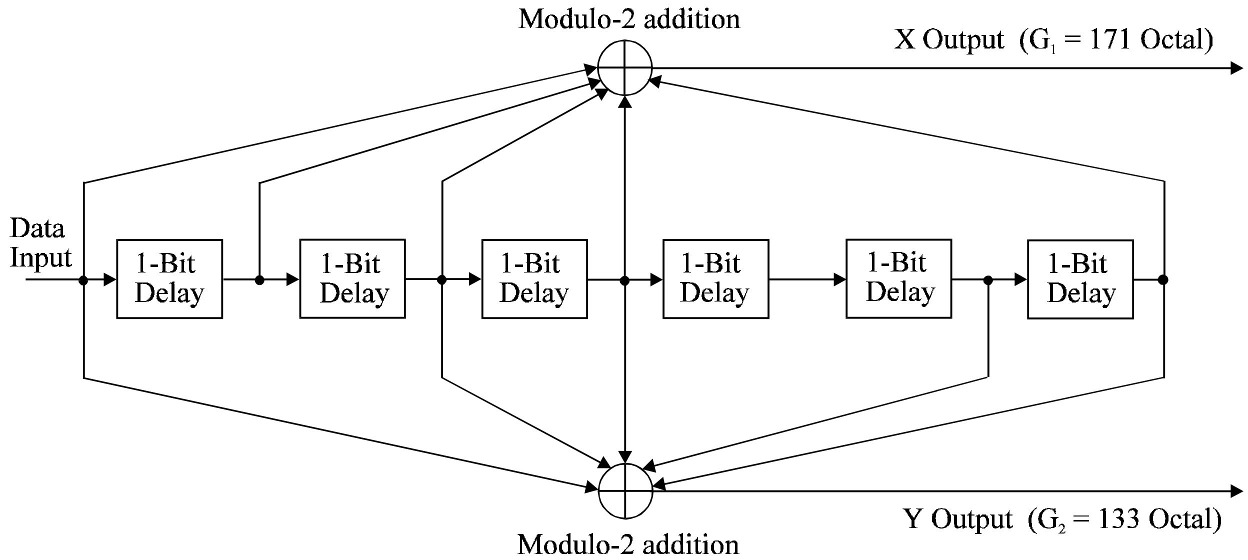


Figure 5: The mother convolutional code of rate ½

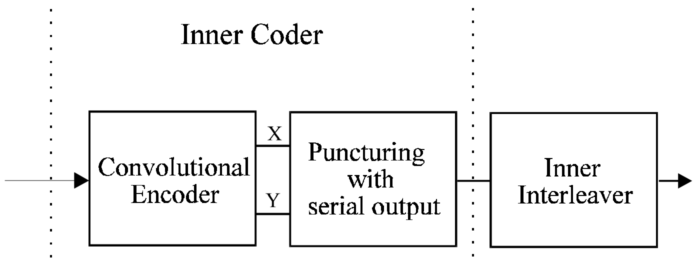


Figure 6: Inner coding and interleaving

4.3.4 Inner interleaving

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.

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:

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

In hierarchical mode:

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

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

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 ($0 \le e < v$),

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 $b_{5,0}$

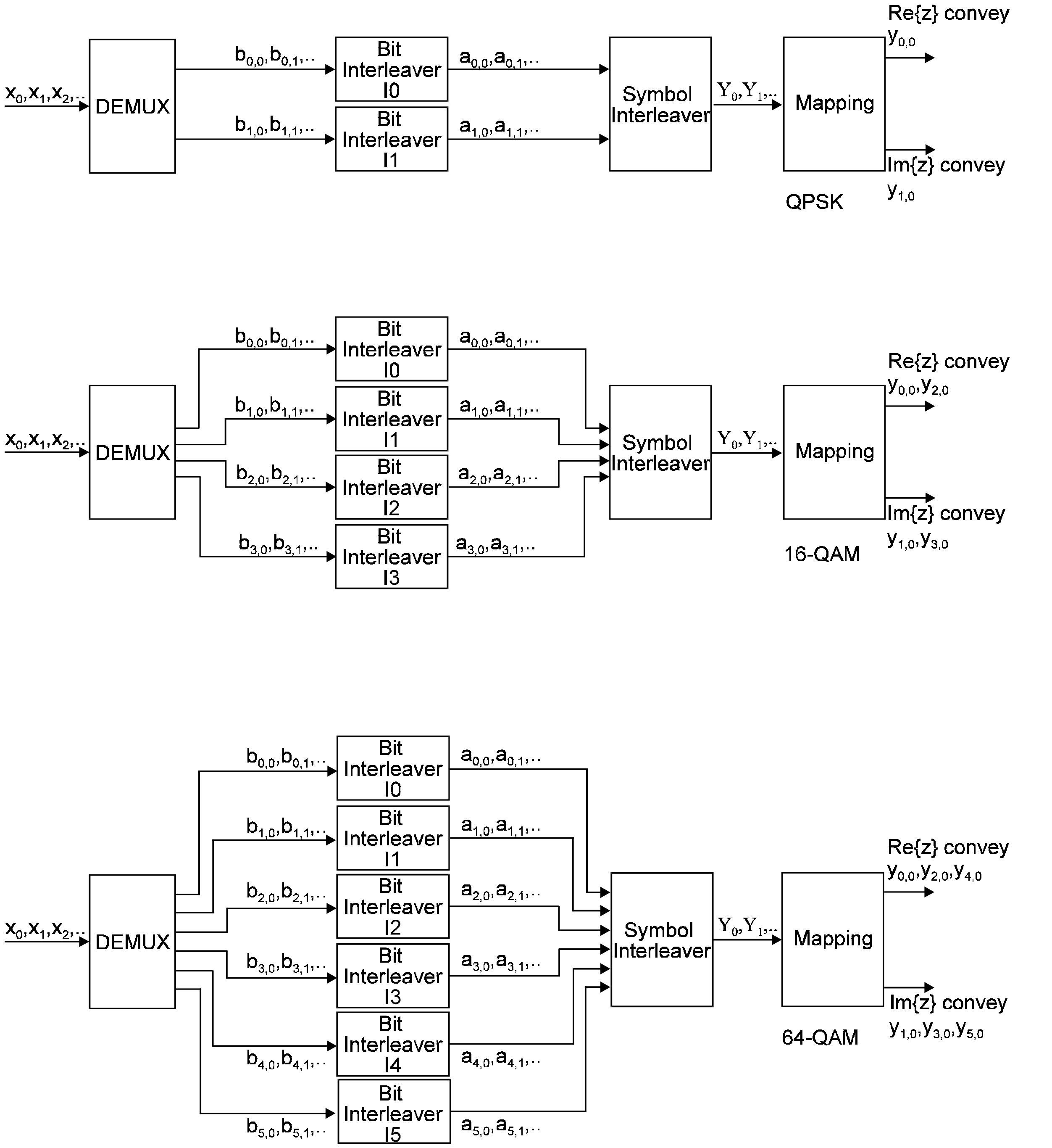


Figure 7a: Mapping of input bits onto output modulation symbols, for non-hierarchical transmission modes

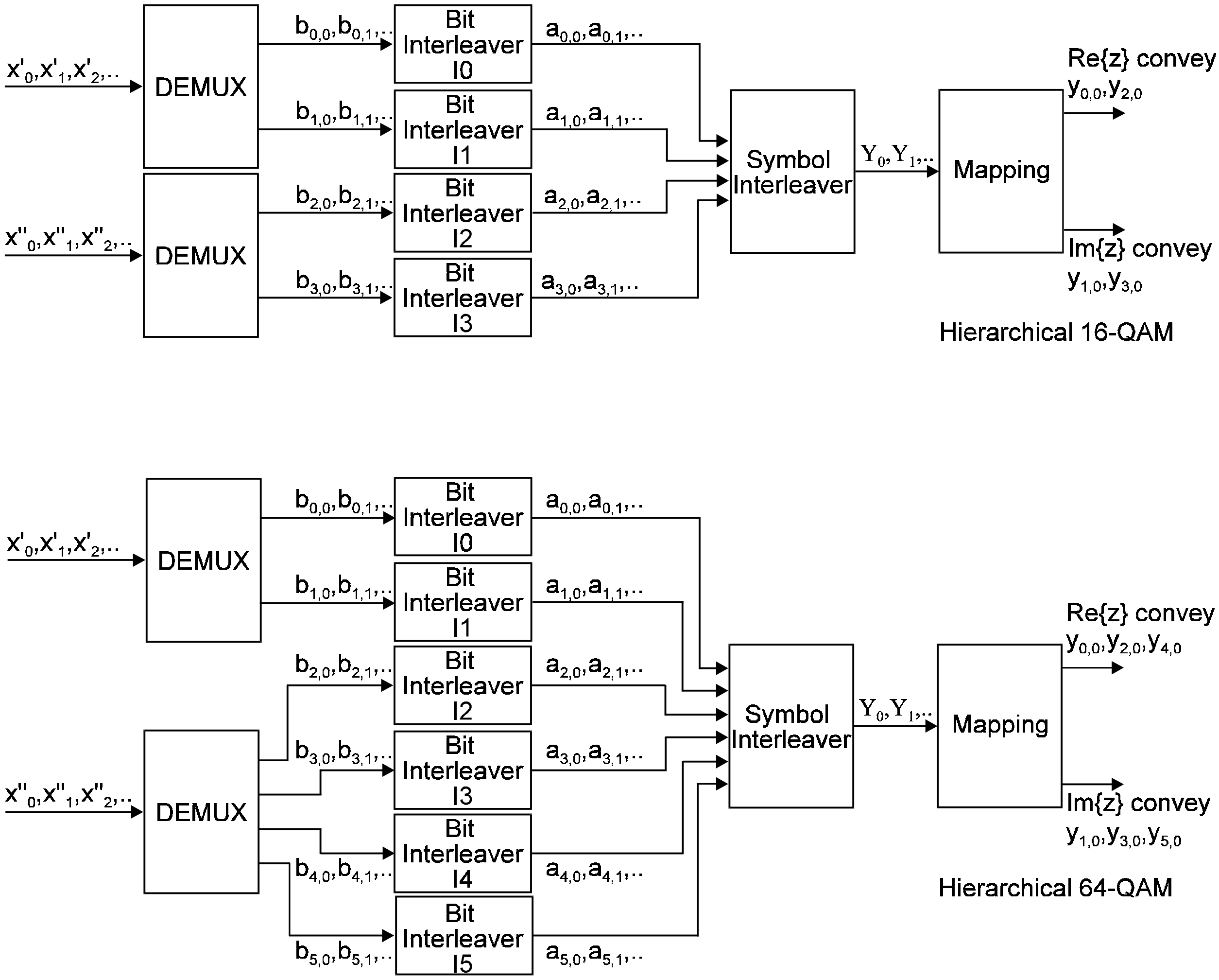


Figure 7b: Mapping of input bits onto output modulation symbols, for hierarchical transmission modes

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.

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

$B(e) = (b_{e,0}, b_{e,1}, b_{e,2}, ..., b_{e,125})$ where e ranges from 0 to v-1

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

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

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.:

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

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 $Y' = (y'_0, y'_1, y'_2, ...y'_{1511})$. Similarly in the 8k mode, a vector $Y' = (y'_0, y'_1, y'_2, ...y'_{6047})$ is assembled from 48 groups of 126 data words.

The interleaved vector $Y = (y_0, y_1, y_2, ...y_{Nmax-1})$ is defined by:

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

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

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 subclause 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: $R'_i [N_r-2, N_r-3,...,1,0] = 0,0,...,0,0$

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

$2<i<N_{max}$: { $R'_i [N_r-3, N_r-4,...,1,0] = R'_{i-1} [N_r -2, N_r -3,...,2,1]$;

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

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:

for q = 0;

for (i = 0; i < M_{max}; i = i + 1);

$$\{\ H(q) = (i \bmod 2) \cdot 2^{N_r-1} + \sum_{j=0}^{N_r-2} R_i(j) \cdot 2^j$$

if (H(q)<N_{max}) then q = q+1 }

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.

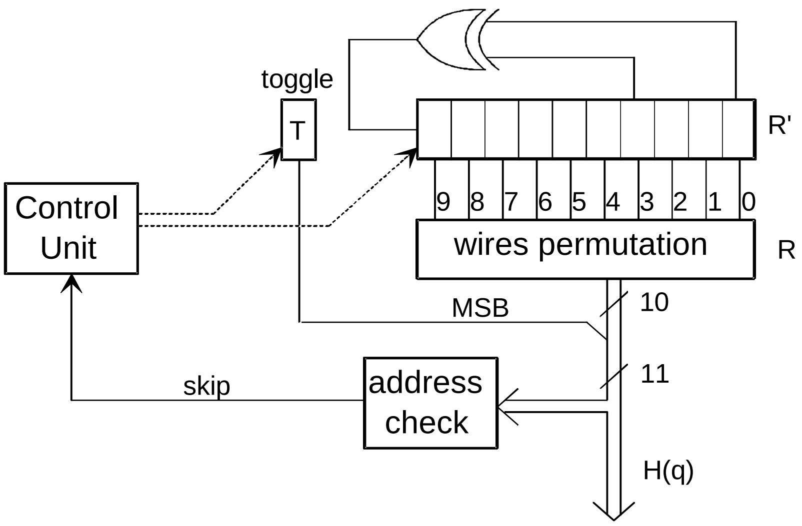


Figure 8a: Symbol interleaver address generation scheme for the 2k mode

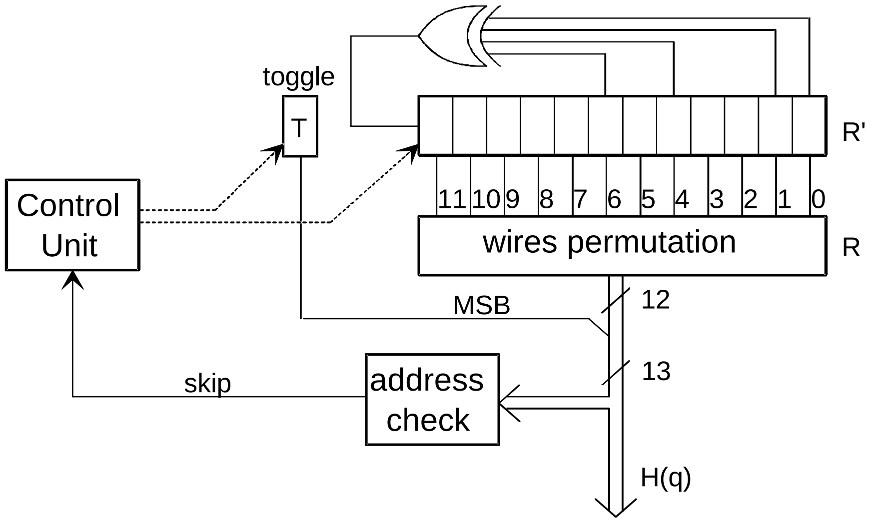


Figure 8b: Symbol interleaver address generation scheme for the 8K mode

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

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

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 subclause 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 either QPSK, 16-QAM, 64-QAM, non-uniform-16-QAM or non-uniform-64-QAM using Gray mapping.

Gray mapping is applied according to the following method for QPSK, 16-QAM and 64-QAM. The mapping shall be performed according to figure 9.

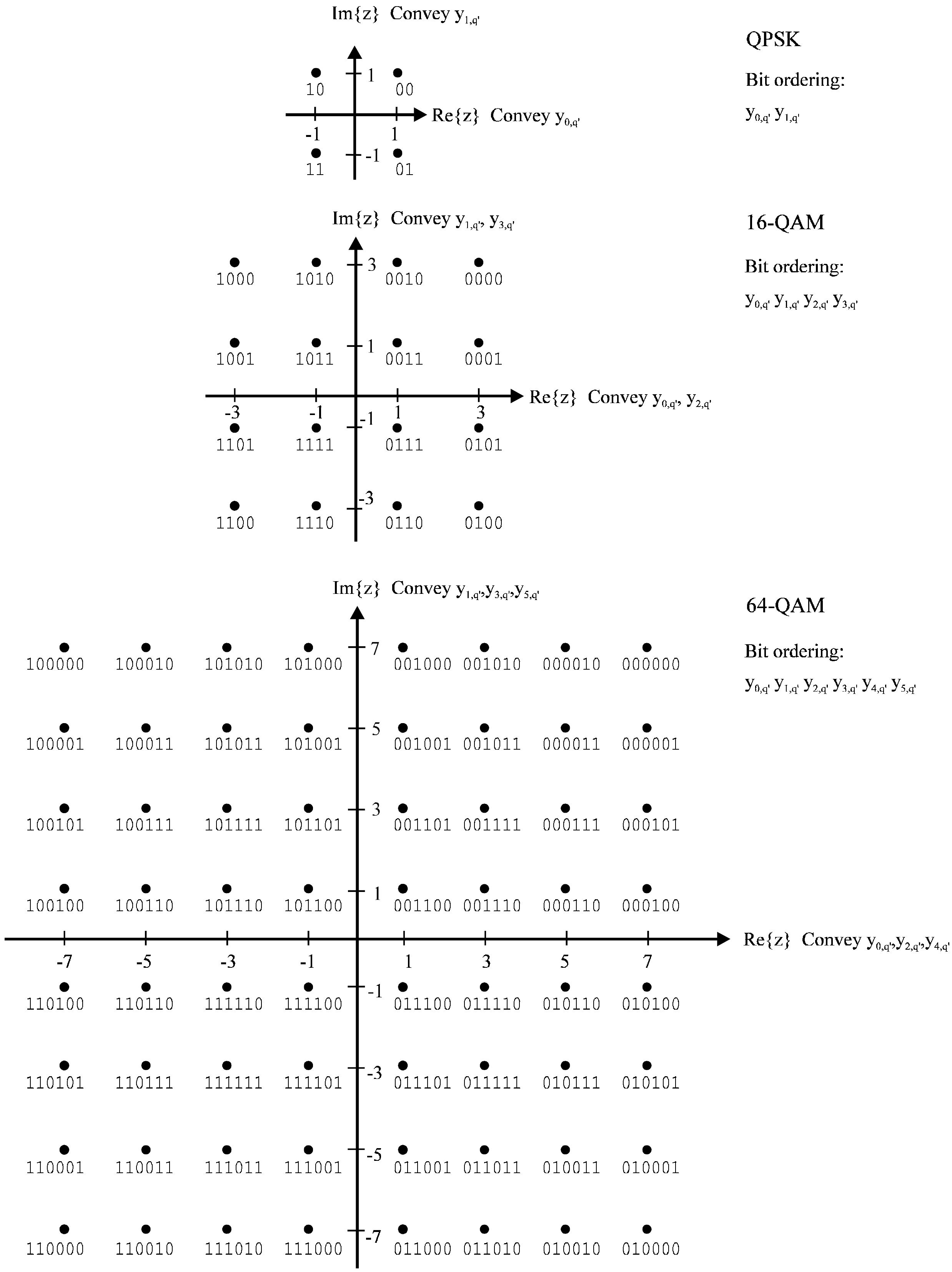


Figure 9a: The QPSK, 16-QAM and 64-QAM mappings and the corresponding bit patterns

(non-hierarchical, and hierarchical with α = 1)

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

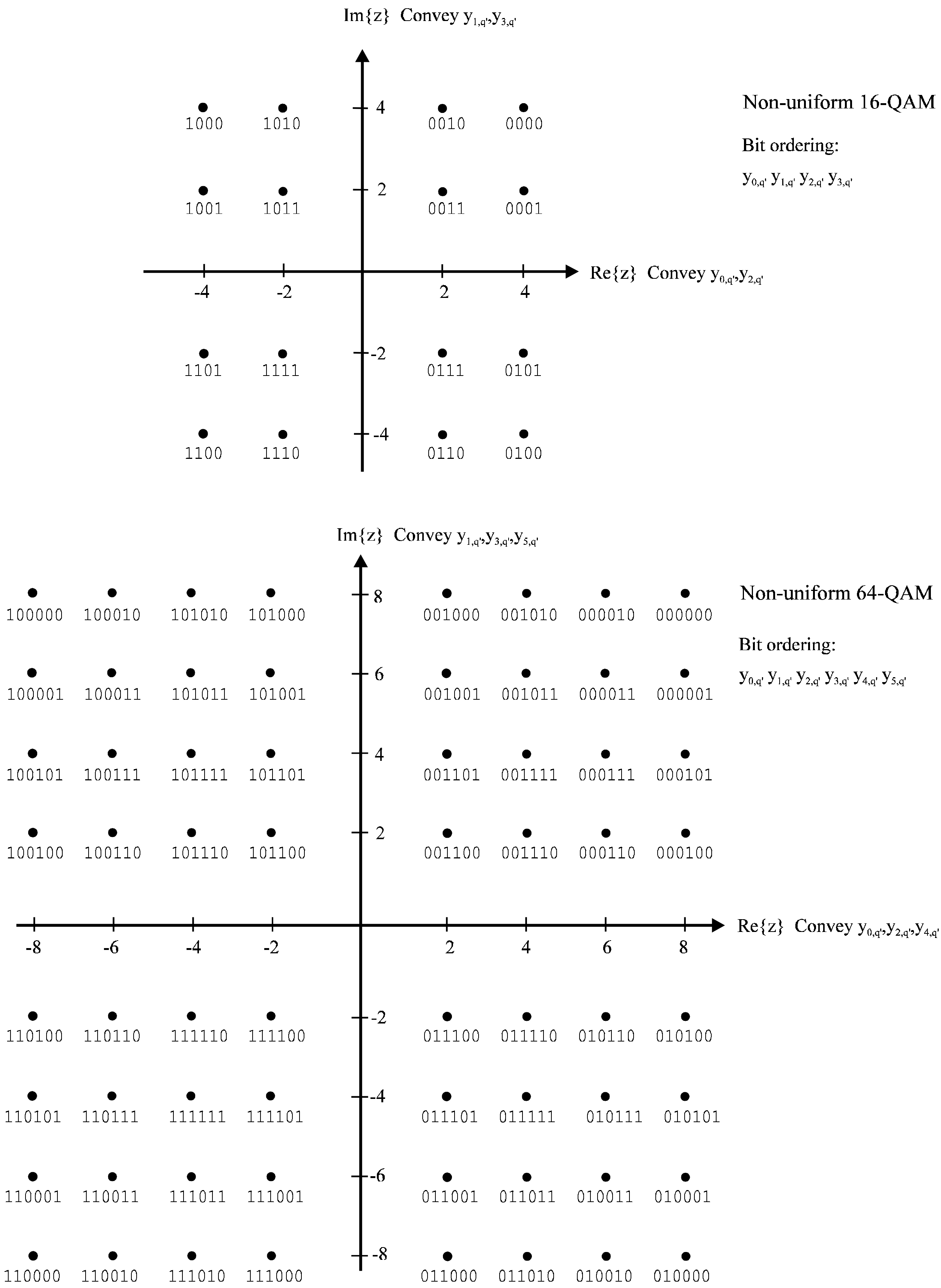


Figure 9b: Non-uniform 16-QAM and 64-QAM mappings with $\alpha = 2$

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

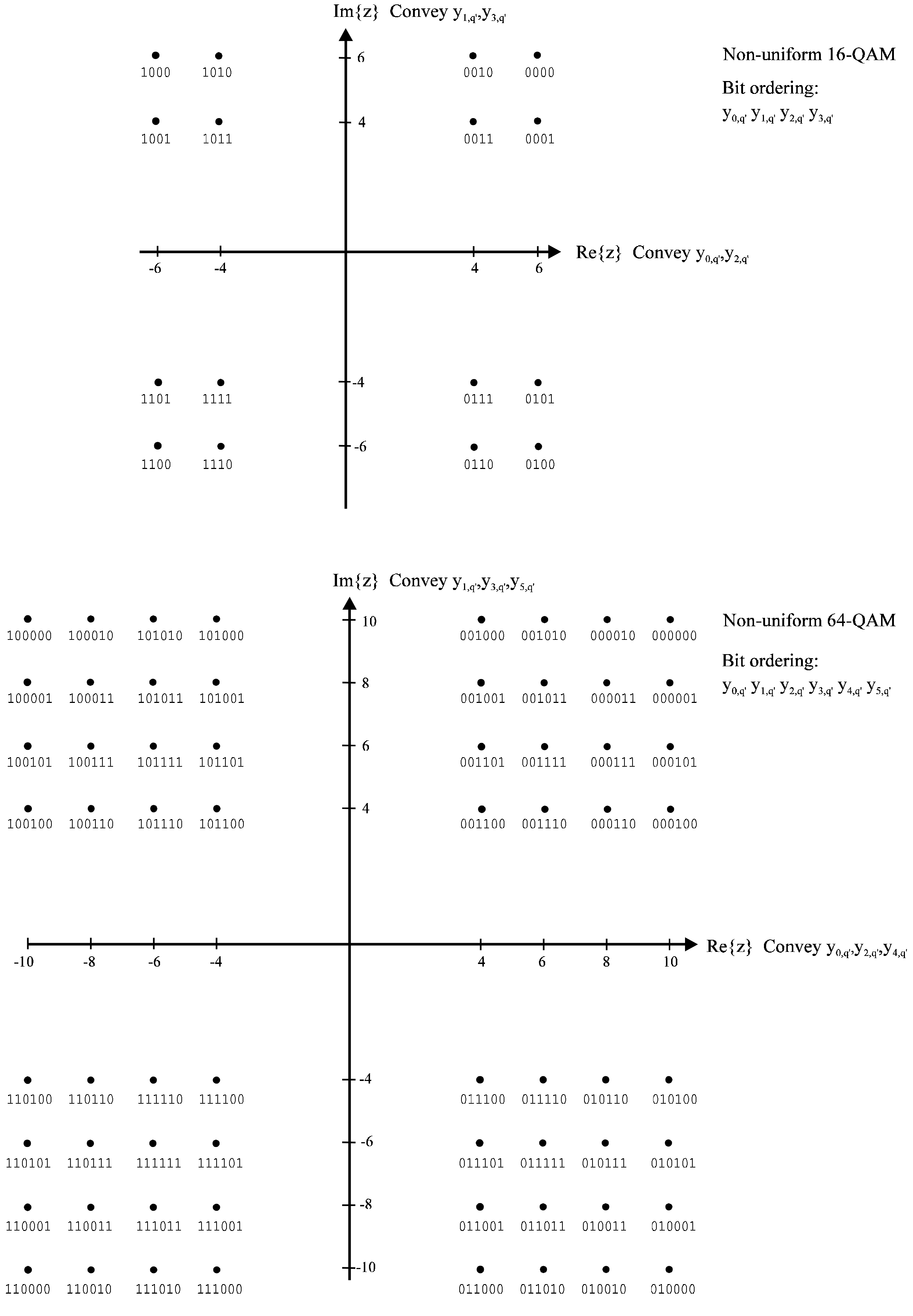


Figure 9c: Non-uniform 16-QAM and 64-QAM mappings with α = 4

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

The transmitted signal is organised 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 by 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 where the different values are given both in multiples of the elementary period T = 7/64 µs and in microseconds.

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 synchronisation, frequency synchronisation, time synchronisation, 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 table 4.

Table 4: Numerical values for the OFDM parameters for the 8k and 2k mode

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	896 µs	224 µs
Carrier spacing $1/T_U$ (note 1)	*1 116 Hz*	*4 464 Hz*
Spacing between carriers K_{min} and K_{max} $(K-1)/T_U$ (note 2)	*7,61 MHz*	*7,61 MHz*
NOTE 1: Values in italics are approximate values. NOTE 2: 6,66 MHz in the case of 7 MHz wide channels.		

The emitted signal is described by the following expression:

$$s(t) = \mathrm{Re}\left\{ e^{j \cdot 2\pi \cdot f_c \cdot t} \cdot \sum_{m=0}^{\infty} \sum_{l=0}^{67} \sum_{k=K_{min}}^{K_{max}} c_{m,l,k} \cdot \psi_{m,l,k}(t) \right\}$$

where

$$\psi_{m,l,k}(t) = \begin{cases} e^{j \cdot 2\pi \cdot \frac{k'}{T_U} \cdot (t - \Delta - l \cdot T_s - 68 \cdot m \cdot T_s)} & (l + 68 \cdot m) \cdot T_s \le t \le (l + 68 \cdot m + 1) \cdot T_s \\ 0 & \text{else} \end{cases}$$

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

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				2 048 × T 224 µs			
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

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

Table 6: Normalisation factors for data symbols

Modulation scheme		Normalisation 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

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 subclause 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 PRBS (Pseudo Random Binary Sequence) which is a series of values, one for each of the transmitted carriers (see subclause 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 subclause 4.6).

The PRBS sequence is generated according to figure 10.

The PRBS is initialised 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).

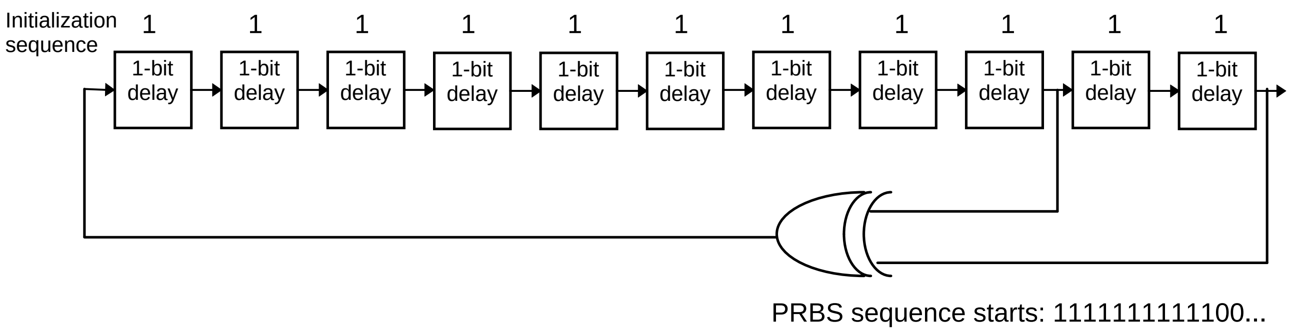


Figure 10: Generation of PRBS sequence

TheThe 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 subclause 4.5.5). Thus the corresponding modulation is given by:

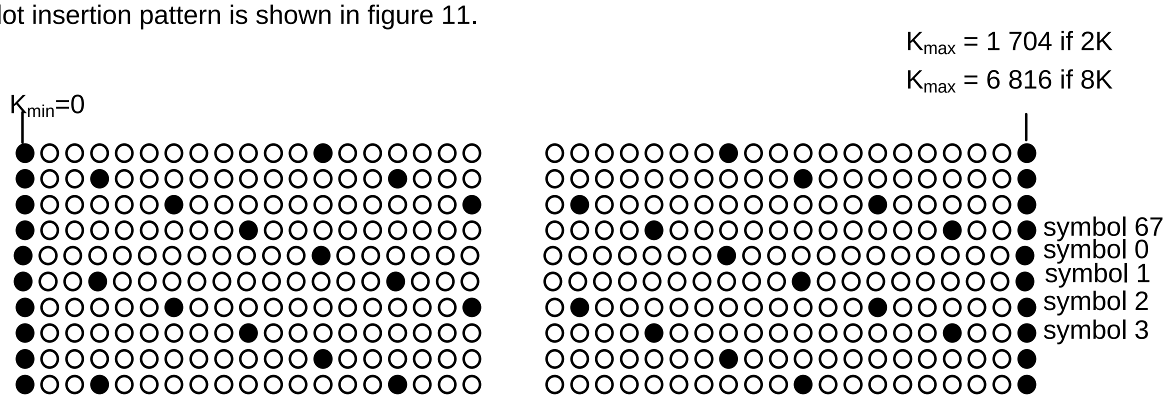
$$\mathrm{Re}\{c_{m,l,k}\} = 4 / 3 \times 2 \; (½ - w_k)$$

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

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.



TPS pilots and continual pilots between K_{min} and K_{max} are not indicated

● boosted pilot

○ data

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 9.

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

Table 9: Carrier indices for continual pilot carriers

Continual pilot carrier positions (index number k)	
2k mode	**8k mode**
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 1101 1107 1110 1137 1140 1146 1206 1269 1323 1377 1491 1683 1704	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 1050 1101 1107 1110 1137 1140 1146 1206 1269 1323 1377 1491 1683 1704 1752 1758 1791 1845 1860 1896 1905 1959 1983 1986 2037 2136 2154 2187 2229 2235 2322 2340 2418 2463 2469 2484 2508 2577 2592 2622 2643 2646 2673 2688 2754 2805 2811 2814 2841 2844 2850 2910 2973 3027 3081 3195 3387 3408 3456 3462 3495 3549 3564 3600 3609 3663 3687 3690 3741 3840 3858 3891 3933 3939 4026 4044 4122 4167 4173 4188 4212 4281 4296 4326 4347 4350 4377 4392 4458 4509 4515 4518 4545 4548 4554 4614 4677 4731 4785 4899 5091 5112 5160 5166 5199 5253 5268 5304 5313 5367 5391 5394 5445 5544 5562 5595 5637 5643 5730 5748 5826 5871 5877 5892 5916 5985 6000 6030 6051 6054 6081 6096 6162 6213 6219 6222 6249 6252 6258 6318 6381 6435 6489 6603 6795 6816

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

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

Thus the corresponding modulation is given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 4 / 3 \times 2 \left(½ - w_k \right)$$

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

4.5.5 Amplitudes of all reference information

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

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

4.6 Transmission Parameter Signalling (TPS)

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 10: Carrier indices for TPS carriers

2k mode	8k mode
34 50 209 346 413 569 595 688 790 901 1219 1262 1286 1469 1594 1687	34 50 209 346 413 569 595 688 790 901 1073 1219 1262 1286 1469 1594 1687 1738 1754 1913 2050 2117 2273 2299 2392 2494 2605 2777 2923 2966 2990 3173 3298 3391 3442 3458 3617 3754 3821 3977 4003 4096 4198 4309 4481 4627 4670 4694 4877 5002 5095 5146 5162 5321 5458 5525 5681 5707 5800 5902 6013 6185 6331 6374 6398 6581 6706 6799

The TPS carriers convey information on:

a) modulation including the α value of the QAM constellation pattern (see note);

b) hierarchy information;

c) guard interval (not for initial acquisition but for supporting initial response of the receiver in case of reconfiguration);

d) inner code rates;

e) transmission mode (2k or 8k, not for the initial acquisition but for supporting initial response of the receiver in case of reconfiguration);

f) frame number in a super-frame.

NOTE: The α value defines the modulation based on the cloud spacing of a generalised 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 initialise the TPS modulation on each TPS carrier (see subclause 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 initialisation bit;
- 16 synchronisation bits;
- 37 information bits;
- 14 redundancy bits for error protection.

Of the 37 information bits, 23 are used at present. The remaining 14 bits are reserved for future use, and should be set to zero.

4.6.2 TPS transmission format

The transmission parameter information shall be transmitted as shown in table 11.

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 subclauses 4.6.2.1 to 4.6.2.8. The leftmost bit is sent first.

Table 11: TPS signalling information and format

Bit number	Format	Purpose/Content
s_0	see subclause 4.6.2.1	Initialisation
s_1- s_{16}	0011010111101110 or 1100101000010001	Synchronization word
s_{17} - s_{22}	010 111	Length indicator
s_{23}, s_{24}	see table 12	Frame number
s_{25}, s_{26}	see table 13	Constellation
s_{27}, s_{28}, s_{29}	see table 14	Hierarchy information
s_{30}, s_{31}, s_{32}	see table 15	Code rate, HP stream
s_{33}, s_{34}, s_{35}	see table 15	Code rate, LP stream
s_{36}, s_{37}	see table 16	Guard interval
s_{38}, s_{39}	see table 17	Transmission mode
s_{40} - s_{53}	all set to "0"	Reserved for future use
s_{54} - 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 Initialisation

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

4.6.2.2 Synchronisation

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

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

s_1 - s_{16} = 0011010111101110.

The second and fourth TPS block have the following synchronisation 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) to signal the number of used bits of the TPS. This length indicator has the value s_{17} - s_{22} = 010111 at present.

4.6.2.4 Frame number

Four frames constitute one super-frame. The frames inside the super-frame are numbered from 0 to 3 according to table 12:

Table 12: 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 13. In order to determine the modulation scheme, the receiver shall also decode the hierarchy information given in table 14.

Table 13: 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 14.

Table 14: Signalling format for the α values

Bits s_{27}, s_{28}, s_{29}	α value
000	Non hierarchical
001	α = 1
010	α = 2
011	α = 4
100	reserved
101	reserved
110	reserved
111	reserved

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 15 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 15.

Table 15: 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 16:

Table 16: Signalling format for each of the guard interval values

Bits s_{36}, s_{37}	Guard interval values (Δ/T_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 17: Signalling format for transmission mode

Bits s_{38}, s_{39}	Transmission mode
00	2k mode
01	8k mode
10	reserved
11	reserved

4.6.2.10 Error protection of TPS

The 53 bits containing the TPS synchronisation and information 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:

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

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. $E[c \bullet c^*] = 1$.

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

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

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

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

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

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

4.7 Number of RS-packets per OFDM super-frame

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 18.

The first data byte transmitted in an OFDM super-frame shall be one of the SYNC/ $\overline{\mathrm{SYNC}}$ bytes.

Table 18: Number of Reed-Solomon packets per OFDM super-frame for all combinations of guard interval, 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	1008	504	2016	756	3024
2/3	336	1344	672	2688	1008	4032
3/4	378	1512	756	3024	1134	4536
5/6	420	1680	840	3360	1260	5040
7/8	441	1764	882	3528	1323	5292

Table 19: Useful bitrate (Mbit/s) for all combinations of guard interval, constellation and code rate for non-hierarchical systems

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 the hierarchical schemes the useful bit rates can be obtained from table 19 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 subclause 4.3.5.

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

$$f_k = f_c + \frac{k'}{T_U}$$

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

is defined by the following expression:

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

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. 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 *7,608 258* MHz for the 8k mode *or 7,611 607* MHz for the 2k mode (see note).

NOTE: Values in italics are approximate values.

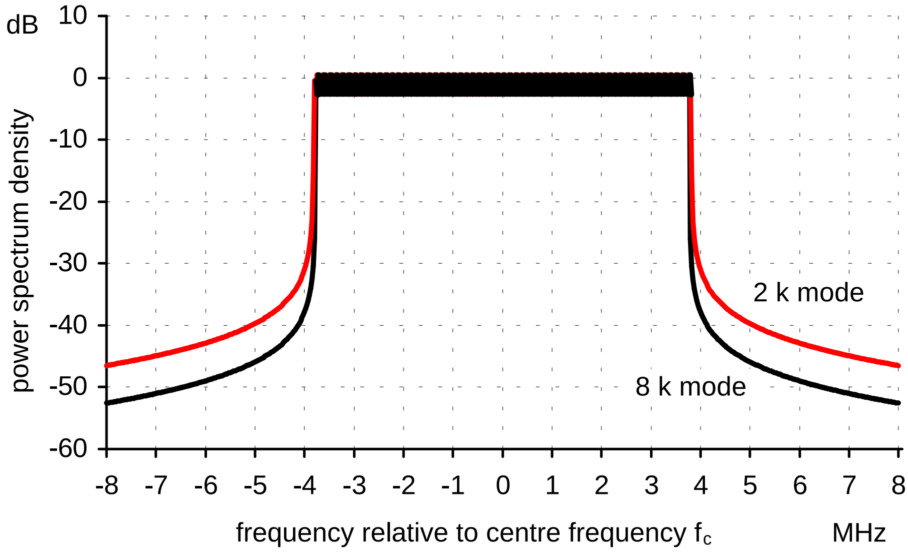


Figure 12: Theoretical DVB transmission signal spectrum for guard interval $\Delta = T_u /4$

4.8.2 Out-of-band spectrum mask

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 20 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 polarisation 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:

correction = minimum analogue erp - maximum digital erp.

Corrected breakpoints equal reference breakpoints plus correction (dB).

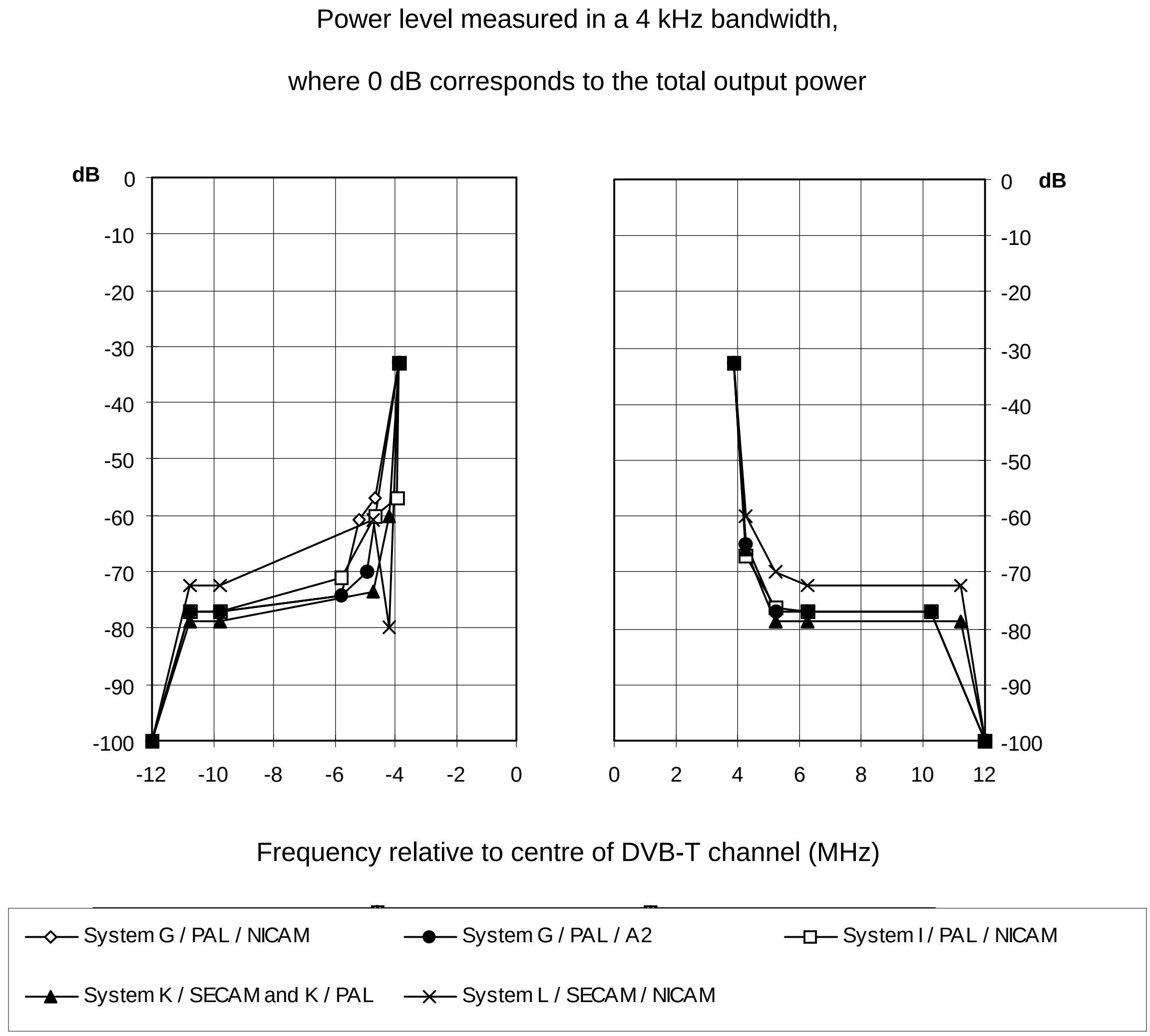


Figure 13: Spectrum masks for a digital terrestrial television transmitter operating on a lower or higher adjacent channel to a co-sited analogue television transmitter

Table 20: Breakpoints for spectrum mask

Breakpoints										
	G / PAL / NICAM		G / PAL / A2		I / PAL / NICAM		K / SECAM K / PAL		L / SECAM / NICAM	
See Note below	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 20 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 21.

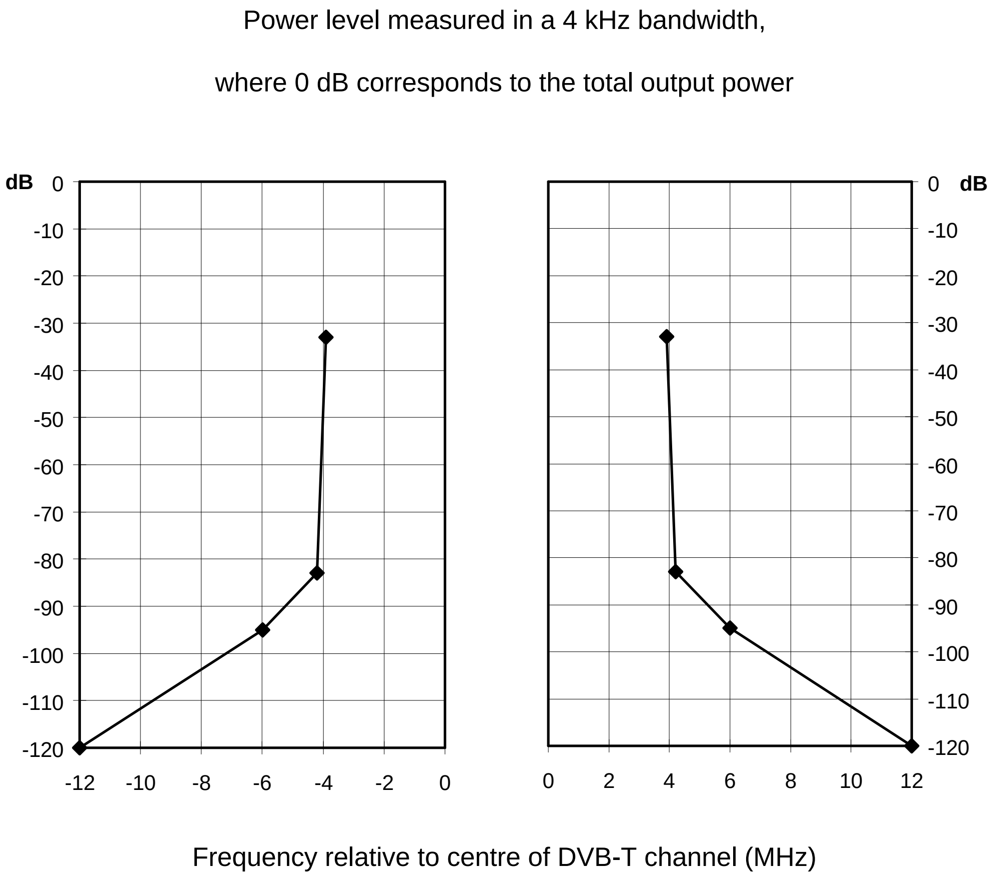


Figure 14: Spectrum mask for critical cases

Table 21: 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

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

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

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

Annex A (normative): Simulated system performance

Tables A.1, A.2 and A.3 give simulated performance anticipating 'perfect channel estimation and without phase noise' of channel coding and modulation combinations, and are subject to confirmation by testing. These results are given for the Gaussian channel, Ricean channel (F_1) and Rayleigh channel (P_1). F_1 and P_1 are described in annex B. Associated useful bit rates available are also indicated as a function of the guard interval to active symbol duration for the four different values of guard interval.

Table A.1: Required C/N for non-hierarchical transmission to achieve a BER = 2 x 10^{-4} after the Viterbi decoder for all combinations of coding rates and modulation types. The net bit rates after the Reed-Solomon decoder are also listed

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

NOTE: Figures in italics are approximate values.

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.

Table A.2: Required C/N for hierarchical transmission to achieve a BER = 2 x 10^{-4} after Viterbi decoder

			Required C/N for BER = 2 x 10^{-4} after Viterbi QEF after Reed-Solomon			Bitrate (Mbit/s)			
Modu-lation	**Code Rate**	**α**	**Gaussian Channel**	**Ricean Channel (F_1)**	**Rayleigh Channel (P_1)**	**Δ/T_U = 1/4**	**Δ/T_U = 1/8**	**Δ/T_U =.1/32**	**Δ/T_U = 1/16**
QPSK in non-uniform 16-QAM	1/2	2	*4,8*	*5,4*	*6,9*	*4,98*	*5,53*	*5,85*	*6,03*
	2/3		*7,1*	*7,7*	*9,8*	*6,64*	*7,37*	*7,81*	*8,04*
	3/4		*8,4*	*9,0*	*11,8*	*7,46*	*8,29*	*8,78*	*9,05*
							+		
	1/2		*13,0*	*13,3*	*14,9*	*4,98*	*5,53*	*5,85*	*6,03*
	2/3		*15,1*	*15,3*	*17,9*	*6,64*	*7,37*	*7,81*	*8,04*
	3/4		*16,3*	*16,9*	*20,0*	*7,46*	*8,29*	*8,78*	*9,05*
	5/6		*16,9*	*17,8*	*22,4*	*8,29*	*9,22*	*9,76*	*10,05*
	7/8		*17,9*	*18,7*	*24,1*	*8,71*	*9,68*	*10,25*	*10,56*
QPSK in non-uniform 16-QAM	1/2	4	*3,8*	*4,4*	*6,0*	*4,98*	*5,53*	*5,85*	*6,03*
	2/3		*5,9*	*6,6*	*8,6*	*6,64*	*7,37*	*7,81*	*8,04*
	3/4		*7,1*	*7,9*	*10,7*	*7,46*	*8,29*	*8,78*	*9,05*
							+		
	1/2		*17,3*	*17,8*	*19,6*	*4,98*	*5,53*	*5,85*	*6,03*
	2/3		*19,1*	*19,6*	*22,3*	*6,64*	*7,37*	*7,81*	*8,04*
	3/4		*20,1*	*20,8*	*24,2*	*7,46*	*8,29*	*8,78*	*9,05*
	5/6		*21,1*	*22,0*	*26,0*	*8,29*	*9,22*	*9,76*	*10,05*
	7/8		*21,9*	*22,8*	*28,5*	*8,71*	*9,68*	*10,25*	*10,56*

NOTE: Figures in italics are approximate values.

Results for QPSK in non-uniform 64-QAM with $\alpha = 4$ are not included due to the poor performance of the 64-QAM signal.

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

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

NOTE: Figures in italics are approximate values.

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:

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

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:

$$K = \frac{r_0^{\,2}}{\sum_{i=1}^{N} r_i^{\,2}}$$

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

$$\rho_o = \sqrt{10 \cdot \sum_{i=1}^{N} \rho_i^{\,2}}$$

b) Portable reception, Rayleigh fading (P_1):

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

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

Table B.1: Attenuation, 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*

NOTE: Figures in italics are approximate values.

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 indeces 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 indeces 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
4602, 4983, 5233, 4858, 4730, 5111	2
36, 417, 667, 292, 164, 545	3
4656, 5037, 5287, 4912, 4784, 5165	4
48, 429, 679, 304, 176, 557	5
2376, 2757, 3007, 2632, 2504, 2885	6
780, 1161, 1411, 1036, 908, 1289	7
6906, 7287, 7537, 7162, 7034, 7415	8
4590, 4971, 5221, 4846, 4718, 5099	9
5286, 4911, 5161, 4786, 4658, 5039	10
2364, 2745, 2995, 2620, 2492, 2873	11
pilot	12
4788, 5169, 4663, 5044, 4916, 4541	13
....	. . .
4194, 3819, 4069, 4450, 4322, 3947	1 691
pilot	1 692
7782, 8163, 7657, 8038, 7910, 8291	1 693
6624, 6249, 6499, 6124, 6752, 6377	1 694
3402, 3027, 3277, 3658, 3530, 3155	1 695
546, 171, 421, 46, 674, 299	1 696
8574, 8955, 8449, 8830, 8702, 8327	1 697
8376, 8757, 9007, 8632, 8504, 8885	1 698
1680, 2061, 1555, 1936, 1808, 2189	1 699
7620, 8001, 8251, 7876, 7748, 8129	1 700
5700, 5325, 5575, 5956, 5828, 5453	1 701
8826, 8451, 8701, 8326, 8954, 8579	1 702
8724, 8349, 8599, 8980, 8852, 8477	1 703
pilot	1 704

History

Document history			
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November 1996	Vote	V 115:	1996-11-25 to 1997-01-17