ETSI TS 102 551-2 V2.1.1 (2007-08)

Technical Specification

Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Inner Physical Layer of the Radio Interface; Part 2: Multiple carrier transmission

Reference

RTS/SES-00287-2

Keywords

digital, layer 1, radio, satellite

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

An SDR system enables broadcast to fixed and mobile receivers through satellites and complementary terrestrial transmitters. Functionalities, architecture and technologies of such systems are described in TR 102 525 (see bibliography).

The present document is part 2 of a multi-part deliverable covering the Satellite Digital Radio (SDR) Systems; Inner Physical Layer of the Radio Interface, as identified below:

Part 1: "Single carrier transmission";

Part 2: "Multiple carrier transmission";

Part 3: "Multiple carrier transmission Mode 1".

Several existing and planned ETSI standards specify parts of the SDR system, with the aim of interoperable implementations. The physical layer of the radio interface (air interface) is divided up into the outer physical layer, the inner physical layer with a single carrier transmission, and the inner physical layer with multiple carriers transmission. These parts can be used all together in SDR compliant equipment, or in conjunction with other existing and future specifications.

The present document specifies the inner physical layer with multiple carrier transmission. The inner physical layer with single carrier transmission is specified in TS 102 551-1 (see bibliography), and the outer physical layer in TS 102 550 (see bibliography).

The present version 2.1.1 supersedes version 1.1.1 and is not compatible with it.

Changes from version 1.1.1 are:

1) Notes saying that the "AMSS preamble" is under study have been removed, since this technical element is no longer foreseen.

2) The description of the Mode 1 has been changed in order to make the standard easier to use. The current version makes reference to an ETSI DVB standard and lists the differences. In the revised version the relevant part of the ETSI DVB standard EN 301 744 is copied.

3) The Mode 1 has been changed in order to increase commonalities with the DVB-SH EN 302 583 standard.

4) The pilot structure for Modes 2 to 4 has been changed.

The items 1 and 2 are editorial changes, while 3 and 4 are non-backward compatible technical changes.

1 Scope

The present document concerns the radio interface of SDR broadcast receivers. It specifies functionality of the inner physical layer. It allows implementing this part of the system in an interoperable way. The present document specifies the case of multiple carrier transmission, whereas TS 102 551-1 (see bibliography) specifies single carrier transmission.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication and/or edition number or version number) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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[1] ETSI EN 300 744 (V1.5.1): "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

α: constellation ratio which determines the QAM constellation for the modulation for hierarchical transmission

3.2 Symbols

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

2k@5MHz	OFDM with 2k (i.e. 2 048 length) IFFT in 5 MHz channel spacing
α	hierarchical constellation scaling factor

3.3 Abbreviations

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

16QAM	16 Quadrature Amplitude Modulation
AMSS	Amplitude Modulated Spreading Sequence
C-TS	Channel Transport Stream
CU	Capacity Unit
DBPSK	Differential Binary Phase Shift Keying
DVB	Digital Video Broadcasting
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
IPL	Inner Physical Layer

IPL-MC	Inner Physical Layer, Multiple Carrier
IPL-SC	Inner Physical Layer, Single Carrier
OFDM	Orthogonal Frequency Division Multiplex
OPL	Outer Physical Layer
PRBS	Pseudo Random Binary Sequence
QAM	Quadrature Amplitude Modulation
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
RFU	Reserved for Future Use
TPS	Transmission Parameter Signalling
XOR	EXclusive OR

4 Inner physical layer - Multi Carrier

The functionality of the Inner Physical Layer (Multi Carrier), in the following denoted IPL-MC, is to provide a robust modulation scheme for multi carrier transmission. The multi carrier transmission is applicable either to satellite or terrestrial transmission.

The IPL-MC is embedded between the OPL (C-TS delivery) and the RF frontend (modulation) as depicted in Figure 1.

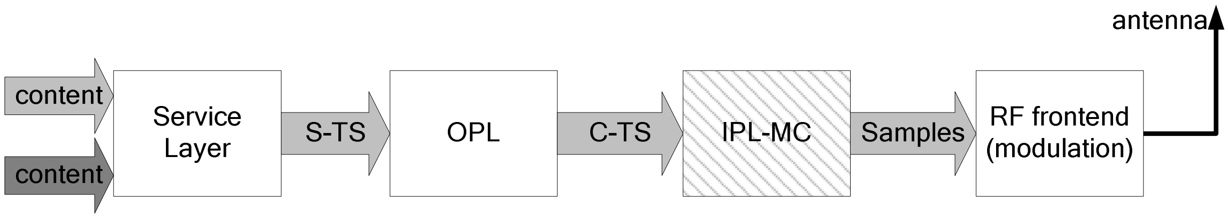

Figure 1: General block diagram of the ETSI SES SDR system concept with selection of IPL-MC

The general block diagram of the IPL-MC functionality for either modes 1 or modes 2, 3 and 4 are given in figures 2 and 3.

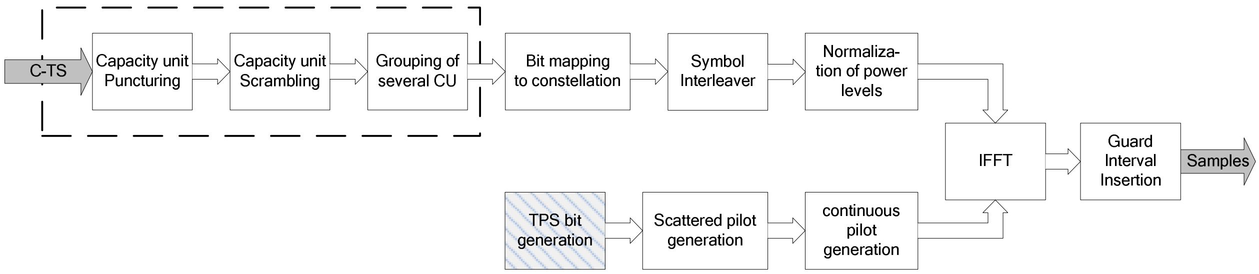

Figure 2: Block diagram of the ETSI SES SDR compliant IPL-MC in mode 1

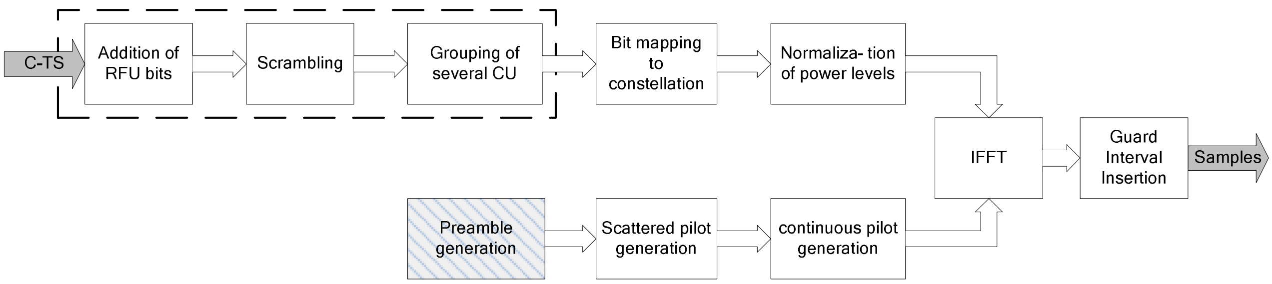

Figure 3: Block diagram of the ETSI SES SDR compliant IPL-MC in mode 2, 3 and 4

To achieve maximum commonalities with existing, wide-spread standards like DVB-T and its successor DVB-H, one profile is based on EN 300 744 [1]. To increase the robustness in rapidly changing channels or high delay spread scenarios, three modes using a higher pilot density together with a distinct frequency-domain preamble are introduced.

4.1 Interfacing to OPL (Outer Physical Layer)

Its interface to the OPL (Outer Physical Layer) is the C-TS (channel transport stream), which is defined in TS 102 550 (see bibliography). For this special IPL-MC, the parameters which are passed to the OPL are derived within TS 102 550 (see bibliography).

Two types of IPL-MC exist: One providing a single-input C-TS interface, another providing double-input interface to allow hierarchical modulation. In the latter case, both C-TS need to be aligned in time, framing and throughput.

If more than one carrier needs to be supported, multiple instances of the IPL-MC need to be instantiated in parallel.

The parameters that are passed to the OPL are as follows:

- IPL-MC frame length in integer number of CU (capacity units);
- IPL-MC frame length in number of IPL-MC symbols;
- number of inputs (to distinguish between normal and hierarchical transmission).

For mode 1, the length of one IPL-MC frame equals the length of the DVB-T superframe, whereas the length of one Phy sections equals the length of one DVB-T frame. Four Phy sections compose on IPL-MC frame in mode 1. The notations "IPL-MC frame" and "Phy sections" will be used throughout the document instead of "DVB-T superframe" and "DVB-T frame".

For modes 2 to 4, one IPL-MC frame is composed of five Phy sections and preceded by one preamble. Their parameters are defined in clause 4.2.2.

With these parameters, the exact throughput of the IPL-MC can be derived in CU per time. The smallest unit to be processed by the IPL-MC is one CU.

To be able to benefit from the gain of hybrid configurations (e.g. using IPL-SC together with IPL-MC), it is mandatory to have equal frame lengths on both IPLs.

If modes 2, 3 or 4 of the IPL-MC are used, a joint frame length of 432 ms is chosen. For mode 1 of the IPL-MC, the joint frame length is 487,424 ms (4 × 121,856 ms) or 438,68 ms (4 × 109,67 ms), dependent on the selection of the guard interval. This is achieved by concatenation of an integer number of IPL-MC frames.

4.2 The profile approach - different multi carrier modes

4.2.1 Profile definition

To cope with different design constraints that arise from the possible use scenarios of the IPL-MC, it has been decided within SES SDR to define different profiles. The main target frequency bands and channel bandwidths are:

Table 1: Definition of different profiles

Profile name	IPL-MC-A	IPL-MC-B	IPL-MC-C	IPL-MC-D
Typical use	S-Band DVB-T	S-Band SDR	L-Band SDR	S-Band SDR
Supported modes	1	2	3 and 4	3 and 4
Carrier frequency	2,0 GHz to 2,3 GHz	2,0 GHz to 2,3 GHz	1,4 GHz to 1,5 GHz	2,0 GHz to 2,3 GHz
Channel bandwidth	4,76 MHz	4,76 MHz	1,536 MHz	1,536 MHz
Channel spacing	5 MHz	5 MHz	1,712 MHz	1,712 MHz

The present document does not restrict its use to the application scenarios as denoted above. Other frequency bands or channel bandwidths may be used but the parameter selection may not be optimal. Due to the definition of a framing adaptation layer towards the IPL of DVB-T, the complete IPL of DVB-T can be reused without any changes. However, only the 2k mode of DVB-T is considered here.

4.2.2 Modes definition

The different modes that are defined are as follows.

Table 2: Definition of different modes

Mode 1 2k@5MHz pilots equal to DVB-T	IPL identical to IPL of DVB-T. Parameter set inline with DVB-T 5 MHz mode (4,76 MHz bandwidth, 2k number of sub-carriers)
Mode 2 2k@5MHz new pilot pattern	Mode optimized for requirements of frequency bands using channel spacing of 5 MHz with 2k number of carriers. Parameter set recommended for networks with high delay spread and high vehicle speed
Mode 3 1k@1,7MHz new pilot pattern	Mode optimized for requirements of frequency bands using channel spacing of 1,7 MHz. Parameter set recommended for networks with very high delay spread (e.g. SFN network with high power repeater), 1k number of carriers, preamble symbol, continuous and scattered pilots with pilot density of approximately 17 %
Mode 4 0,5k@1,7MHz new pilot pattern	Similar to mode 3. Support of higher vehicle speed (carrier spacing doubled, shorter guard interval), 0,5k number of carriers

While mode 1 is identical to DVB-T, the other modes use a completely new pilot pattern.

The parameters for all modes are denoted in Table 3 and Table 4.

4.2.3 Parameters for QPSK subcarrier mapping

The following table displays the parameters defined for the QPSK modulation of the OFDM subcarriers.

Table 3: Parameters derived in modes 1 to 4 for QPSK modulation of the OFDM subcarriers

	unit	DVB-T 2k (unchanged)	SES SDR 2k (with preamble)	SES SDR 1k (with preamble)	SES SDR 0,5k (with preamble)
Mode Identifier		**1**	**2**	**3**	**4**
FFT length		2 048	2 048	1 024	512
Used sub-carriers		1 705	1 509	729	365
Guard interval ratio		0,25	0,25	0,25	0,25
Sampling Frequency (fractional)	MHz	40/7	484/75	484/225	484/225
Sampling Frequency (rounded)	MHz	5,714 3	6,453 3	2,1511	2,1511
Pilots per OFDM symbol		193	262	127	64
Capacity unit size incl. RFU	bits	(Punctured) 2 016	2 064	2 064	2 064
Modulation index		2	2	2	2
Signal Bandwidth	MHz	4,7573	4,754 9	1,531 4	1,533 5
Samples per symbol		2 560	2 560	1 280	640
Symbol length incl. guard interval	µs	448,00	396,69	595,04	297,52
Guard interval length	µs	89,60	79,34	119,01	59,50
sub-carrier distance in kHz	kHz	2,79	3,15	2,10	4,20
Data sub-carriers per symbol		1 512	1 247	602	301
OFDM Symbols per Phy section		68	24	24	24
Data sub-carriers per Phy section		102 816	29 928	14 448	7 224
Bit per Phy section		205 632	59 856	28 896	14 448
CU per Phy section		**102**	**29**	**14**	**7**
Length of Phy section	ms	30,46	9,52	14,28	7,14
Padding bits		0	0	0	0
preamble per IPL-MC frame		0	1	1	1
Phy sections per IPL-MC frame		4	5	5	5
sub-carrier per IPL-MC frame		411 264	150 887	72 842	36 421
Bit per IPL-MC frame		822 528	301 774	145 684	72 842
Length of IPL-MC frame	ms	121,86	48,00	72,00	36,00
CU per IPL-MC frame		**408**	**145**	**70**	**35**
Padding bits (informative only)		0	0	0	0

4.2.4 Parameters for 16QAM subcarrier mapping

The following table displays the parameters defined for the 16QAM modulation of the OFDM subcarriers.

Table 4: Parameters derived in modes 1 to 4 for 16QAM modulation of the OFDM subcarriers

	unit	DVB-T 2k (unchanged)	SES SDR 2k (with preamble)	SES SDR 1k (with preamble)	SES SDR 0.5k (with preamble)
Mode Identifier		**1**	**2**	**3**	**4**
FFT length		2 048	2 048	1 024	512
Used sub-carriers		1 705	1 509	729	365
Guard interval ratio		0,25	0,25	0,25	0,25
Sampling Frequency (fractional)	MHz	40/7	484/75	484/225	484/225
Sampling Frequency (rounded)	MHz	5,714 3	6,453 3	2,151 1	2,151 1
Pilots per OFDM symbol		193	262	127	64
Capacity unit size incl. RFU	bits	(Punctured) 2 016	2 064	2 064	2 064
Modulation index		4	4	4	4
Signal Bandwidth	MHz	4,757 3	4,754 9	1,531 4	1,533 5
Samples per symbol		2 560	2 560	1 280	640
Symbol length incl. guard interval	µs	448,00	396,69	595,04	297,52
Guard interval length	µs	89,60	79,34	119,01	59,50
sub-carrier distance in kHz	kHz	2,79	3,15	2,10	4,20
Data sub-carriers per symbol		1 512	1 247	602	301
OFDM Symbols per Phy section		68	24	24	24
Data sub-carriers per Phy section		102 816	29 928	14 448	7 224
Bit per Phy section		411 264	119 712	57 792	28 896
CU per Phy section		**204**	**58**	**28**	**14**
Length of Phy section	ms	30,46	9,52	14,28	7,14
Padding bits		0	0	0	0
preamble per IPL-MC frame		0	1	1	1
Phy sections per IPL-MC frame		4	5	5	5
sub-carrier per IPL-MC frame		411 264	150 887	72 842	36 421
Bit per IPL-MC frame		1 645 056	603 548	291 368	145 684
Length of IPL-MC frame	ms	121,86	48,00	72,00	36,00
CU per IPL-MC frame		**816**	**290**	**140**	**70**
Padding bits (informative only)		0	0	0	0

4.3 Generation of one Phy section

4.3.1 Overview

The generation of one Phy section is performed as follows:

- handling of data payload (capacity units, CU, etc.);
- puncturing of capacity units, applicable only to mode 1;
- handling of signalling bits (RFU: reserved for future use), applicable only to modes 2, 3 and 4;
- scrambling for energy dispersal;
- accumulation of CU for one Phy section.

4.3.1.1 Overview of mode 1

Figure 4 displays the generation of one Phy section in mode 1.

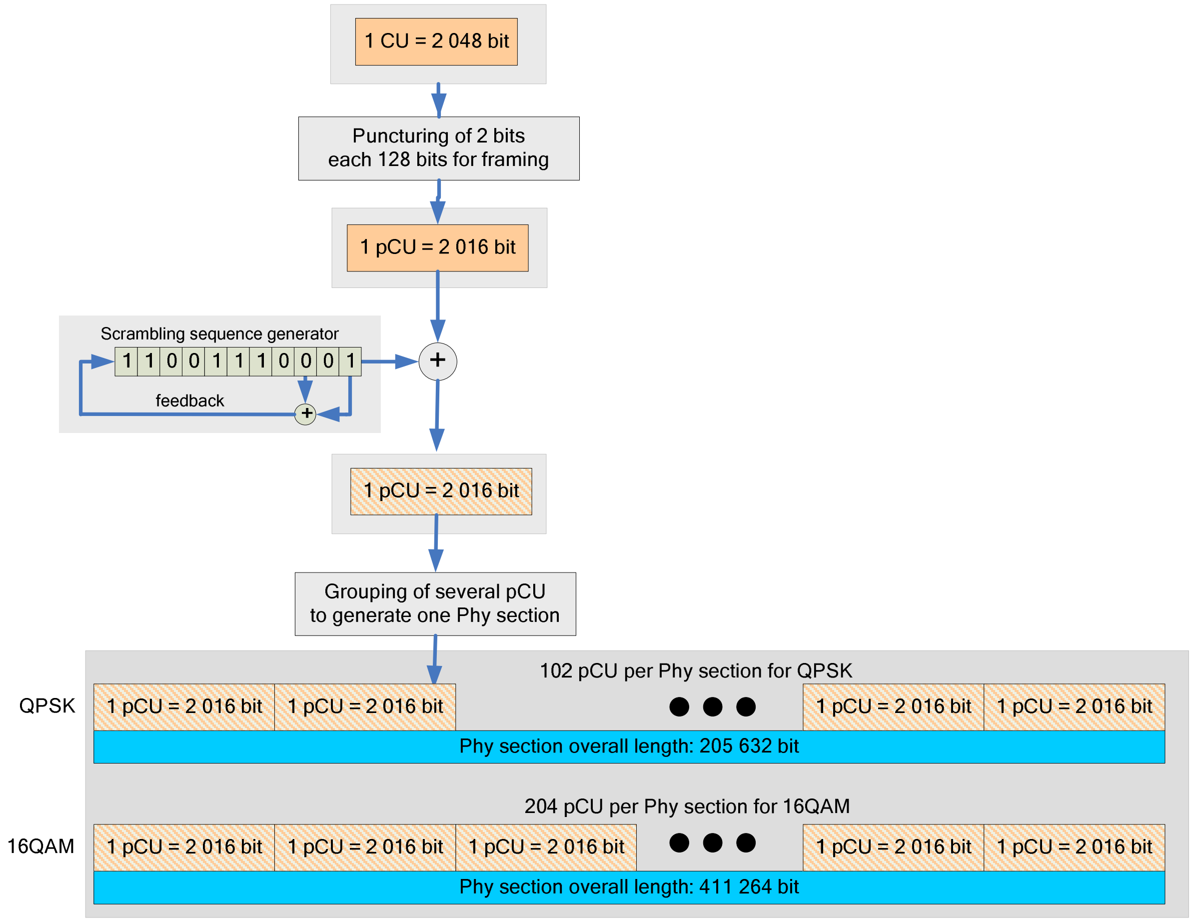

Figure 4: Overview of the generation of one Phy section for mode 1

4.3.1.2 Overview of mode 2, 3 and 4

Figure 5 displays the generation of one Phy section in mode 2, 3 and 4.

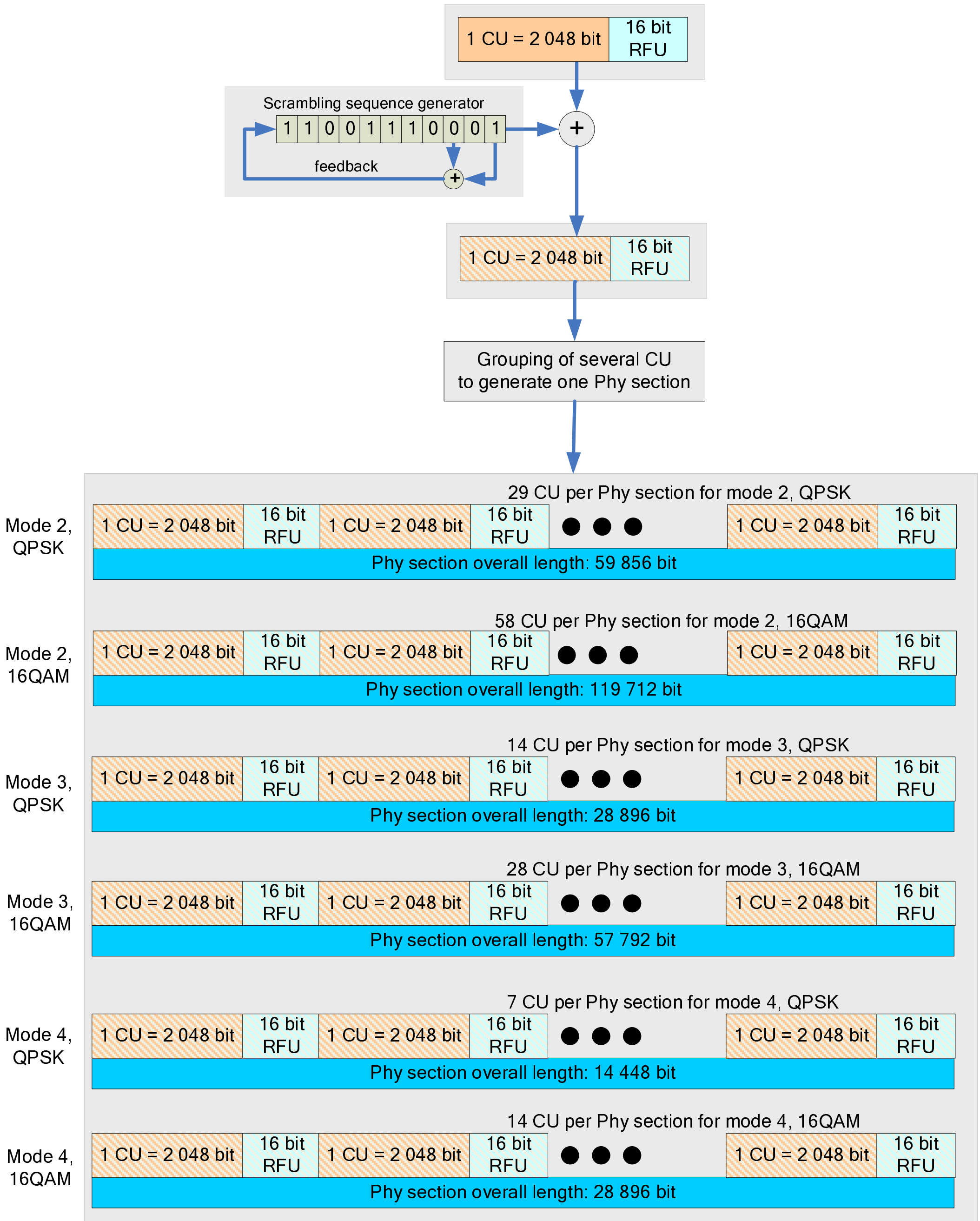

Figure 5: Overview of the generation of one Phy section for modes 2, 3 and 4

4.3.2 Puncturing of capacity units

NOTE: The present clause 4.3.2 only applies to mode 1 transmission.

In transmission mode 1, the sequence of CU as generated in TS 102 550 (V1.2.1, see bibliography) has to be modified to be transported using the mode 1 symbol structure. Each capacity unit comprising 2048 bits is punctured as depicted in Figure 6. The puncturing is applied to all capacity units, including capacity units containing the signalling pipe and the start-of-frame preamble. The block size for one pCU is 2 016 bits after puncturing, see also Figure 4.

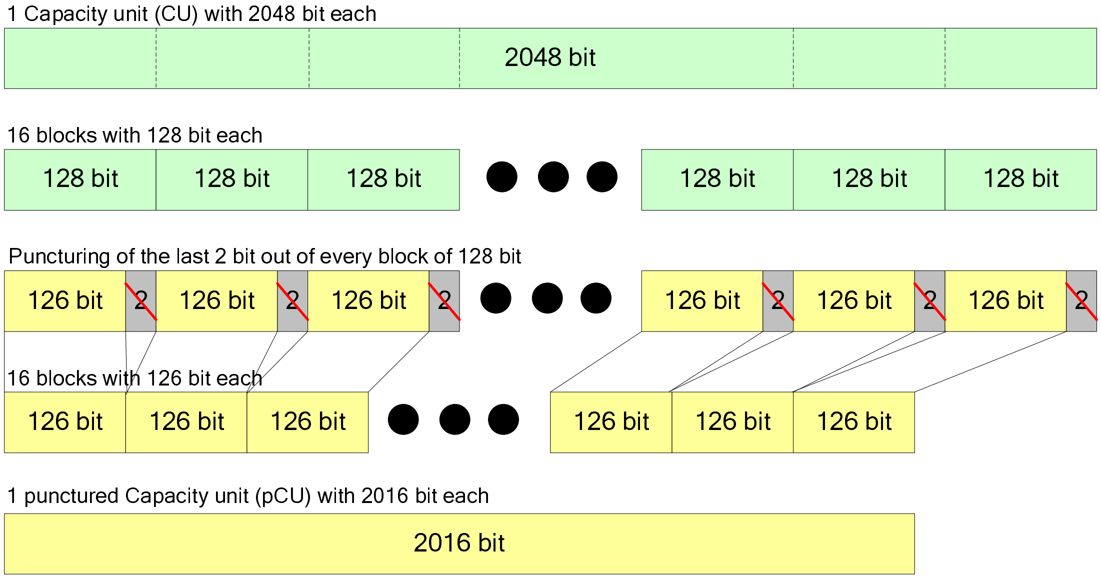

Figure 6: Adaptation of C-TS bitstream to mode 1 transmission

4.3.3 RFU section insertion

NOTE: the present clause 4.3.3 only applies to mode 2, 3 and 4 transmission

In modes 2, 3 and 4, each CU is followed by 16 signalling bits which are currently not used but are reserved for future use. All bits are set to zero. The block size for one CU after RFU insertion is 2 064 bits, see also Figure 5.

4.3.4 Energy dispersal (scrambling)

Energy dispersal is applied to the data payload and the RFU bits. The energy dispersal is performed using a length 2 047 (2^{11} - 1) scrambler with an internal shift register of length 11. The scrambler is described using the following generator polynomial as derived from ITU-T Recommendation O.153 (see bibliography).

$X^{11} + X^9 + 1$, initial state is set to "11001110001" (see Figure 7):

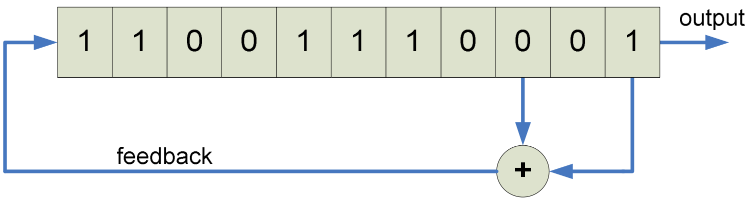

Figure 7: Scrambler used for energy dispersal

The output of the scrambler of length 2 016 (in mode 1) or 2 064 (in mode 2-4) is XOR-ed with the first 2 016 bit or 2 064 bit of the bitstream as depicted in Figure 4 and Figure 5. The scrambler is initialized at each start of one CU. If the size of the data that has to be scrambled exceeds one cycle of the scrambler, then the scrambler just continues periodically.

4.3.5 Accumulation of CU into one Phy section

According to the transport capability of the different modes and different modulation orders, the Phy sections are generated. Refer to Table 3 and Table 4 for details.

CU padding at the end of the IPL-MC frame: As it is a mandatory requirement of the C-TS multiplexer at the output of the OPL to adapt the number of CU to the transport capability of the IPL-MC frame, no additional padding of empty CU is necessary; however, padding of empty CU may be foreseen to support such erroneous situations.

4.4 Pilot tone insertion and signalling

The present clause specifies the reference signals for the different modes.

4.4.1 Mode 1: 2k@5MHz; identical to DVB-T

Mode 1 is directly adapted from [1].

4.4.1.1 Signal constellation and mapping

The system uses Orthogonal Frequency Division Multiplex (OFDM) transmission. All data carriers in one Phy section are modulated using either QPSK, 16-QAM or non-uniform 16-QAM constellations. The constellations, and the details of the Gray mapping applied to them, are illustrated in Figure 17 to Figure 20.

The exact proportions of the constellations depend on a parameter α, which can take the two values 2 or 4. The parameter α is the minimum distance separating two constellation points carrying different HP-bit values divided by the minimum distance separating any two constellation points.

4.4.1.2 Symbol interleaver

The purpose of the symbol interleaver is to rearrange the 1 512 data symbols of the active carriers per OFDM symbol, and therefore acts on vectors of 1 512 data symbols.

The 1 512 data symbols are grouped in a vector Y' = $(y''_0, y''_1, y''_2, ...y''_{1511})$. 21 symbols of Y'' form a group of symbols, thus the 1 512 data symbols are split into 72 groups.

The interleaved vector Y = $(y_0, y_1, y_2, ...y_{Nmax-1})$ at the output of the symbol interleaver is defined by:

$y_{H(q) =} y'_q$ for even symbols for q = 0, ..., 1 511

$y_q = y'_{H(q)}$ for odd symbols for q = 0, ..., 1 511

The symbol index, defining the position of the current OFDM symbol in the Phy section, is defined in clause 4.4.1.3.

An $(N_r - 1)$ bit binary word R'_{ii} is defined, where R'_{ii} takes the following values for N_r =11:

ii = 0,1: R'_{ii} $[N_r-2, N_r-3, ..., 1, 0]$ = 0, 0, ..., 0, 0

ii = 2: R'_{ii} $[N_r-2, N_r-3, ..., 1, 0]$ = 0, 0, ..., 0, 1

2 < ii < 2 048: R'_{ii} $[N_r-3, N_r-4, ..., 1, 0]$ = R'_{ii-1} $[N_r -2, N_r -3, ..., 2, 1]$;

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

A vector R_{ii} is derived from the vector R'_{ii} by the bit permutations given in Table 5.

Table 5: Bit permutations for the 2K mode

R'_{ii} bit positions	9	8	7	6	5	4	3	2	1	0
R_{ii} bit positions	0	7	5	1	8	2	6	9	3	4

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

q=0;
for (ii = 0; ii < 2048; ii = ii + 1) {
$$H(q) = (ii \bmod 2) \cdot 2^{N_r - 1} + \sum_{j=0}^{N_r - 2} R_i(j) \cdot 2^j;$$
;
if (H(q) < 1512) {
q = q + 1;
}
}

A schematic block diagram of the algorithm used to generate the permutation function is represented in Figure 8.

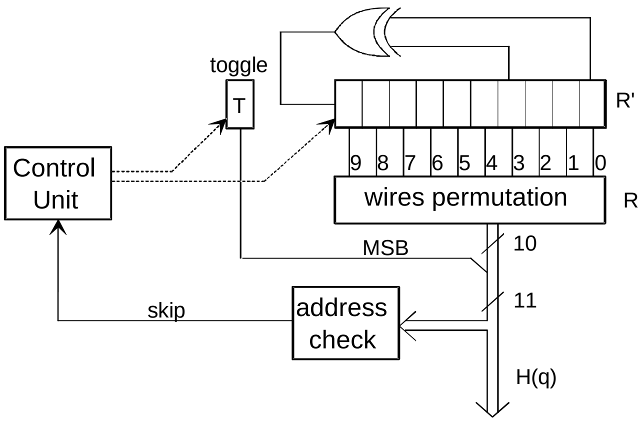

Figure 8: Symbol interleaver address generation scheme for mode 1

4.4.1.3 IPL-MC frame structure

The present clause specifies the OFDM frame structure to use for transmission mode 1.

The transmitted signal is organized in Phy sections. Each Phy section has a duration of T_F, and consists of 68 OFDM symbols. Four Phy sections constitute one IPL-MC frame. Each symbol is constituted by a set of K = 1 705 carriers and transmitted with a duration T_S. It is composed of two parts: a useful part with duration T_U and a guard interval with a duration Δ. The guard interval consists in a cyclic continuation of the useful part, T_U, and is inserted before it. Two values of guard intervals may be used according to Table 22.

The symbols in one Phy section 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 the following reference information is contained:

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

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

The carriers are indexed by $k \in [K_{min}; K_{max}]$ and determined by $K_{min} = 0$ and $K_{max} = 1\ 704$. 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 mode 1 are given in Table 6 for 5 MHz channels.

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

The elementary period T is 7/40 µs for 5 MHz channels.

Table 6: Numerical values for the OFDM parameters for mode 1 in 5 MHz channels

Parameter	Mode 1
Number of carriers K	1 705
Value of carrier number K_{min}	0
Value of carrier number K_{max}	1 704
Duration T_U	358,40 µs
Carrier spacing $1/T_U$	2 790,179 Hz
Spacing between carriers K_{min} and K_{max} $(K-1)/T_U$	4,75 MHz

4.4.1.4 Reference signals

This clause specifies the mode independent Reference signals processes and the parameters to use for transmission mode 1.

4.4.1.4.1 Functions and derivation

Various cells within the IPL-MC frame are modulated with reference information whose transmitted value is known to the receiver. Cells containing reference information are transmitted at "boosted" power level (see clause 4.4.1.4.5). 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 mode 1.

The value of the scattered or continual pilot information is derived from a Pseudo Random Binary Sequence (PRBS) which is a series of values, one for each of the transmitted carriers (see clause 4.4.1.4.2).

4.4.1.4.2 Definition of reference sequence

The continual and scattered pilots are modulated according to a PRBS sequence, w_k, corresponding to their respective carrier index k. This sequence also governs the starting phase of the TPS information (described in clause 4.4.1.4.2).

The PRBS sequence is generated according to Figure 9.

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

Initialization sequence.

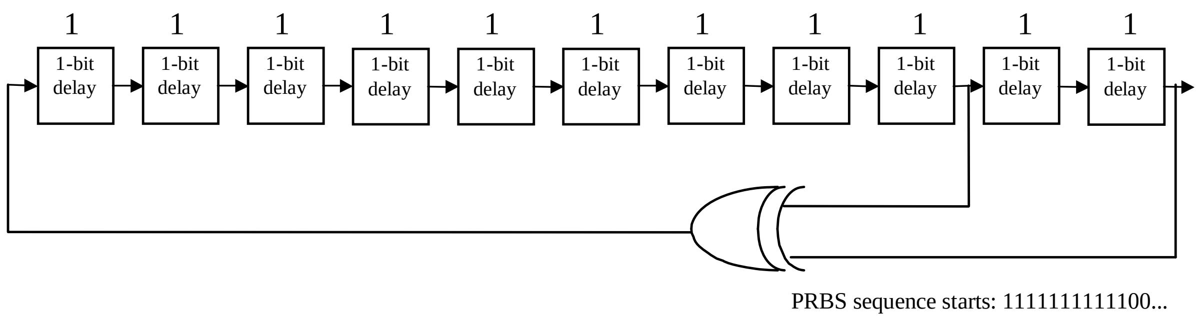

Figure 9: Generation of PRBS sequence

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

$$X^{11} + X^2 + 1 \text{ (see Figure 9)}$$

4.4.1.4.3 Location of scattered pilot cells

Reference information, taken from the reference sequence, is transmitted in scattered pilot cells in every symbol. Scattered pilot cells are always transmitted at the "boosted" power level (see clause 4.4.1.3.4). Thus the corresponding modulation is given by:

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

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

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 10.

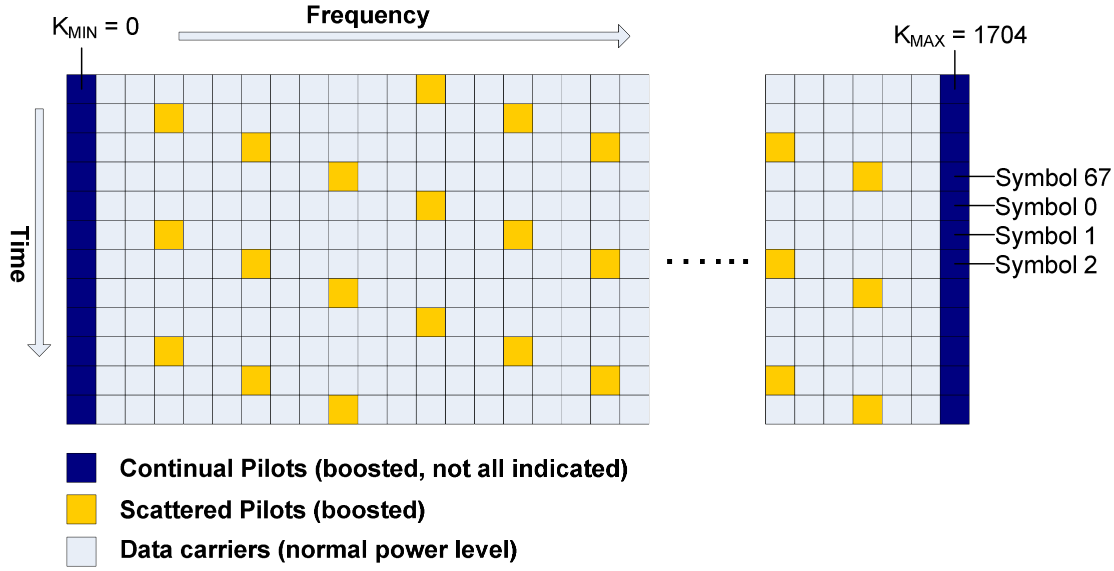

Figure 10: Frame structure showing pilot insertion pattern

4.4.1.4.4 Location of continual pilot carriers

In addition to the scattered pilots described above, 45 continual (see note) pilots in mode 1 are inserted according to Table 7.

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

Table 7: Continual pilot carrier positions (index number k)

Mode 1						
0	48	54	87	141	156	192
201	255	279	282	333	432	450
483	525	531	618	636	714	759
765	780	804	873	888	918	939
942	969	984	1 050	1 101	1 107	1 110
1 137	1 140	1 146	1 206	1 269	1 323	1 377
1 491	1 683	1 704				

All continual pilots are modulated according to the reference sequence, see clause 4.4.1.3.2.

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

Thus the corresponding modulation is given by:

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

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

4.4.1.4.5 Amplitudes of all reference information

The modulation of all data cells is normalized so that $E[c \times c^*] = 1$.

All cells which are continual or scattered pilots, i.e. they are members of the sets defined in clause 4.4.1.3.3 or clause 4.4.1.3.4, are transmitted at boosted power so that for these $E[c \times c^*] = 16/9$.

4.4.1.5 TPS transmission format

The present clause specifies the Transmission Parameter Signalling (TPS).

The TPS carriers are used for the purpose of signalling parameters related to the transmission scheme, i.e. to channel modulation. The TPS is transmitted in parallel on 17 TPS carriers for mode 1. Every TPS carrier in the same symbol conveys the same differentially encoded information bit. The following carrier indices contain TPS carriers.

Table 8: Carrier indices for TPS carriers

Mode 1				
34	50	209	346	413
569	595	688	790	901
1 073	1 219	1 262	1 286	1 469
1 594	1 687			

The TPS carriers convey information on:

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

b) hierarchy information;

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

d) SDR indicator;

e) transmission mode (2K);

f) Phy section number in an IPL-MC frame;

g) cell identification.

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

4.4.1.5.1 Scope of the TPS

The TPS is defined over 68 consecutive OFDM symbols, referred to as one Phy section. Four consecutive Phy sections correspond to one IPL-MC frame.

The reference sequence corresponding to the TPS carriers of the first symbol of each Phy section are used to initialize the TPS modulation on each TPS carrier (see clause 4.4.1.3.2).

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

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

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

4.4.1.5.2 TPS transmission format

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

The mapping of each of the transmission parameters: constellation characteristics, α value, code rate(s), Phy section indicator and guard interval onto the bit combinations is performed according to clauses TPS_01 to TPS_11.
The left most bit is sent first.

Table 9: TPS signalling information and format

Bit number	Format	Purpose/Content
s_0	See clause TPS_01	Initialization
$s_1$to s_{16}	See clause TPS_02	Synchronization word
s_{17} to s_{22}	See clause TPS_03	Length indicator
s_{23}, s_{24}	See clause TPS_04	Phy section number
s_{25}, s_{26}	See clause TPS_05	Constellation
s_{27}, s_{28}, s_{29}	See clause TPS_06	Hierarchy information
s_{30}, s_{31}, s_{32}	See clause TPS_07 [fixed to "111"]	SDR indicator
s_{33}, s_{34}, s_{35}	See clause TPS_07 [fixed to "111"]	SDR indicator
s_{36}, s_{37}	See clause TPS_08	Guard interval
s_{38}, s_{39}	See clause TPS_09 [fixed to "00"]	Transmission mode
s_{40} to s_{47}	See clause TPS_10	Cell identifier
s_{48} to s_{53}	[all set to "0"]	Not used
s_{54} to s_{67}	See clause TPS_11 BCH code	Error protection

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

Clause TPS_01:
The first bit, s_0, is an initialization bit for the differential 2-PSK modulation. The modulation of the TPS initialization bit is derived from the PRBS sequence defined in chapter 4.4.1.3.2. This process is described in chapter 4.4.1.4.3.

Clause TPS_02:
Bits 1 to 16 of the TPS is a synchronization word.

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

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

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

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

Clause TPS_03:
The first 6 bits of the TPS information is used as a TPS length indicator (binary count starting from and including bit s_{17}) to signal the number of used bits of the TPS.

The transmission of the Cell Identification (see clause TPS_10) is optional. The TPS length indicator carries then the values:

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

Clause TPS_04:
Four Phy sections constitute one IPL-MC frame. The frames inside the IPL-MC frame are numbered from 1 to 4. The mapping from bits s_{23}, s_{24} to the frame number is given in Table 10.

Table 10: Signalling format for Phy section number

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

Clause TPS_05:
The constellation shall be signalled by 2 bits according to Table 11. In order to determine the modulation scheme, the receiver shall also decode the hierarchy information given in Table 12.

Table 11: Signalling format for the possible constellation patterns

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

Clause TPS_06:
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 Figure 18 to Figure 20, where α is signalled by three bits according to Table 12.

Table 12: Signalling format for the α values

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

Clause TPS_07:
The SDR standard does not make use of signalling the code rate through the TPS bits, but this information is contained in the signalling pipe as described in TS 102 550 (see bibliography).

Respecting the TPS structure introduced in [1], the code rate selector bits s_{30} to s_{35} are all set to "1". This is the so-called "SDR indicator" and is not in conflict with the definition in [1].

Table 13: Signalling format for each of the code rates

Bits s_{30}, s_{31}, s_{32} (HP stream) s_{33}, s_{34}, s_{35} (LP stream)	Code rate
000	Reserved
001	Reserved
010	Reserved
011	Reserved
100	Reserved
101	Reserved
110	Reserved
111	SDR indicator

Clause TPS_08:
The value of the guard interval is signalled according to Table 14:

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

Bits s_{36}, s_{37}	Guard interval values (Δ/T_U)
00	Reserved
01	Reserved
10	1/8
11	1/4

Clause TPS_09:
Two bits are used to signal the transmission mode. Only 2K mode is used.

Table 15: Signalling format for transmission mode

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

Clause TPS_10:
The eight bits s_{40} to s_{47} are used to identify the cell from which the signal comes from. The most significant byte of the cell_id [4], i.e. b_{15} - b_{8}, shall be transmitted in Phy sections with number 1 and 3. The least significant byte of the cell_id, i.e. b_7 - b_0, shall be transmitted in Phy sections with number 2 and 4. The mapping of bits is according to Table 16. If the provision of the cell_id is not foreseen the eight bits shall be set to zero.

Table 16: Mapping of the cell_id on the TPS bits

TPS bit number	Phy section number 1 or 3	Phy section number 2 or 4
s_{40}	cell_id b_{15}	cell_id b_7
s_{41}	cell_id b_{14}	cell_id b_6
s_{42}	cell_id b_{13}	cell_id b_5
s_{43}	cell_id b_{12}	cell_id b_4
s_{44}	cell_id b_{11}	cell_id b_3
s_{45}	cell_id b_{10}	cell_id b_2
s_{46}	cell_id b_9	cell_id b_1
s_{47}	cell_id b_8	cell_id b_0

Clause TPS_11:
The 53 bits containing the TPS synchronization and information (bits s_1 - s_{53}) are extended with 14 parity bits of the BCH (67,53, t = 2) shortened code, derived from the original systematic BCH (127,113, t = 2) code.

Code generator polynomial:

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

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

4.4.1.5.3 TPS modulation

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

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

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

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

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

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

4.4.2 Mode 2: 2k@5MHz

Mode 2 is designed to work in a channel grid of 5 MHz. Using an FFT of 2 048 points with 1 509 active carriers, this leads to a carrier spacing of roughly 3,2 kHz and a guard interval length of 79 µs. Mode 2 provides a pilot density of approximately 17 %. The pilots are arranged in groups, each having a length of 52 carriers.

Each IPL-MC frame is generated by the combination of one frequency domain preamble (one entire OFDM symbol) and five Phy sections, each having a length of 24 OFDM symbols. Therefore, each IPL-MC frame consists of 121 OFDM symbols that are denoted from index `l = 0` to `l = 120`.

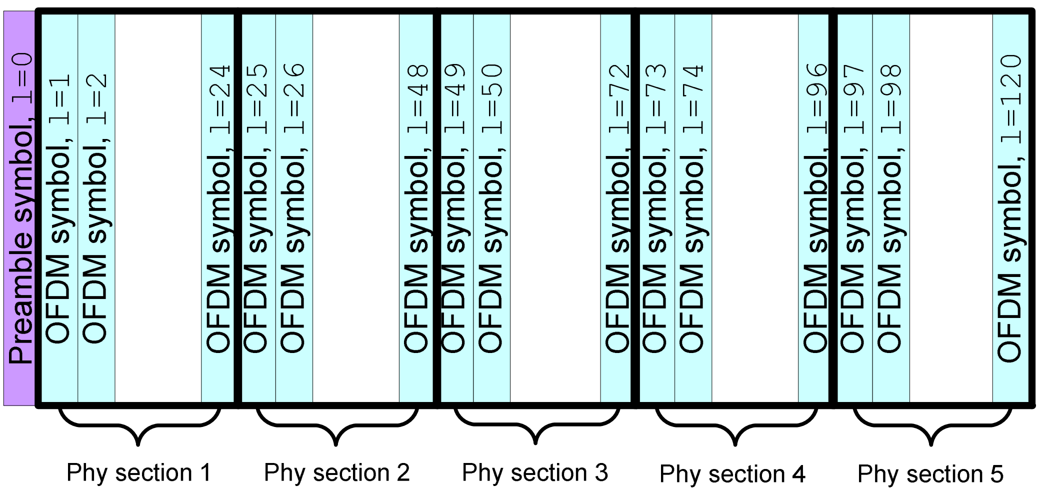

Figure 11: Framing structure of one IPL-MC frame consisting of one preamble and five Phy sections

4.4.2.1 Preamble insertion

The first OFDM symbol (`l = 0`) of each IPL-MC frame is dedicated to be used as a preamble sequence. This preamble is called "frequency domain preamble".

The following sequence is inserted. The notation is made in the frequency domain. Each subcarrier of this preamble is a priori known to the receiver.

The preamble is defined as a vector of modulation symbols in the frequency domain from carrier `Kmin` to `Kmax`. The parameters are as follows:

First active carrier: **Kmin** = 0;
Last active carrier: **Kmax** = 1508;

The preamble is set to the following values in the frequency domain; the amplitude of each active subcarrier is then boosted by `4/3`. The average power of one active subcarrier of the preamble symbol is `E[c×c*] = 16/9`.

```
0, -1, 0, -1, 0, -1, 0, 1,    0, 1, 0, 1, 0, 1, 0, 1,    0, -1, 0, 1, 0, 1, 0, 1,    0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, -1, 0, 1,    0, 1, 0, 1, 0, -1, 0, 1,    0, 1, 0, 1, 0, -1, 0, 1,    0, 1, 0, 1, 0, 1, 0, 1,
0, -1, 0, 1, 0, -1, 0, 1,    0, -1, 0, 1, 0, 1, 0, -1,    0, 1, 0, -1, 0, -1, 0, -1,    0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,    0, -1, 0, -1, 0, 1, 0, 1,    0, -1, 0, 1, 0, -1, 0, 1,    0, 1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, 1, 0, 1,    0, -1, 0, -1, 0, -1, 0, 1,    0, -1, 0, 1, 0, 1, 0, 1,    0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,    0, -1, 0, 1, 0, 1, 0, -1,    0, 1, 0, -1, 0, -1, 0, 1,    0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, 1, 0, -1, 0, 1,    0, -1, 0, 1, 0, -1, 0, 1,    0, 1, 0, -1, 0, -1, 0, 1,    0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, 1, 0, 1, 0, -1,    0, 1, 0, 1, 0, 1, 0, 1,    0, -1, 0, 1, 0, -1, 0, -1,    0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, 1, 0, 1, 0, -1,    0, 1, 0, 1, 0, 1, 0, -1,    0, 1, 0, -1, 0, 1, 0, -1,    0, -1, 0, 1, 0, -1, 0, -1,
0, 1, 0, -1, 0, 1, 0, -1,    0, 1, 0, -1, 0, 1, 0, 1,    0, -1, 0, -1, 0, 1, 0, -1,    0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, -1, 0, 1,    0, -1, 0, -1, 0, 1, 0, 1,    0, 1, 0, 1, 0, 1, 0, -1,    0, 1, 0, -1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, -1,    0, -1, 0, -1, 0, -1, 0, -1,    0, -1, 0, -1, 0, -1, 0, 1,    0, -1, 0, -1, 0, 1, 0, 1,
0, -1, 0, -1, 0, 1, 0, 1,    0, 1, 0, 1, 0, 1, 0, 1,    0, 1, 0, 1, 0, 1, 0, -1,    0, 1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, -1, 0, -1,    0, 1, 0, 1, 0, -1, 0, -1,    0, -1, 0, -1, 0, -1, 0, -1,    0, 1, 0, -1, 0, -1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,    0, 1, 0, -1, 0, 1, 0, -1,    0, -1, 0, 1, 0, 1, 0, -1,    0, -1, 0, -1, 0, -1, 0, 1,
0, 1, 0, -1, 0, -1, 0, -1,    0, -1, 0, 1, 0, 1, 0, -1,    0, 1, 0, 1, 0, 1, 0, 1,    0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, -1, 0, 1,    0, 1, 0, 1, 0, -1, 0, -1,    0, -1, 0, -1, 0, -1, 0, -1,    0, -1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, 1, 0, -1,    0, 1, 0, 1, 0, -1, 0, -1,    0, 1, 0, -1, 0, -1, 0, 1,    0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, -1,    0, -1, 0, -1, 0, 1, 0, -1,    0, 1, 0, 1, 0, 1, 0, -1,    0, -1, 0, 1, 0, 1, 0, -1,
0, 1, 0, 1, 0, -1, 0, -1,    0, 1, 0, 1, 0, 1, 0, 1,    0, -1, 0, 1, 0, 1, 0, 1,    0, 1, 0, -1, 0, -1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,    0, 1, 0, -1, 0, 1, 0, 1,    0, -1, 0, 1, 0, -1, 0, 1,    0, 1, 0, -1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,    0, -1, 0, -1, 0, 1, 0, -1,    0, 1, 0, -1, 0, -1, 0, 1,    0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, 1, 0, -1, 0, -1,    0, -1, 0, -1, 0, 1, 0, 1,    0, -1, 0, 1, 0, -1, 0, 1,    0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, 1, 0, 1,    0, 1, 0, 1, 0, -1, 0, -1,    0, -1, 0, 1, 0, -1, 0, 1,    0, -1, 0, 1, 0, -1, 0, -1,
0, -1, 0, 1, 0, 1, 0, 1,    0, -1, 0, 1, 0, 1, 0, 1,    0, 1, 0, 1, 0, -1, 0, -1,    0, 1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, -1, 0, -1,    0, -1, 0, 1, 0, 1, 0, -1,    0, -1, 0, -1, 0, -1, 0, 1,    0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,    0, -1, 0, -1, 0, -1, 0, 1,    0, -1, 0, 1, 0, -1, 0, -1,    0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,    0, -1, 0, 1, 0, -1, 0, -1,    0, -1, 0, 1, 0, 1, 0, -1,    0, 1, 0, 1, 0, -1, 0, -1,
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0, 1, 0, 1, 0, 1, 0, 1,    0, -1, 0, 1, 0, -1, 0, -1,    0, -1, 0, 1, 0, -1, 0, 1,    0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,    0, -1, 0, 1, 0, -1, 0, -1,    0, 1, 0, -1, 0, 1, 0, 1,    0, 1, 0, -1, 0, -1, 0, 1,
0, -1, 0, 1, 0, -1, 0, 1,    0, -1, 0, 1, 0, -1, 0, -1,    0, -1, 0, -1, 0, 1, 0, 1,    0, -1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,    0, -1, 0, 1, 0, 1, 0, 1,    0, -1, 0, 1, 0, 1, 0, -1,    0, -1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, 1,    0, -1, 0, -1, 0, -1, 0, -1,    0, 1, 0, -1, 0, 1, 0, -1,    0, -1, 0, -1, 0, 1, 0, -1,
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0, -1, 0, 1, 0, 1, 0, 1,    0, -1, 0, -1, 0, -1, 0, 1,    0, 1, 0, -1, 0, -1, 0, 1,    0, -1, 0, -1, 0, -1, 0, -1,
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0, 1, 0, 1, 0, -1, 0, 1,    0, 1, 0, 1, 0, -1, 0, 1,    0, -1, 0, 1, 0, 1, 0, 1,    0, -1, 0, 1, 0, 1, 0, 1,
0, 1, 0, -1, 0, -1, 0, 1,    0, -1, 0, 1, 0, 1, 0, 1,    0, 1, 0, 1, 0, -1, 0, 1,    0, -1, 0, 1, 0, -1, 0, 1,
0, -1, 0, -1, 0, 1, 0, -1,    0, -1, 0, -1, 0, 1, 0, -1,    0, -1, 0, -1, 0, 1, 0, 1,    0, -1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, -1,    0, -1, 0, -1, 0, 1, 0, -1,    0, 1, 0, -1, 0, 1, 0, 1,    0, -1, 0, -1, 0, -1, 0, -1,
0, -1, 0, 1, 0, -1, 0, -1,    0, -1, 0, 1, 0, -1, 0, 1,    0, -1, 0, 1, 0, -1, 0, 1,    0, -1, 0, -1, 0, -1, 0, -1,
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0, 1, 0, 1, 0, -1, 0, -1,    0, -1, 0, 1, 0, 1, 0, -1,    0, -1, 0, -1, 0, 1, 0, -1,    0, 1, 0, -1, 0, -1, 0, -1,
0, 1, 0, -1, 0;
```
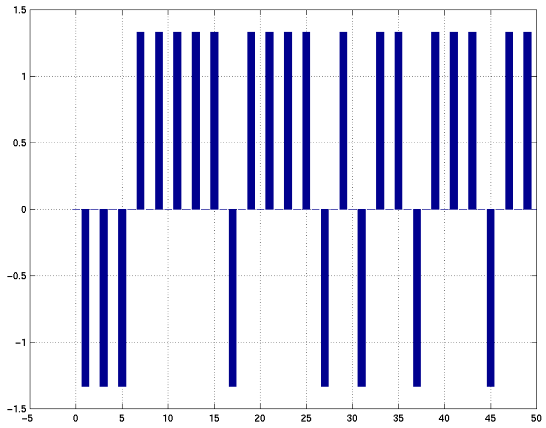
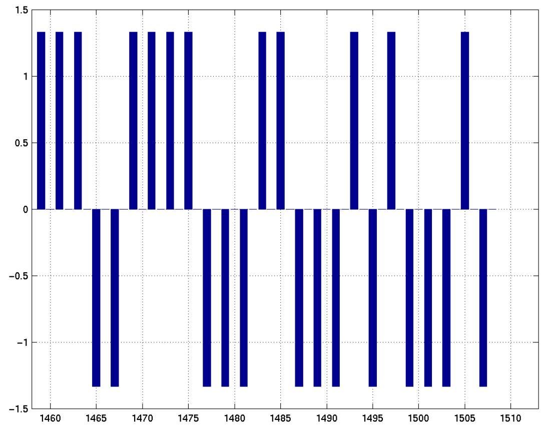



First carriers of the preamble around `Kmin = 0` (start)



Last carriers of the preamble around `Kmax = 1 508` (end)

4.4.2.2 Scattered pilots

Scattered pilots are introduced with a repetition pattern of 24 OFDM symbols into the Phy sections. Therefore this pilot pattern repeats five times within the 120 OFDM symbols (excluding the preamble) that form one IPL-MC frame.

In the frequency domain, the scattered pilots have a period of 52 symbols. Following the notation introduced before, the parameters for pilot tone insertion are as stated below:

Number of different segments in the frequency domain:	**NumberOfSegments** = 29;
Carrier increment per segment:	**SegmentIncrement** = 52;
Carrier offset per OFDM symbol:	**SymbolOffset** = ... {2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6};
OFDM symbol count (per OFDM frame):	**l** = {1, 2, 3, ... , 118, 119, 120};

The index of scattered pilots of segment `m` in an OFDM symbol at time index `l` is denoted using the following formula:

```
Idx(l,m)=[1 7 13 19 25 31 37 43]+SymbolOffset[(l-1) mod 24]+m × SegmentIncrement;
{m ∈ [0; 28]; l ∈ [1; 120]}
```

The amplitude of the scattered pilots are chosen to `4/3`. The average power of the scattered pilots (`E[c×c*] = 16/9`) is higher than the average power of the data symbols which are normalized to power `1`, therefore the pilots are denoted as boosted pilots.

The phase of the scattered pilots (within one segment) is described using the following vector:

```
ScatPilotPhase = [ 0 0 π π 0 π 0 π ]
```

The entity of all scattered pilots per segment are further phase-rotated by the vector `GroupPhase`, dependent on the selection of the mapping scheme of the data subcarriers as defined in Table 17.

Table 17: `GroupPhase` definition for mode 2

GroupPhase	Selected mapping scheme
[0 π 0 0 π 0 0 π 0 0 π π 0 π π ... 0 0 π 0 π π π π 0 π 0 π 0 0 π]	QPSK
[π π π 0 π 0 π π π 0 0 π 0 π 0 ... 0 0 π 0 0 π 0 0 π π π 0 π 0 π]	16QAM, non-hierarchical
[π 0 0 0 0 π 0 π 0 π 0 π 0 π 0 ... π 0 π π π 0 π 0 0 0 π 0 π π 0]	16QAM, hierarchical, α=2
[π 0 0 0 π π 0 π π π 0 π 0 π π ... 0 0 π 0 π π 0 π 0 0 π π 0 π 0]	16QAM, hierarchical, α=4

For informative purpose, the whole vector of the position of the scattered pilots for an OFDM symbol at time index `l=1` (first OFDM with scattered pilots after the preamble symbol) is denoted here:

```
Idx = {     3     9    15    21    27    33    39    45
           55    61    67    73    79    85    91    97
          107   113   119   125   131   137   143   149
          159   165   171   177   183   189   195   201
          211   217   223   229   235   241   247   253
          263   269   275   281   287   293   299   305
          315   321   327   333   339   345   351   357
          367   373   379   385   391   397   403   409
          419   425   431   437   443   449   455   461
          471   477   483   489   495   501   507   513
          523   529   535   541   547   553   559   565
          575   581   587   593   599   605   611   617
          627   633   639   645   651   657   663   669
          679   685   691   697   703   709   715   721
          731   737   743   749   755   761   767   773
          783   789   795   801   807   813   819   825
          835   841   847   853   859   865   871   877
          887   893   899   905   911   917   923   929
          939   945   951   957   963   969   975   981
          991   997  1003  1009  1015  1021  1027  1033
         1043  1049  1055  1061  1067  1073  1079  1085
         1095  1101  1107  1113  1119  1125  1131  1137
         1147  1153  1159  1165  1171  1177  1183  1189
         1199  1205  1211  1217  1223  1229  1235  1241
         1251  1257  1263  1269  1275  1281  1287  1293
         1303  1309  1315  1321  1327  1333  1339  1345
         1355  1361  1367  1373  1379  1385  1391  1397
         1407  1413  1419  1425  1431  1437  1443  1449
         1459  1465  1471  1477  1483  1489  1495  1501};
```

4.4.2.3 Continuous pilots

The index of continuous pilots does not change from OFDM symbol `l` to OFDM symbol `l+1`. Its indices are denoted using the following description:

```
Idx = 0:SegmentIncrement:Kmax;
```

which is equivalent to:

```
Idx = [   0    52   104   156   208   260   312   364   416   468
        520   572   624   676   728   780   832   884   936   988
       1040  1092  1144  1196  1248  1300  1352  1404  1456  1508];
```

The amplitude of the continuous pilots is chosen to `4/3`. The average power of the continuous pilots (`E[c×c*] = 16/9`) is higher than the average power of the data symbols which are normalized to power `1`, therefore the pilots are denoted as boosted pilots.

The phase of the continuous pilot (within one segment) is set to the following value:

```
ContPilotPhase = [  0 ]
```

Each continuous pilot (one per segment) is phase-rotated by the vector `GroupPhase`, dependent on the selection of the mapping scheme of the data subcarriers. The definition of `GroupPhase` can be derived from Table 17.

An illustration of the scattered and continuous pilots is given in Figure 12.

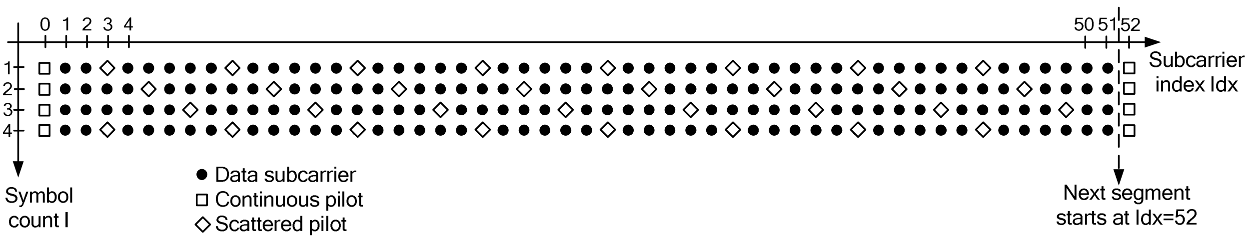


Figure 12: Pilot pattern (scattered and continuous pilots) for the first segment and the first symbols `l=1` to `l=4`

4.4.3 Mode 3: 1k@1,7MHz

Mode 3 is designed to work in a channel spacing of 1,7 MHz. Using an FFT of 1 024 points with 729 active carriers, this leads to a carrier spacing of roughly 2,1 kHz and a guard interval length of 120 µs. Mode 3 provides a pilot density of approximately 17 %. The pilots are arranged in groups, each having a length of 52 carriers.

Note that for maximizing throughput on bandwidth limited carriers, the structure of mode 3 may be complemented by the selection of different parameters. To increase throughput, additional carriers may be introduced on the band edges, e.g. 44 additional carriers including 8 pilot carriers. This "overlay mode" will not change the structure of the modes defined here within.

Each IPL-MC frame is generated by the combination of one frequency domain preamble (one entire OFDM symbol) and five Phy sections, each having a length of 24 OFDM symbols. Therefore, each IPL-MC frame consists of 121 OFDM symbols that are denoted from index `l = 0` to `l = 120`.

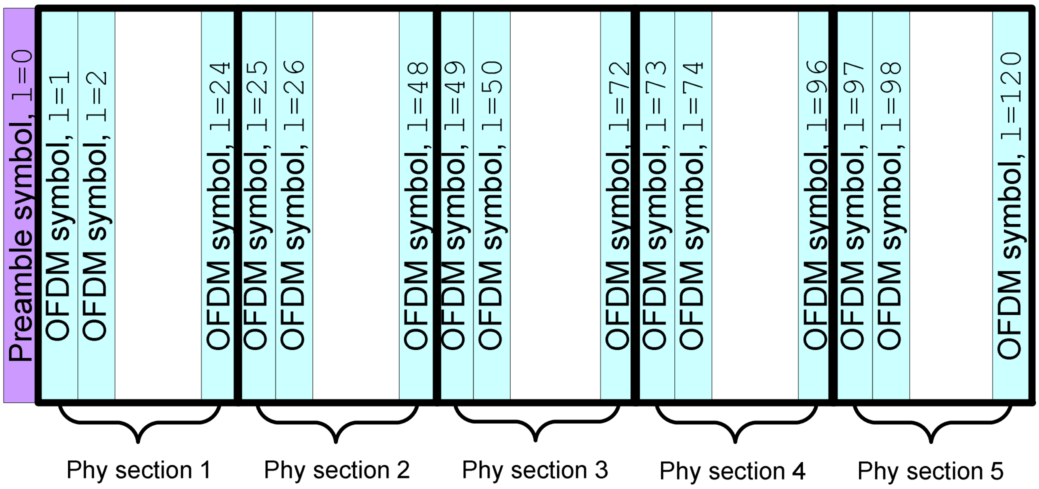


Figure 13: Framing structure of one IPL-MC frame consisting of one preamble and five Phy sections

4.4.3.1 Preamble insertion

The first OFDM symbol (`l = 0`) of each IPL-MC frame is dedicated to be used as a preamble sequence. This preamble is the so-called "frequency domain preamble".

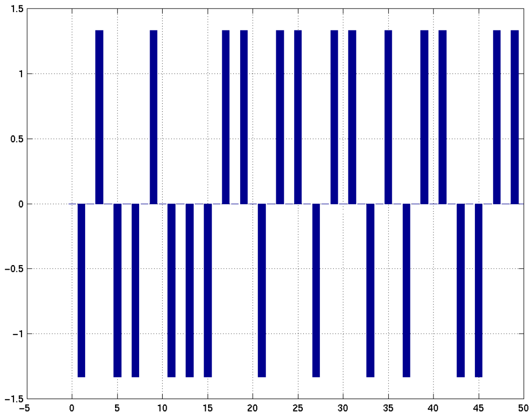
The following sequence is inserted. The notation is made in the frequency domain. Each subcarrier of this preamble is a priori known to the receiver.

The preamble is defined as a vector of modulation symbols in the frequency domain from carrier `Kmin` to `Kmax`. The parameters are as follows:

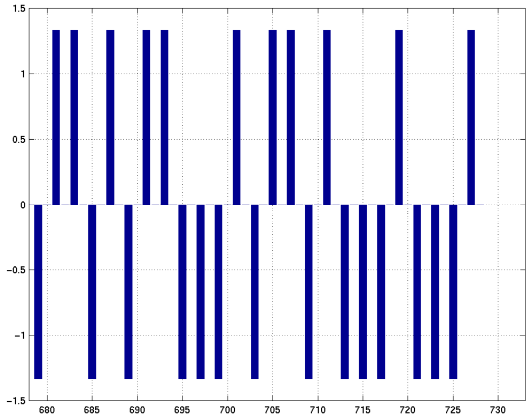
First active carrier: **Kmin** = 0;
Last active carrier: **Kmax** = 728.

The preamble is set to the following values in the frequency domain; the amplitude of each active subcarrier is then boosted by 4/3. The average power of one active subcarrier of the preamble symbol is E[c×c*] = 16/9.

```
0, -1, 0, 1, 0, -1, 0, -1,
0, -1, 0, 1, 0, -1, 0, 1,
0, 1, 0, -1, 0, -1, 0, -1,
0, 1, 0, -1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,
0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,
0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,
0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, -1, 0, -1,
0, -1, 0, 1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,
0, -1, 0, -1, 0, -1, 0, -1,
0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,
0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, -1, 0, -1, 0, -1,
0, 1, 0, -1, 0, -1, 0, 1,
0, 1, 0, -1, 0, -1, 0, 1,
0, 1, 0, -1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, 1,
0, -1, 0, 1, 0, -1, 0, 1,
0, -1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, 1,
0, -1, 0, -1, 0, 1, 0, 1,
0, -1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,
0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,
0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, 1,
0, -1, 0, -1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, 1, 0, -1,
0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,
0, -1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, 1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, 1, 0, 1, 0, -1,
0, 1, 0, 1, 0, 1, 0, 1,
0, -1, 0, -1, 0, -1, 0, -1,
0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, -1, 0, -1,
0, 1, 0, 1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, -1,
0, 1, 0, 1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,
0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, -1, 0, -1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,
0, 1, 0, -1, 0, -1, 0, -1,
0, -1, 0, -1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, -1,
0, -1, 0, 1, 0, 1, 0, 1,
0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, -1, 0, 1,
0, -1, 0, 1, 0, -1, 0, -1,
0, -1, 0, 1, 0, -1, 0, 1,
0, -1, 0, -1, 0, -1, 0, -1,
0, -1, 0, 1, 0, 1, 0, 1,
0, -1, 0, -1, 0, 1, 0, 1,
0, -1, 0, -1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, 1,
0, -1, 0, -1, 0, -1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, -1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,
0;
```



First carriers of the preamble around Kmin = 0 (start)



Last carriers of the preamble around Kmax = 728 (end)

4.4.3.2 Scattered pilots

Scattered pilots are introduced with a repetition pattern of 24 OFDM symbols into the Phy sections. Therefore this pilot pattern repeats five times within the 120 OFDM symbols (excluding the preamble) that form one IPL-MC frame.

In the frequency domain, the scattered pilots have a period of 52 symbols. Following the notation introduced before, the parameters for pilot tone insertion are as stated below:

Number of different segments in the frequency domain:	**NumberOfSegments** = 14;
Carrier increment per segment:	**SegmentIncrement** = 52;
Carrier offset per OFDM symbol:	**SymbolOffset** = ... {2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6};
OFDM symbol count (per OFDM frame):	**l** = {1, 2, 3, ... , 118, 119, 120}.

The index of scattered pilots of segment m in an OFDM symbol at time index l is denoted using the following formula:

Idx(l,m)=[1 7 13 19 25 31 37 43]+SymbolOffset[(l-1) mod 24]+m×SegmentIncrement;

{m ∈ [0; 13]; l ∈ [1; 120]}

The amplitude of the scattered pilots is chosen to 4/3. The average power of the scattered pilots (E[c×c*] = 16/9) is higher than the average power of the data symbols which are normalized to power 1, therefore the pilots are denoted as boosted pilots.

The phase of the scattered pilots (within one segment) is described using the following vector:

```
ScatPilotPhase = [  0   0   π   π   0   π   0   π ]
```

The entity of all scattered pilots per segment are further phase-rotated by the vector `GroupPhase`, dependent on the selection of the mapping scheme of the data subcarriers as defined in table 18.

Table 18: `GroupPhase` definition for mode 3

GroupPhase	Selected mapping scheme
[π π 0 0 π 0 π π 0 π 0 π 0 0 π]	QPSK
[0 π 0 π 0 0 π 0 π 0 π π π 0 π]	16QAM, non-hierarchical
[0 0 π π 0 0 π π π 0 0 0 π π 0]	16QAM, hierarchical, α=2
[0 π 0 0 π π 0 0 π 0 π π 0 π 0]	16QAM, hierarchical, α=4

For informative purpose, the whole vector of the positions of the scattered pilots for the OFDM symbol at time index `l=1` (first OFDM with scattered pilots after the preamble symbol) is denoted here:

```
   Idx = {    3     9    15    21    27    33    39    45
             55    61    67    73    79    85    91    97
            107   113   119   125   131   137   143   149
            159   165   171   177   183   189   195   201
            211   217   223   229   235   241   247   253
            263   269   275   281   287   293   299   305
            315   321   327   333   339   345   351   357
            367   373   379   385   391   397   403   409
            419   425   431   437   443   449   455   461
            471   477   483   489   495   501   507   513
            523   529   535   541   547   553   559   565
            575   581   587   593   599   605   611   617
            627   633   639   645   651   657   663   669
            679   685   691   697   703   709   715   721};
```

4.4.3.3 Continuous pilots

The index of continuous pilots does not change from OFDM symbol `l` to OFDM symbol `l+1`. Its indices are denoted using the following description:

```
Idx = 0:SegmentIncrement:Kmax;
```

which is equivalent to:

```
Idx = [0 52 104 156 208 260 312 364 416 468 520 572 624 676 728];
```

The amplitude of the continuous pilots is chosen to `4/3`. The average power of the continuous pilots (`E[c×c*] = 16/9`) is higher than the average power of the data symbols which are normalized to power `1`, therefore the pilots are denoted as boosted pilots.

The phase of the continuous pilot is set to the following value:

```
ContPilotPhase = [  0 ]
```

Each continuous pilot (one per segment) is phase-rotated by the vector `GroupPhase`, dependent on the selection of the mapping scheme of the data subcarriers. The definition of `GroupPhase` can be derived from Table 18.

An illustration of the scattered and continuous pilots is given in Figure 14.

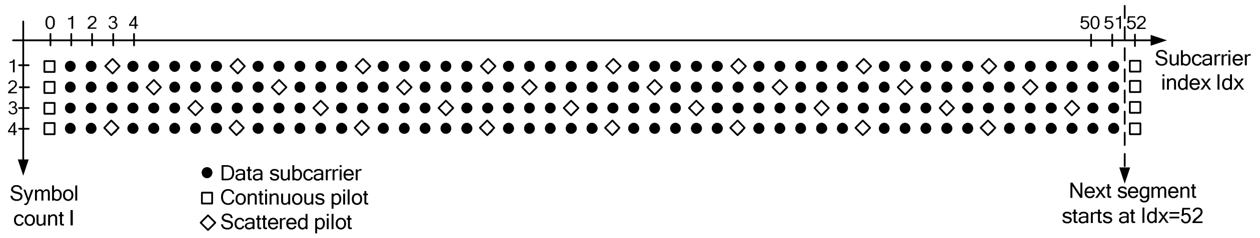


Figure 14: Pilot pattern (scattered and continuous pilots) for the first segment and the first symbols `l=1` to `l=4`

4.4.4 Mode 4: 0,5k@1,7MHz

Mode 4 is designed to work in a channel spacing of 1,7 MHz. Using an FFT of 512 points with 365 active carriers, this leads to a carrier spacing of roughly 4,2 kHz and a guard Interval length of 60 µs. Mode 4 provides a pilot density of approximately 17 %. The pilots are arranged in groups, each having a length of 52 carriers.

Note that for maximizing throughput on bandwidth limited carriers, the structure of mode 4 may be complemented by the selection of different parameters. To increase throughput, additional carriers may be introduced on the band edges, e.g. 22 additional carriers including 4 pilot carriers. This "overlay mode" will not change the structure of the modes defined here within.

Each IPL-MC frame is generated by the combination of one frequency domain preamble (one entire OFDM symbol) and five Phy sections, each having a length of 24 OFDM symbols. Therefore, each IPL-MC frame consists of 121 OFDM symbols that are denoted from index `l = 0` to `l = 120`.

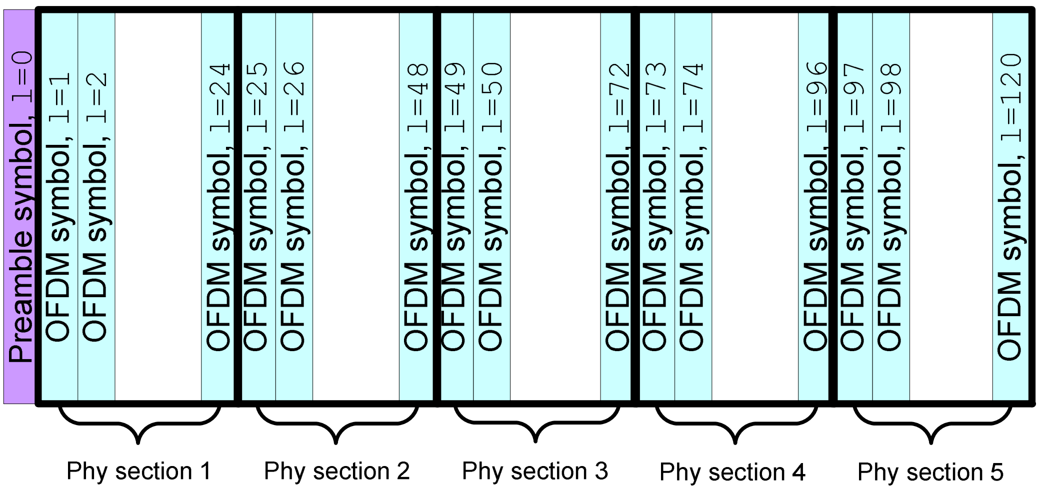


Figure 15: Framing structure of one IPL-MC frame consisting of one preamble and five Phy sections

4.4.4.1 Preamble insertion

The first OFDM symbol (`l = 0`) of each IPL-MC frame is dedicated to be used as a preamble sequence. This preamble is called "frequency domain preamble".

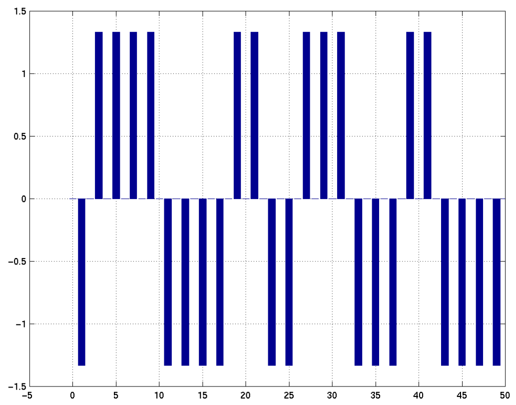
The following sequence is inserted. The notation is made in the frequency domain. Each subcarrier of this preamble is a priori known to the receiver.

The preamble is defined as a vector of modulation symbols in the frequency domain from carrier `Kmin` to `Kmax`. The parameters are as follows:

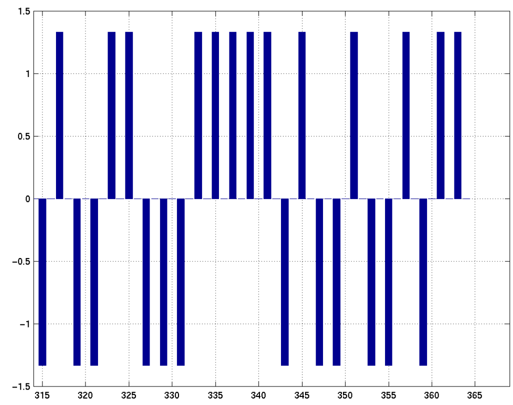
First active carrier: **Kmin** = 0;
Last active carrier: **Kmax** = 364.

The preamble is set to the following values in the frequency domain; the amplitude of each active subcarrier is then boosted by `4/3`. The average power of one active subcarrier of the preamble symbol is `E[c×c*] = 16/9`.

```
0, -1, 0, 1, 0, 1, 0, 1,        0, 1, 0, -1, 0, -1, 0, -1,      0, -1, 0, 1, 0, 1, 0, -1,       0, -1, 0, 1, 0, 1, 0, 1,
0, -1, 0, -1, 0, -1, 0, 1,      0, 1, 0, -1, 0, -1, 0, -1,      0, -1, 0, -1, 0, -1, 0, -1,     0, -1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, 1,        0, 1, 0, -1, 0, 1, 0, 1,        0, 1, 0, -1, 0, 1, 0, 1,        0, -1, 0, -1, 0, -1, 0, 1,
0, -1, 0, 1, 0, 1, 0, 1,        0, 1, 0, -1, 0, 1, 0, -1,       0, 1, 0, 1, 0, -1, 0, 1,        0, -1, 0, -1, 0, -1, 0, 1,
0, -1, 0, -1, 0, -1, 0, 1,      0, -1, 0, 1, 0, -1, 0, -1,      0, 1, 0, 1, 0, -1, 0, 1,        0, -1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,      0, 1, 0, -1, 0, -1, 0, 1,       0, -1, 0, -1, 0, 1, 0, 1,       0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,       0, -1, 0, 1, 0, -1, 0, 1,       0, 1, 0, -1, 0, -1, 0, -1,      0, 1, 0, 1, 0, -1, 0, 1,
0, -1, 0, -1, 0, -1, 0, 1,      0, 1, 0, 1, 0, -1, 0, 1,        0, -1, 0, 1, 0, -1, 0, 1,       0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,       0, 1, 0, 1, 0, -1, 0, 1,        0, 1, 0, 1, 0, -1, 0, 1,        0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,       0, -1, 0, -1, 0, 1, 0, -1,      0, 1, 0, 1, 0, 1, 0, -1,        0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, 1, 0, 1, 0, -1,       0, -1, 0, -1, 0, 1, 0, 1,       0, 1, 0, 1, 0, 1, 0, -1,        0, 1, 0, -1, 0, -1, 0, 1,
0, -1, 0, -1, 0, 1, 0, -1,      0, 1, 0, 1, 0;
```



First carriers of the preamble around `Kmin = 0` (start)



Last carriers of the preamble around `Kmax = 364` (end)

4.4.4.2 Scattered pilots

Scattered pilots are introduced with a repetition pattern of 24 OFDM symbols into the Phy sections. Therefore this pilot pattern repeats five times within the 120 OFDM symbols (excluding the preamble) that form one IPL-MC frame.

In the frequency domain, the scattered pilots have a period of 52 symbols. Following the notation introduced before, the parameters for pilot tone insertion are as stated below:

First active carrier: **Kmin** = 0;
Last active carrier: **Kmax** = 364;
Number of different segments in the frequency domain: **NumberOfSegments** = 7;
Carrier increment per segment: **SegmentIncrement** = 52;
Carrier offset per OFDM symbol: **SymbolOffset** = ...
{2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6,
2, 4, 6, 2, 4, 6, 2, 4, 6, 2, 4, 6};
OFDM symbol count (per OFDM frame): **l** = {1, 2, 3, ... , 118, 119, 120}.

The index of scattered pilots of segment `m` in an OFDM symbol at time index `l` is denoted using the following formula:

```
Idx(l,m)=[1 7 13 19 25 31 37 43]+SymbolOffset[(l-1) mod 24]+m×SegmentIncrement;
{m ∈ [0; 6]; l ∈ [1; 120]}
```

The amplitude of the scattered pilots is chosen to `4/3`. The average power of the scattered pilots (`E[c×c*] = 16/9`) is higher than the average power of the data symbols which are normalized to power `1`, therefore the pilots are denoted as boosted pilots.

The phase of the scattered pilots (within one segment) is described using the following vector:

```
ScatPilotPhase = [   0    0    π    π    0    π    0    π ]
```

The entity of all scattered pilots per segment are further phase-rotated by the vector `GroupPhase`, dependent on the selection of the mapping scheme of the data subcarriers as defined in table 19.

Table 19: `GroupPhase` definition for mode 4

GroupPhase	Selected mapping scheme
[0 0 π 0 π π π 0]	QPSK
[π 0 0 0 π 0 π 0]	16QAM, non-hierarchical
[0 π π 0 0 π 0 π]	16QAM, hierarchical, α=2
[π π 0 π π 0 0 π]	16QAM, hierarchical, α=4

For informative purpose, the whole vector of scattered pilots for the OFDM symbol at time index `l=1` (first OFDM with scattered pilots after the preamble symbol) is denoted here:

```
Idx = {     3     9    15    21    27    33    39    45
           55    61    67    73    79    85    91    97
          107   113   119   125   131   137   143   149
          159   165   171   177   183   189   195   201
          211   217   223   229   235   241   247   253
          263   269   275   281   287   293   299   305
          315   321   327   333   339   345   351   357}.
```

4.4.4.3 Continuous pilots

The index of continuous pilots does not change from OFDM symbol `l` to OFDM symbol `l+1`. Its indices are denoted using the following description:

```
Idx = 0:SegmentIncrement:Kmax.
```

which is equivalent to

```
Idx = [0 52 104 156 208 260 312 364];
```

The amplitude of the continuous pilots is chosen to `4/3`. The average power of the continuous pilots (`E[c×c*] = 16/9`) is higher than the average power of the data symbols which are normalized to power `1`, therefore the pilots are denoted as boosted pilots.

The phase of the continuous pilot (within one segment) is set to the following value:

```
ContPilotPhase = [  0 ]
```

Each continuous pilot (one per segment) is phase-rotated by the vector `GroupPhase`, dependent on the selection of the mapping scheme of the data subcarriers. The definition of `GroupPhase` can be derived from Table 19.

An illustration of the scattered and continuous pilots is given in Figure 16.

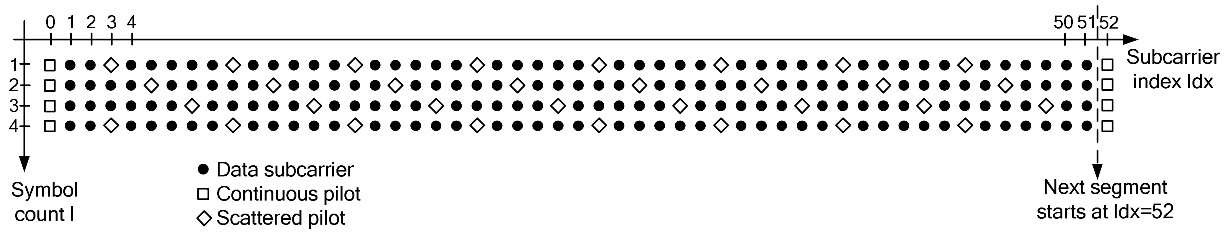


Figure 16: Pilot pattern (scattered and continuous pilots) for the first segment and the first symbols `l=1` to `l=4`

4.5 Bit mapping to constellation

The remaining carriers which are not indexed to be scattered or continuous pilots or TPS carriers, are loaded with data symbols according to the mapping scheme derived from [1]. The notation of the bits is as follows:

The leftmost bit is to be extracted from the input bitstream first, whereas the rightmost bit is to be extracted from the input bitstream as the last one.

4.5.1 QPSK Modulation

The following mapping scheme is used in QPSK modulation mode, denoted as modulation index 2. The transmission order is {`bit[i] bit[i+1]`} where `i` denotes the current time index.

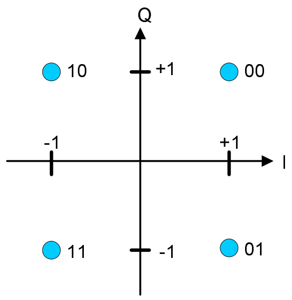


Figure 17: QPSK modulation

4.5.2 16QAM Modulation (non-hierarchical)

The following mapping scheme is used in 16QAM non-hierarchical modulation mode, denoted as modulation index 4. The transmission order is {`bit[i] bit[i+1] bit[i+2] bit[i+3]`} where `i` denotes the current time index.

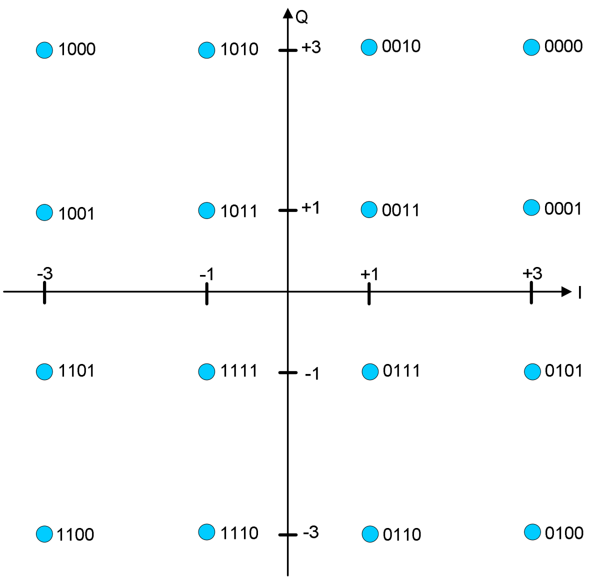


Figure 18: 16QAM modulation

4.5.3 16QAM Modulation (hierarchical)

The following mapping scheme is used in 16QAM hierarchical modulation mode and $\alpha = 2$. The transmission order is `{bit[i] bit[i+1] bit[i+2] bit[i+3]}` where `i` denotes the current time index.

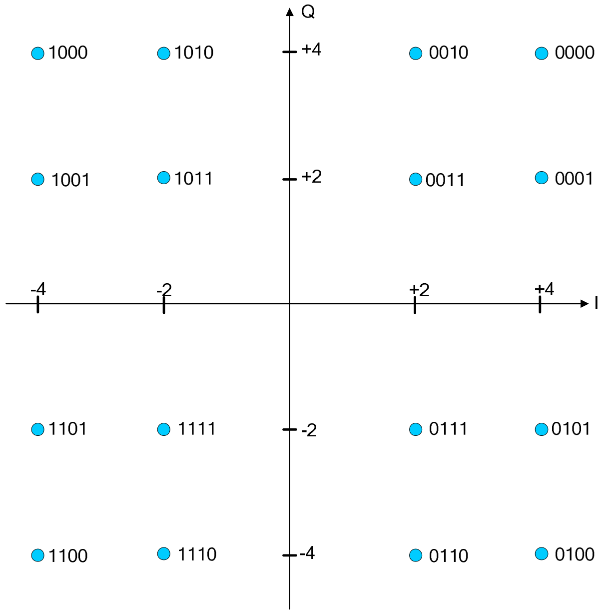


Figure 19: 16QAM hierarchical modulation with $\alpha = 2$

The following mapping scheme is used in 16QAM hierarchical modulation mode and $\alpha = 4$. The transmission order is `{bit[i] bit[i+1] bit[i+2] bit[i+3]}` where `i` denotes the current time index.

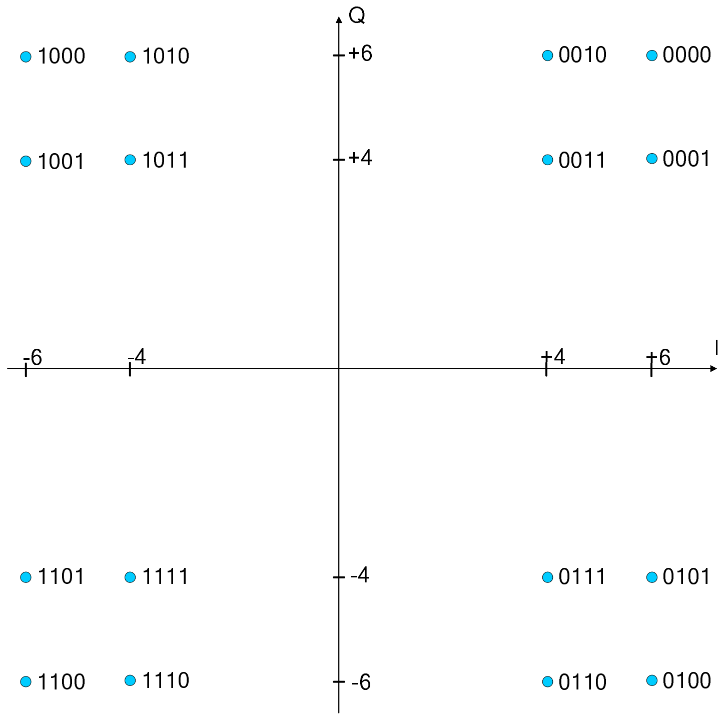


Figure 20: 16QAM hierarchical modulation with $\alpha = 4$

4.5.4 Normalization of power levels

To ensure equal average power of the data subcarriers, all modulated symbols need to be normalized. Normalization is performed by multiplying the mapped symbol with a normalization factor `c`. This normalization factor depends on the modulation and the hierarchical scaling factor α, if applicable, according to Table 20.

Please notify that this normalization is only applied to the data subcarriers.

Table 20: Normalization factors for different modulations

Modulation	Normalization factor
QPSK	$c = 1/\sqrt{2}$
16QAM non-hierarchical	$c = 1/\sqrt{10}$
16QAM hierarchical, α = 2	$c = 1/\sqrt{20}$
16QAM hierarchical, α = 4	$c = 1/\sqrt{52}$

4.6 Pulse shaping and guard interval insertion

Pulse shaping is performed using an IFFT of length 512, 1 024 or 2 048, dependent on the chosen mode. The subcarriers are arranged so that the following subcarrier numbers coincide with the RF carrier frequency (or DC in the complex baseband representation).

Table 21: Mode-dependent active subcarriers and center frequency

Mode	FFTLength	K_{min}	K_{max}	Number of active carriers	carrier number at DC or RF frequency
1	2 048	0	1 704	1 705	852
2	2 048	0	1 508	1 509	754
3	1 024	0	728	729	364
4	512	0	364	365	182

Dependent on the choice of the guard interval length, the last `GuardIntervalRatio×FFTLength` time domain samples of each OFDM symbol are transmitted first, directly consecuted by the `FFTLength` time domain samples.

Additional guard interval ratios may be included in future versions of this specification resulting in other frame lengths than specified herein.

The parameter `GuardIntervalRatio` can be extracted from Table 22. Using these parameters, the following OFDM symbol lengths apply.

Table 22: Guard Interval Ratios and their respective time duration

Mode	FFTLength	GuardIntervalRatio	Guard Interval length (in time domain samples)	OFDM symbol length (in time domain samples)
1	2 048	1/4	512	2 560
1	2 048	1/8	256	2 304
2	2 048	1/4	512	2 560
3	1 024	1/4	256	1 280
4	512	1/4	128	640

Annex A (informative): Bibliography

ITU-T Recommendation O.153 (1992): "Basic parameters for the measurement of error performance at bit rates below the primary rate".

ETSI TS 102 551-1 (V1.1.1): "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Inner Physical Layer of the Radio Interface; Part 1: Single carrier transmission".

ETSI TS 102 550 (V1.1.1): "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Outer Physical Layer of the Radio Interface".

ETSI EN 301 744 (V1.2.1): "Fixed Radio Systems; Point-to-multipoint equipment; Direct Sequence Code Division/Time Division Multiple Access (DS-CD/TDMA); Point-to-multipoint digital packet radio systems in frequency bands in the range 3 GHz to 11 GHz".

ETSI EN 302 583: "Digital Video Broadcasting (DVB); Framing Structure, channel coding and modulation for Satellite Services to Handheld devices (DVB-SH) below 3 GHz".

History

Document history		
V1.1.1	December 2006	Publication
V2.1.1	August 2007	Publication