



*FRAMING STRUCTURE, CHANNEL CODING
AND MODULATION
FOR
Digital Terrestrial Television*

DVB DOCUMENT A012

June 1996

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Foreword

This draft European Telecommunication Standard (ETS) has been produced by the <Technical Committee> (XXX) Technical Committee of the European Telecommunications Standards Institute (ETSI), and is now submitted for the Public Enquiry phase of the ETSI standards approval procedure.

Proposed transposition dates	
Date of latest announcement of this ETS (doa) :	3 months after ETSI publication
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

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

- [1] ISO/IEC 13818 Part 1, 2 , 3 (November 1994) : « Coding of moving pictures and associated audio ».
- [2] ETS 300 421 (1994) : « 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 (1994) : « Digital broadcasting systems for television, sound and data services. Framing structure, channel coding and modulation for cable systems ».

3 Abbreviations, symbols and glossary

3.1 Symbols

$A(e)$	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
$c_{m,l,k}$	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
$H_c(w)$	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 bit 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
$K_{\text{min}}, K_{\text{max}}$	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 bit 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_l	TPS bit of index l
t	Number of bytes which can be corrected by the Reed-Solomon decoder
T	Elementary time period
T_S	Time 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

3.2 Abbreviations

ACI	Adjacent Channel Interference
AFC	Automatic Frequency Control
BER	Bit Error Ratio
BCH	Bose - Chaudhuri - Hocquenghem
D/A	Digital-to-Analogue converter
DBPSK	Differential binary phase shift keying
EDTV	Enhanced Definition Television
ETS	European Telecommunication Standard
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FIFO	First-In, First-Out shift register
HEX	Hexadecimal notation
HDTV	High Definition Television
HP	High priority bit stream
IF	Intermediate frequency
LSB	Least Significant Bit
LDTV	Limited Definition Television
LO	Local Oscillator
LP	Low priority bit stream
MPEG	Moving Picture Experts Group
MSB	Most Significant Bit
MUX	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
SECAM	Système Séquentiel Couleur A Mémoire
SDTV	Standard Definition Television
SFN	Single Frequency Network
TPS	Transmission Parameter Signalling
TV	Television
UHF	Ultra-High Frequency
VHF	Very-High Frequency

3.3 Glossary

Constraint length	Number of delay elements +1 in the convolutional coder.
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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 [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 [2] and Cable Baseline Specifications [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 “2 k mode” and an “8 k mode”. The “2 k mode” is suitable for single transmitter operation and for small SFN networks with limited transmitter distances. The “8 k 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 must 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 stream 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 could thus be ‘simulcast’ as a low-bit-rate, rugged version and another version of higher bit rate and lesser ruggedness. Alternatively, entirely different programmes could 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.

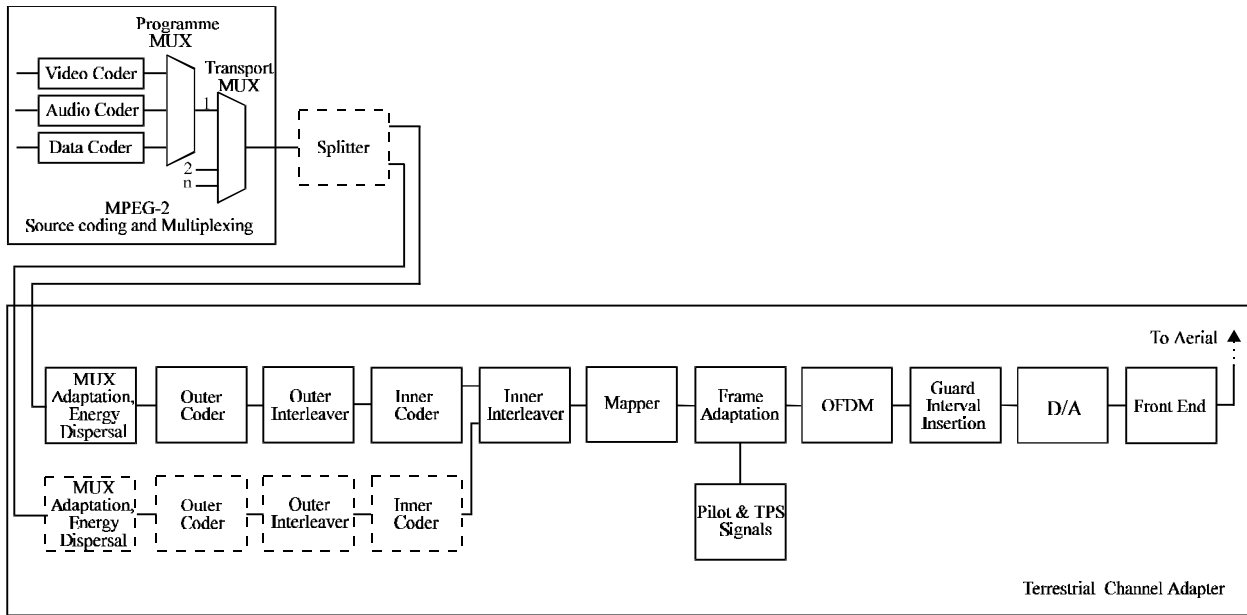


Figure 1 : Functional block diagram of the System.

4.2 Interfacing

The Baseline System as defined in this specification is delimited by the following interfaces :

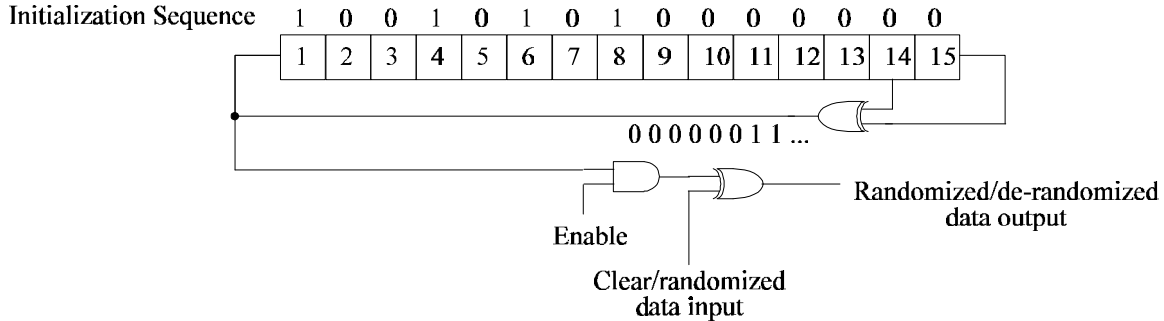
Table 1 : Interfaces for the Baseline System

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. 01000111). 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.



Data input (MSB first): 10111000xxxxxxxxx...

PRBS sequence: 00000011...

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 specification ETS 300 421 [2]. Elsewhere, in both the satellite specification and in this specification, a different polynomial notation is used which conforms with the standard textbook of Peterson and Weldon (Error correcting codes, 2nd ed, 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 1503 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 bytes) 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 : 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*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 : 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.

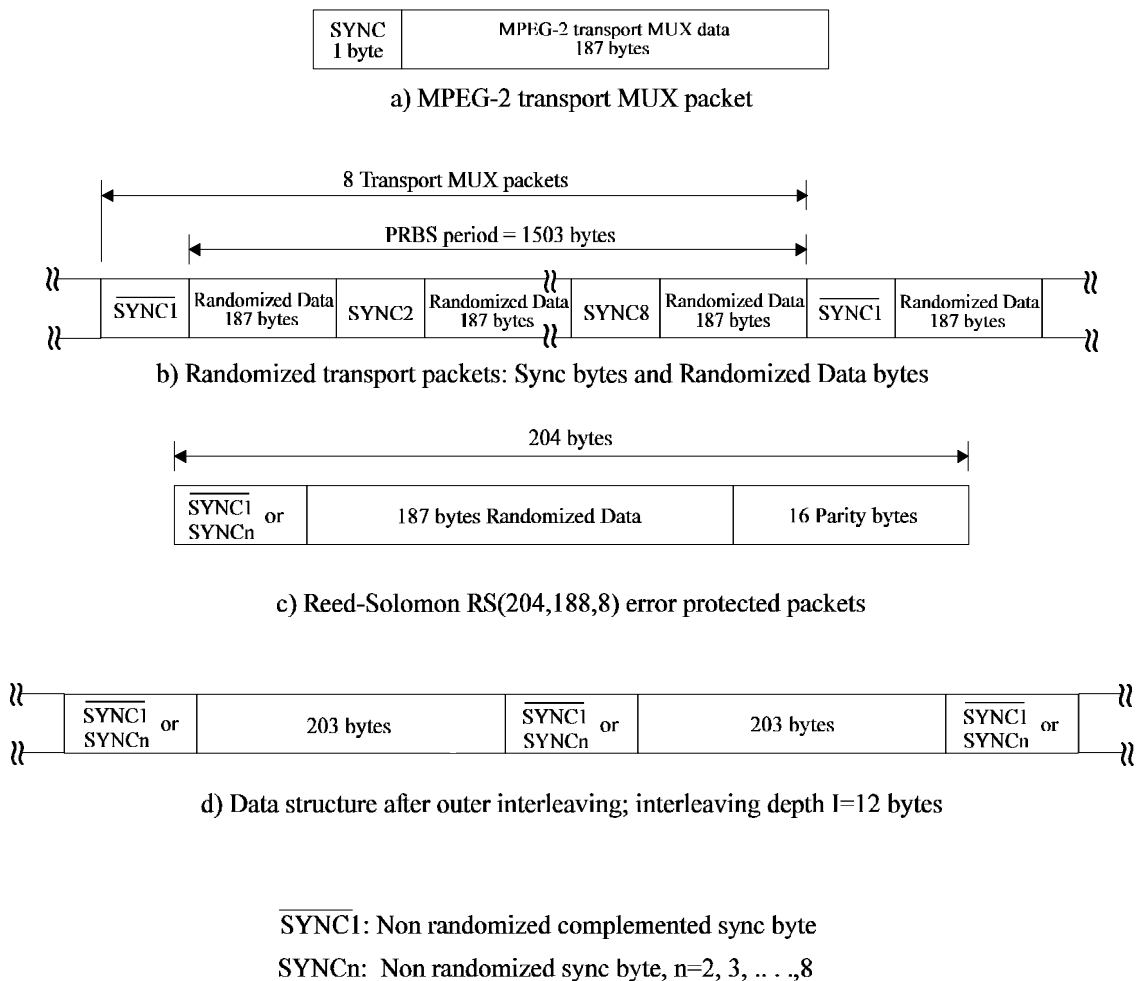


Figure 3 : Steps in the process of adaptation, energy dispersal, outer coding and interleaving. SYNC1 is the non randomised complemented sync byte and SYNCn is the non randomised sync byte, n=2,3,...,8.

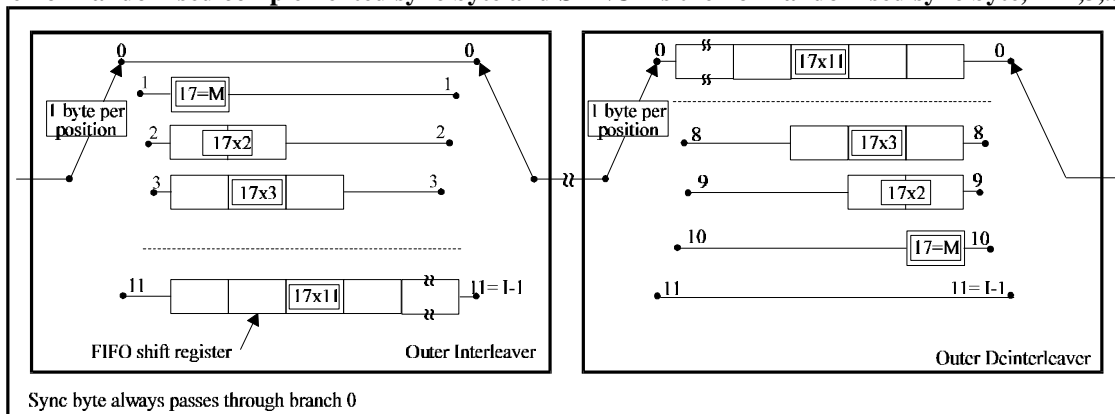


Figure 4 : Conceptual diagram of the outer interleaver and deinterleaver

4.3.3 Inner Coding

The system shall allow for a range of punctured convolutional codes, based on a mother convolutional code of rate $\frac{1}{2}$ 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 $\frac{1}{2}$ the system shall allow punctured rates of $\frac{2}{3}$, $\frac{3}{4}$, $\frac{5}{6}$ and $\frac{7}{8}$.

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 $\overline{\text{SYNC}}$ must lie at the point labelled “data input” in figure 5. The superframe is defined in section 4.4.

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

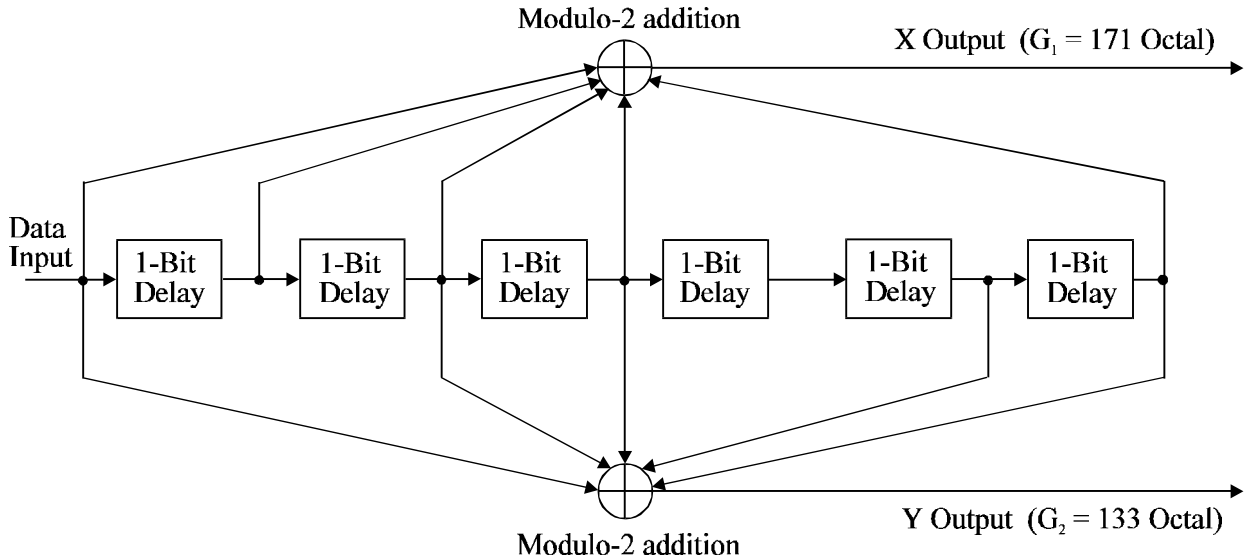
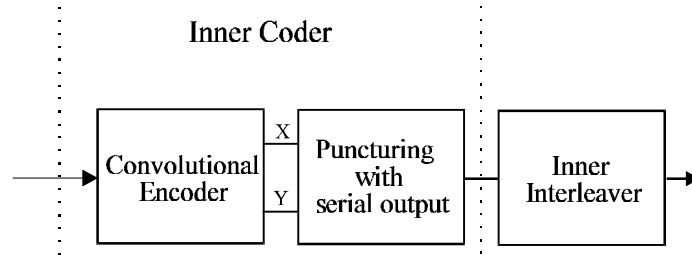


Figure 5 : The mother convolutional code of rate $\frac{1}{2}$.

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 2, 4 or 6 sub-streams, depending on the order and type of modulation. In non-hierarchical mode, the single input stream is demultiplexed into v sub-streams, where $v = 2$ for QPSK, $v = 4$ for 16-QAM, and $v = 6$ for 64-QAM. In hierarchical mode, both high and low priority streams are demultiplexed into two sub-streams for 16-QAM modulation, and for 64-QAM modulation the high priority stream is demultiplexed into two sub-streams and the low priority stream is demultiplexed into four 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 :

$$x_{di} = b_{di(\text{mod})v, di(\text{div})v}$$

In hierarchical mode :

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

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

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

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

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.

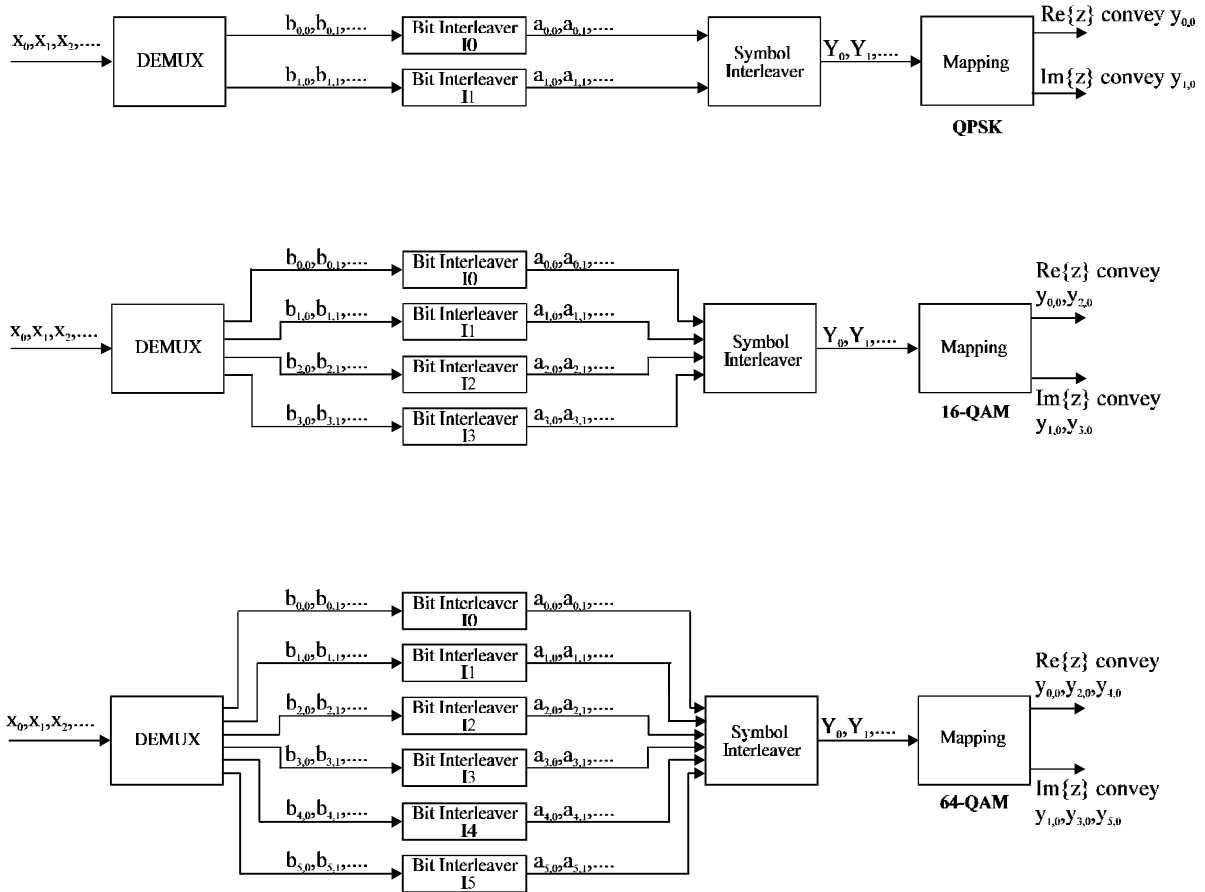


Figure 7a. Mapping of input bits onto output modulation symbols, for non-hierarchical transmission modes.

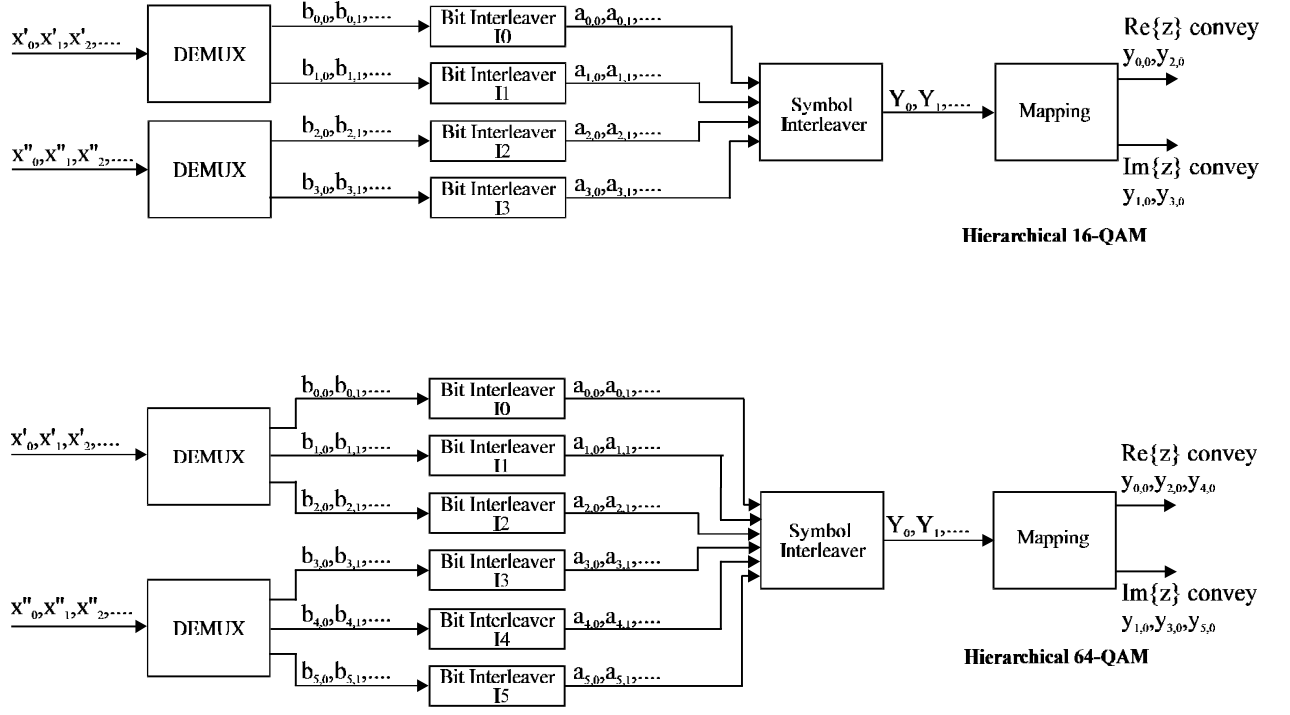


Figure 7b. Mapping of input bits onto output modulation symbols, for hierarchical transmission modes.

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 :

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

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.

$H_c(w)$ 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 1512 (2k mode) or 6048 (8k mode) active carriers per OFDM symbol. The symbol interleaver acts on blocks of 1512 (2k mode) or 6048 (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 $N_{\max} = 1512$ in the 2k mode and $N_{\max} = 6048$ in the 8k mode.

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

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

An $(N_r - 2)$ bit binary word R'_i is defined, with $N_r = \log_2 M_{\max}$, where $M_{\max} = 2048$ in the 2k mode and $M_{\max} = 8192$ in the 8k mode, where R'_i takes the following values :

- $i=0,1$: $R'_i [N_r-2, N_r-3, \dots, 1, 0] = 0, 0, \dots, 0, 0$
- $i=2$: $R'_i [N_r-2, N_r-3, \dots, 1, 0] = 0, 0, \dots, 0, 1$
- $2 < i < N_{\max}$: $\{ R'_i [N_r-3, N_r-4, \dots, 1, 0] = R'_{i-1} [N_r-2, N_r-3, \dots, 2, 1] ;$
in the 2k mode : $R'_i [9] = R'_{i-1} [0] \text{ \#\#\# } R'_{i-1} [3]$
in the 8k mode : $R'_i [11] = R'_{i-1} [0] \text{ \#\#\# } R'_{i-1} [1] \text{ \#\#\# } R'_{i-1} [4] \text{ \#\#\# } R'_{i-1} [6] \}$

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 (j)	9	8	7	6	5	4	3	2	1	0
R_i bit positions (rule[j])	0	7	5	1	8	2	6	9	3	4

Table 3b, Bit permutations for the 8K mode :

R'_i bit positions (j)	11	10	9	8	7	6	5	4	3	2	1	0
R_i bit positions (rule[j])	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.

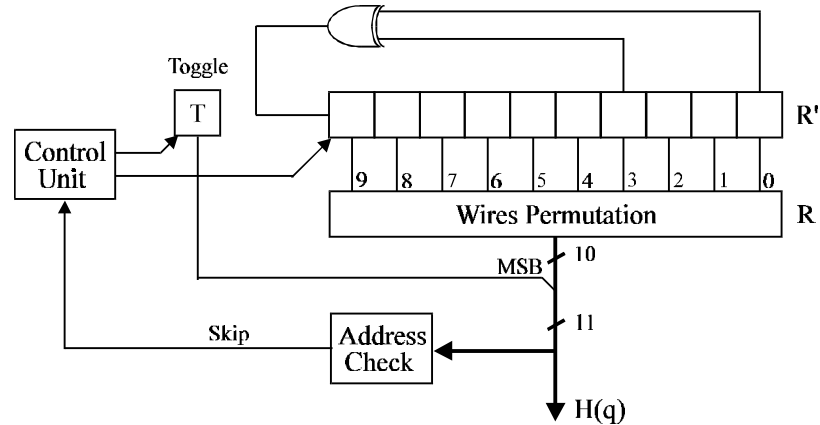


Figure 8a. Symbol interleaver address generation scheme for the 2k mode

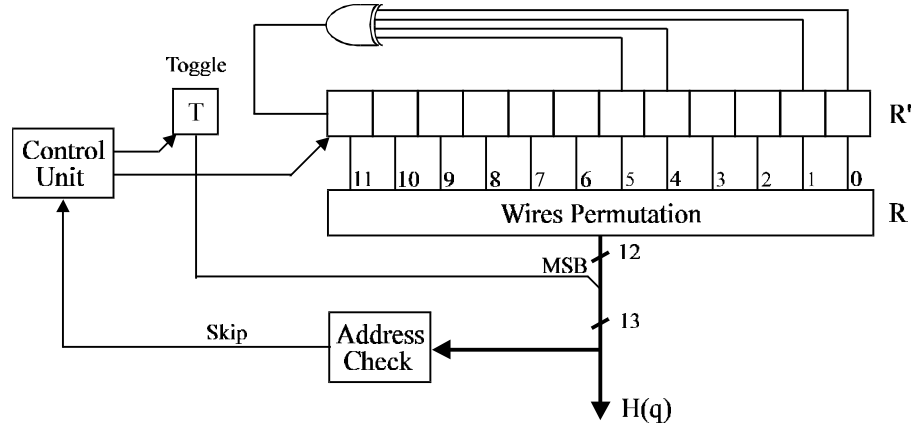


Figure 8b. Symbol interleaver address generation scheme for the 8K mode

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

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

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 section 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.

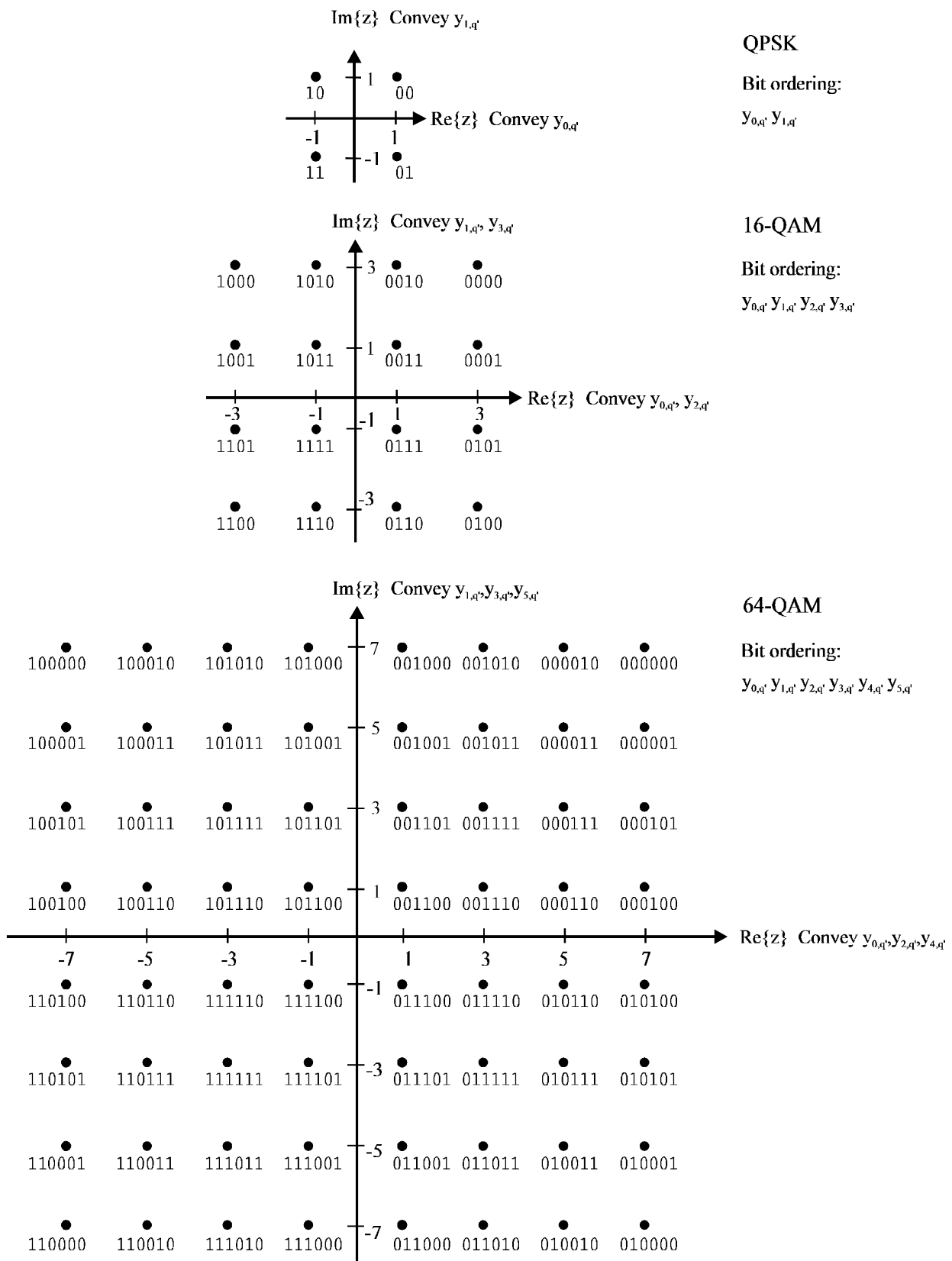


Figure 9a: The QPSK, 16-QAM and 64-QAM mappings and the corresponding bit patterns (non-hierarchical, and hierarchical with $\alpha=1$). The $y_{u,q'}$ denote the bits representing a complex modulation symbol z .

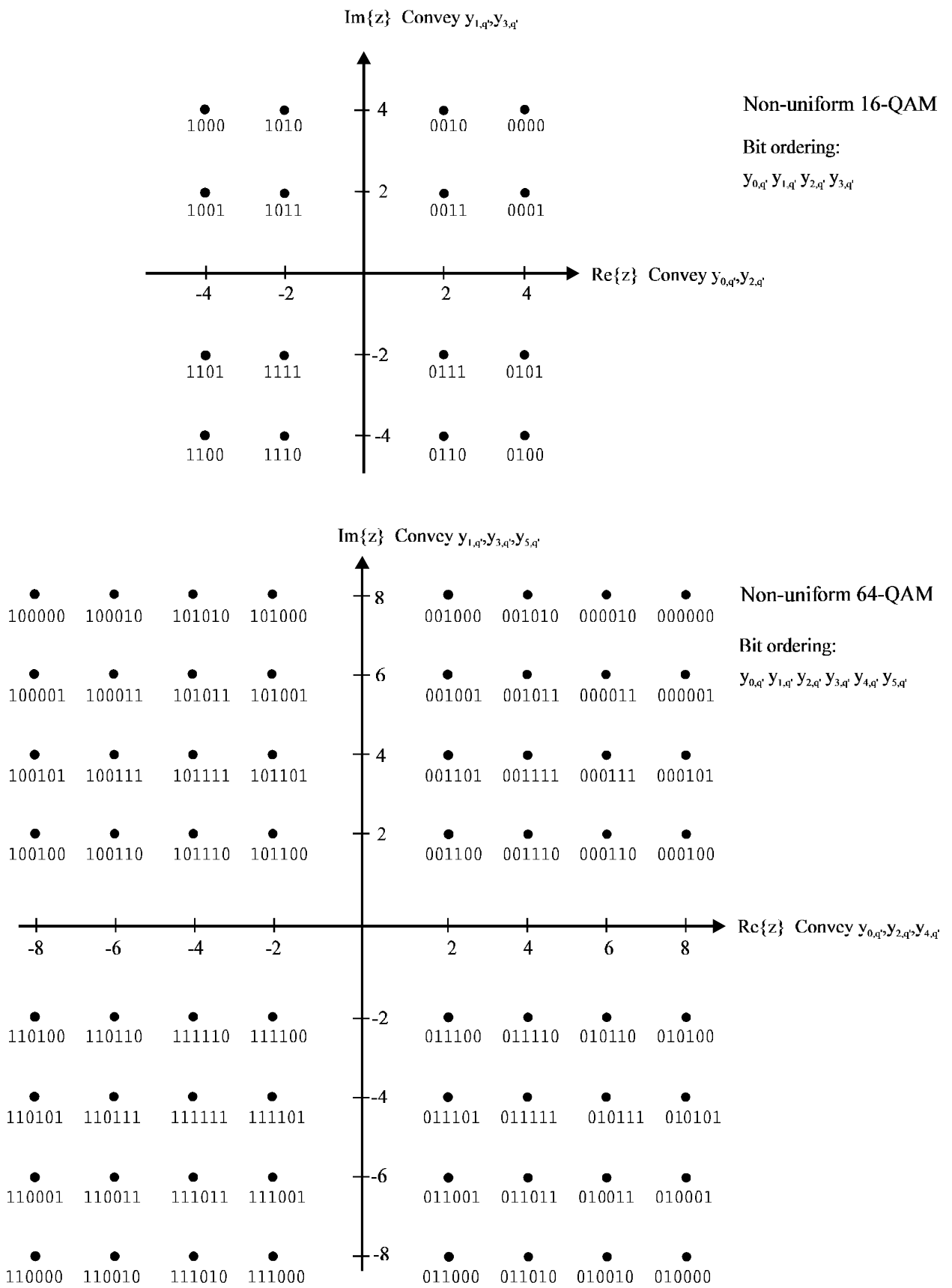


Figure 9b: Non-uniform 16-QAM and 64-QAM mappings with $\alpha = 2$.
The $y_{w,q}$ denote the bits representing a complex modulation symbol z .

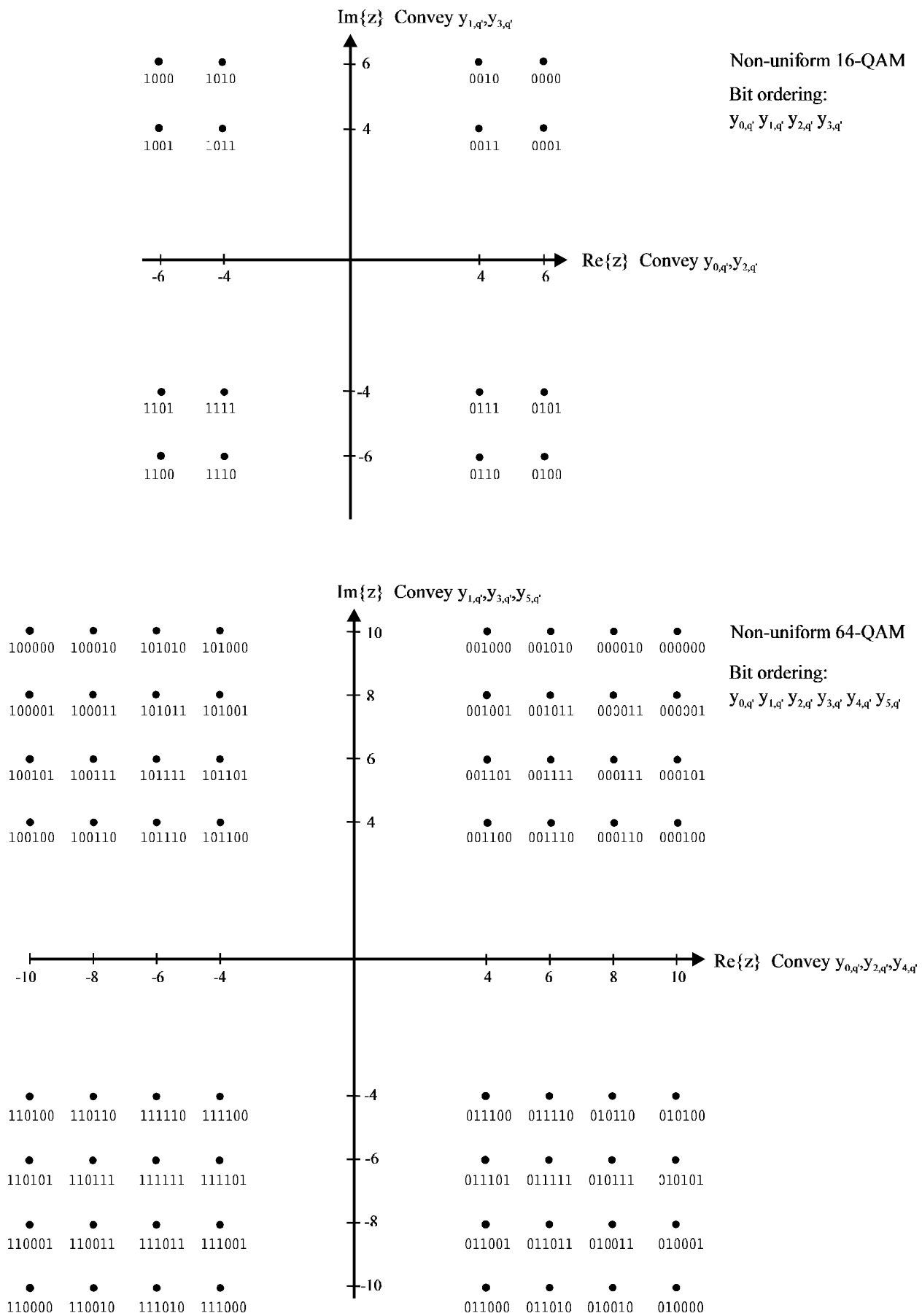


Figure 9c: Non-uniform 16-QAM and 64-QAM mappings with $\alpha = 4$.
 The $y_{u,q}$ denote the bits representing a complex modulation symbol z .

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 1000 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 must 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 must 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 $K = 6817$ carriers in the 8 k mode and $K = 1705$ carriers in the 2 k 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 $T = 7/64 \mu s$ and in micro seconds.

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 $K_{\max} = 1704$ in 2 k mode and 6816 in 8 k mode respectively. The spacing between adjacent carriers is $1/T_U$ while the spacing between carriers K_{\min} and K_{\max} is determined by $(K-1)/T_U$. The numerical values for the OFDM parameters for the 8 k and 2 k modes are given in table 4.

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

Parameter	8 k mode	2 k 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 μ s	224 μ s
Carrier spacing $1/T_U$	1 116 Hz	4 464 Hz
Spacing between carriers K_{\min} and K_{\max} $(K-1)/T_U$ (see note)	7,61 MHz	7,61 MHz
NOTE : 6,66 MHz in the case of 7 MHz wide channels.		

The emitted signal is described by the following expression :

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

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

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	8 k mode				2 k 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 μ s				2 048*T 224 μ s			
Duration of guard interval Δ	2 048*T 224 μ s	1 024*T 112 μ s	512*T 56 μ s	256*T 28 μ s	512*T 56 μ s	256*T 28 μ s	128*T 14 μ s	64*T 7 μ s
Symbol duration $T_S = \Delta + T_U$	10 240*T 1 120 μ s	9 216*T 1 008 μ s	8 704*T 952 μ s	8 448*T 924 μ s	2 560*T 280 μ s	2 304*T 252 μ s	2 176*T 238 μ s	2 112*T 231 μ s

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 : 1512 useful carriers in 2 k mode and 6048 useful carriers in 8 k mode.

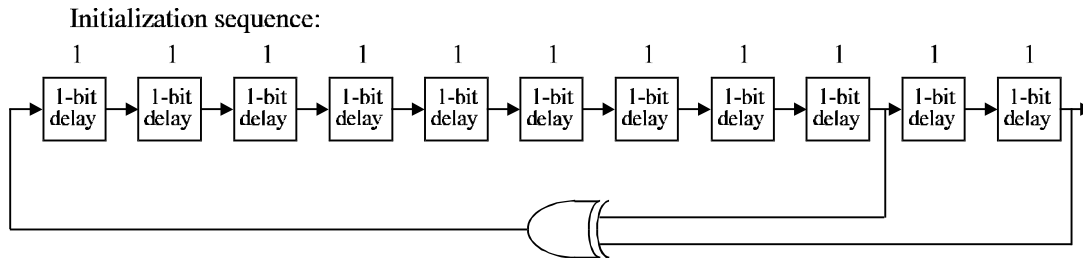
The value of the scattered or continual pilot information is derived from a PRBS (pseudo random binary sequence) which is a series of values, one for each of the transmitted carriers (see 4.5.2).

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 section 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).



PRBS sequence starts : 111111111100.....

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

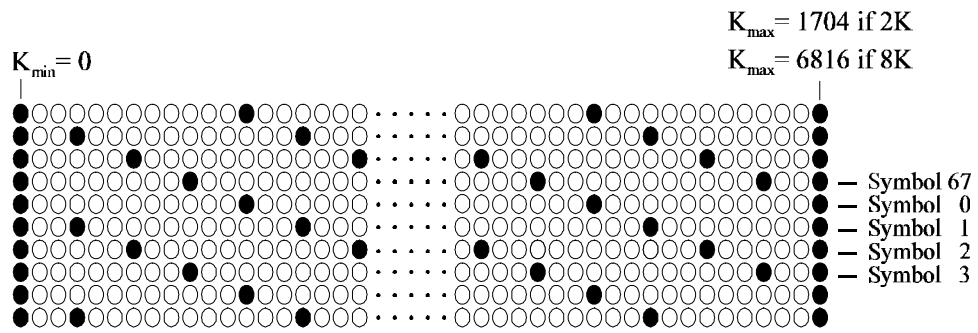
Reference information, taken from the reference sequence, is transmitted in scattered pilot cells in every symbol. Scattered pilot cells are always transmitted at the “boosted” power level (see subclause 4.5.5). Thus the corresponding modulation is given by

$$\begin{aligned} \text{Re}\{c_{m,k,l}\} &= 4/3 \times 2(1/2 - w_k) \\ \text{Im}\{c_{m,k,l}\} &= 0 \end{aligned}$$

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 (l ranging from 0 to 67), carriers for which index k belongs to the subset $\{k = K_{\min} + 3 \cdot (l \bmod 4) + 12p \mid p \text{ integer}, p \geq 0, k \in [K_{\min}; K_{\max}]\}$ are scattered pilots. 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 carriers 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 8 k mode and 45 in the 2 k 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)	
2 k mode	8 k mode
0 48 54 87 141 156 192 201 255 279 282 333 432	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	450 483 525 531 618 636 714 759 765 780 804 873
888 918 939 942 969 984 1050 1101 1107 1110	888 918 939 942 969 984 1050 1101 1107 1110
1137 1140 1146 1206 1269 1323 1377 1491 1683	1137 1140 1146 1206 1269 1323 1377 1491 1683
1704	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

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

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

4.5.5 Amplitudes of all reference information

As explained in section 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 above, 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 2 k mode and on 68 carriers for the 8 k 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.

2 k mode	8 k mode
34 50 209 346 413 569 595 688 790	34 50 209 346 413 569 595 688 790 901 1073 1219 1262 1286
901 1073 1219 1262 1286 1469 1594	1469 1594 1687 1738 1754 1913 2050 2117 2273 2299 2392 2494
1687	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 :

- 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 initial acquisition but for supporting initial response of the receiver in case of reconfiguration)
- 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 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 section 4.6.2.1	Initialisation
$s_1 - s_{16}$	0011010111101110 or 1100101000010001	Synchronization word
$s_{17} - s_{22}$	010111	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 4.5.2. This process is described in section 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 are 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 must 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, 9b, and 9c. 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	$\alpha = 1$
010	$\alpha = 2$
011	$\alpha = 4$
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 (2 k mode or 8 k mode).

Table 17 : Signalling format for transmission mode

Bits S_{38}, S_{39}	Transmission mode
00	2 k mode
01	8 k 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. $E[c \cdot c^*] = 1$.

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 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 :

$$\text{Re}\{c_{m,k,0}\} = 2(1/2 - w_k)$$

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

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/ $\overline{\text{SYNC}}$ 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	
	2 k mode	8 k mode	2 k mode	8 k mode	2 k mode	8 k 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
<p>NOTE : For the hierarchical schemes the useful bit rates can be obtained from table 19 as follows :</p> <p>HP stream : figures from QPSK columns ; LP stream, 16 QAM : figures from QPSK columns ; LP stream, 64 QAM : figures from 16 QAM columns.</p>					

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

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

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

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 14. 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 7,608888 MHz for the 8 k mode or 7,615584 MHz for the 2 k mode.

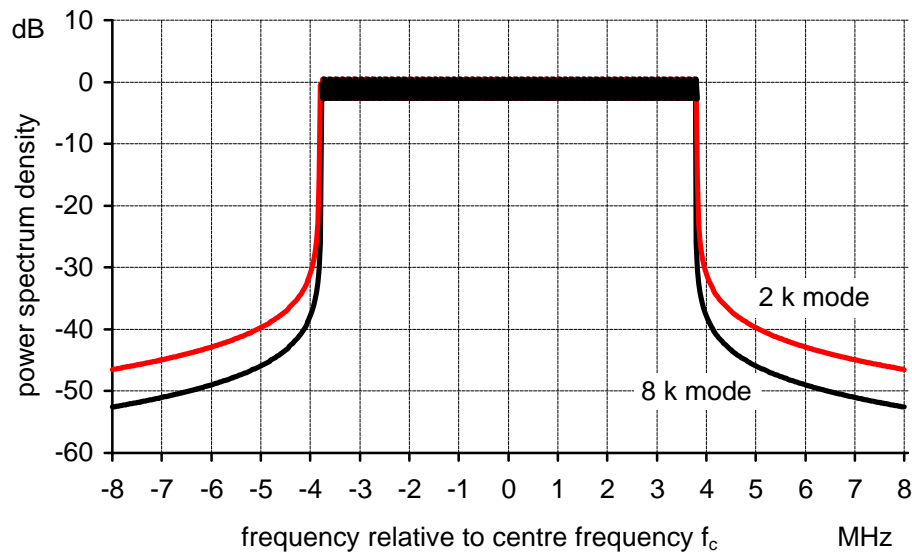


Figure 11 : Theoretical DVB transmission signal spectrum for guard interval $\Delta = T_u/4$

4.8.2 Spectrum mask

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

The out-of-band radiated signal will be specified if necessary.

4.8.3 Centre frequency of RF signal

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

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

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

Annex A (normative/ informative) : Simulated system performance

Tables A.1.1 and A.1.2 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 A1.1 : Required C/N for non-hierarchical transmission to achieve a BER = $2 \cdot 10^{-4}$ after the Viterbi decoder for all combinations of coding rates and modulation types. The net bitrates after the Reed-Solomon decoder are also listed.

		Required C/N for BER= $2 \cdot 10^{-4}$ after Viterbi QEF after Reed-Solomon			Bitrate (Mbit/s)			
Modulation	Code rate	Gaussian channel	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	3,1	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 : 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 A1.2 : Required C/N for hierarchical transmission to achieve a BER = $2 \cdot 10^{-4}$ after Viterbi decoder

			Required C/N for BER= $2 \cdot 10^{-4}$ after Viterbi QEF after Reed-Solomon			Bitrate (Mbit/s)			
Modulation	Code Rate	α	Gaussian Channel	Ricean Channel (F ₁)	Rayleigh Channel (P ₁)	$\Delta/T_U = 1/4$	$\Delta/T_U = 1/8$	$\Delta/T_U = .1/32$	$\Delta/T_U = 1/16$
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 : 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 A1.3 : Required C/N for hierarchical transmission to achieve a BER = $2 \cdot 10^{-4}$ after Viterbi decoder

			Required C/N for BER= $2 \cdot 10^{-4}$ after Viterbi QEF after Reed-Solomon			Bitrate (Mbit/s)			
Modulation	Code Rate	α	Gaussian Channel	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	8,9	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
						+			
	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 in non- uniform 64-QAM	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
						+			
	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 : 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 (normative/ informative) : Definition of P₁ and F₁

The performance of the system have been simulated with two channel models for fixed reception - F₁ and portable reception - P₁, respectively.

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

Fixed reception F₁ :

$$y(t) = \frac{\rho_0 \cdot x(t) + \sum_{i=1}^N \rho_i \cdot e^{-j2\pi\theta_i} \cdot x(t - \tau_i)}{\sqrt{\sum_{i=0}^N \rho_i^2}}$$

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 A.2.1 ;
- ρ_i is the attenuation of the i'th path - listed in table A.2.1 ;
- τ_i is the relative delay of the i'th path - listed in table A.2.1.

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 :

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

Portable reception, Rayleigh fading (P₁) :

$$y(t) = k \cdot \sum_{i=1}^N \rho_i \cdot e^{-j2\pi\theta_i} \cdot x(t - \tau_i) \quad \text{where} \quad k = \frac{1}{\sqrt{\sum_{i=1}^N \rho_i^2}}$$

θ_i , ρ_i and τ_i are given as above in table A.2.1

Table B.1 : Attenuation, phase and delay values for F₁ and P₁

i	ρ_i	τ_i [μs]	θ_i [rad]
1	0,057662	1,003019	4,855121
2	0,176809	5,422091	3,419109
3	0,407163	0,518650	5,864470
4	0,303585	2,751772	2,215894
5	0,258782	0,602895	3,758058
6	0,061831	1,016585	5,430202
7	0,150340	0,143556	3,952093
8	0,051534	0,153832	1,093586
9	0,185074	3,324866	5,775198
10	0,400967	1,935570	0,154459
11	0,295723	0,429948	5,928383
12	0,350825	3,228872	3,053023
13	0,262909	0,848831	0,628578
14	0,225894	0,073883	2,128544
15	0,170996	0,203952	1,099463
16	0,149723	0,194207	3,462951
17	0,240140	0,924450	3,664773
18	0,116587	1,381320	2,833799
19	0,221155	0,640512	3,334290
20	0,259730	1,368671	0,393889

History

Document history	
12 Feb 1996	pre-processed for TMDVB working group before submission to JTC#14 3/96 (az).
12 Mar 1996	received from DVB Project Office for submission to JTC#14 3/93 for approval (az)