ETSI TS 102 551-2 V1.1.1 (2006-12)

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
DTS/SES-00285-2

Keywords
digital, layer 1, radio, satellite

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

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

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Important notice

Individual copies of the present document can be downloaded from:
http://www.etsi.org

The present document may be made available in more than one electronic version or in print. In any case of existing or perceived difference in contents between such versions, the reference version is the Portable Document Format (PDF). In case of dispute, the reference shall be the printing on ETSI printers of the PDF version kept on a specific network drive within ETSI Secretariat.

Users of the present document should be aware that the document may be subject to revision or change of status. Information on the current status of this and other ETSI documents is available at
http://portal.etsi.org/tb/status/status.asp

If you find errors in the present document, please send your comment to one of the following services:
http://portal.etsi.org/chaircor/ETSI_support.asp

Copyright Notification

No part may be reproduced except as authorized by written permission.
The copyright and the foregoing restriction extend to reproduction in all media.

© European Telecommunications Standards Institute 2006.
All rights reserved.

DECTTM, **PLUGTESTS**TM and **UMTS**TM are Trade Marks of ETSI registered for the benefit of its Members.
TIPHONTM and the **TIPHON logo** are Trade Marks currently being registered by ETSI for the benefit of its Members.
3GPPTM is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners.

Contents

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://webapp.etsi.org/IPR/home.asp).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

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".

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).

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.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

[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
DVB	Digital Video Broadcasting
IFFT	Inverse Fast Fourier Transform
IPL	Inner Physical Layer
IPL-MC	Inner Physical Layer, Multiple Carrier
IPL-SC	Inner Physical Layer, Single Carrier

MPEG-TS	MPEG Transport Stream
OPL	Outer Physical Layer
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
RFU	Reserved for Future Use
S-TS	Service Transport Stream
TPS	Transmission Parameter Signalling
TS	ETSI Technical Specification
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.

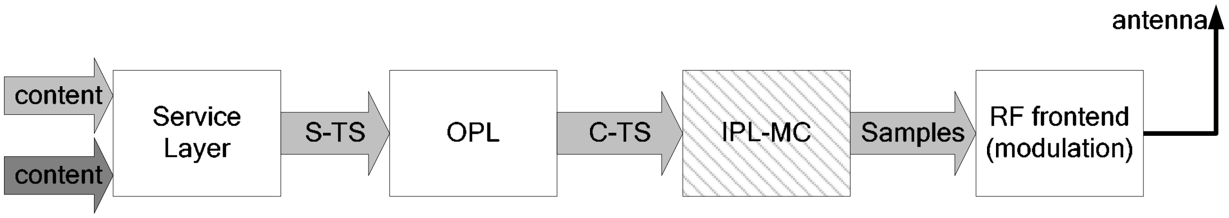


Figure 1: General block diagram of the ETSI SES SDR system concept with selection of IPL-MC

The general block diagram of the IPL-MC functionality is given in Figure 2.

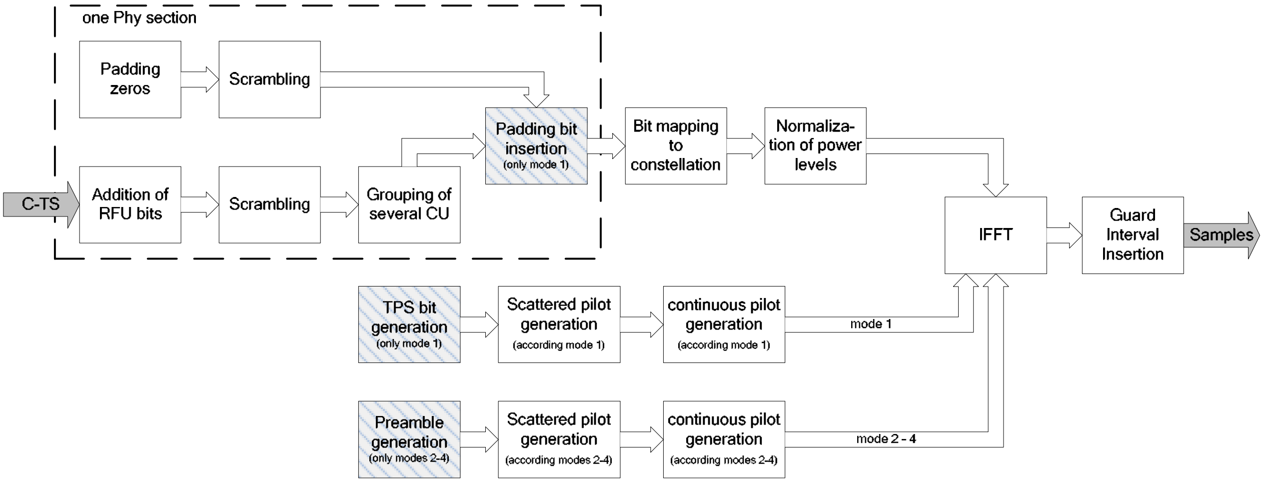


Figure 2: Block diagram of the ETSI SES SDR compliant IPL-MC

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:

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

For mode 1, one IPL-MC frame equals the DVB-T superframe. The OFDM frame of DVB-T is called Phy section. Four Phy sections compose on IPL-MC frame in mode 1.

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, the joint frame length of 432 ms is chosen for the IPL-MC frame length. 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.

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:

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.

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 1 and Table 2.

4.2.3 Parameters for QPSK subcarrier mapping

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

Table 1: 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	2 056	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		**100**	**29**	**14**	**7**
Length of Phy section	ms	30,46	9,52	14,28	7,14
Padding bits		32	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		**400**	**145**	**70**	**35**
Padding bits (informative only)		128	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 2: 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	2 056	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		**200**	**58**	**28**	**14**
Length of Phy section	ms	30,46	9,52	14,28	7,14
Padding bits		64	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		**800**	**290**	**140**	**70**
Padding bits (informative only)		256	0	0	0

4.3 Generation of one Phy section

4.3.1 Overview

One Phy section consists of the following two parts:

- data payload (capacity units, CU, etc.);
- signalling bits (RFU: reserved for future use);
- padding bits (only for mode 1).

Insertion of padding bits is only relevant for mode 1, therefore mode 1 and the other modes are handled differently.

4.3.1.1 Overview of mode 1

Figure 3 displays the generation of one Phy section in mode 1.

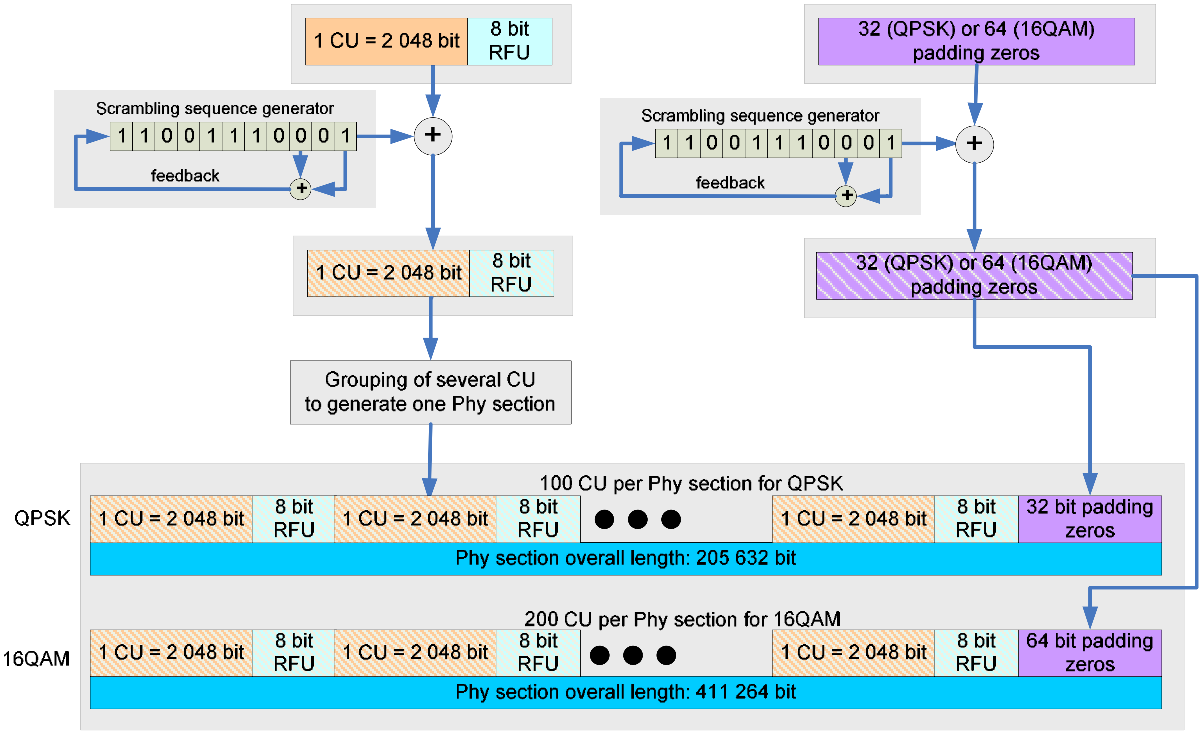


Figure 3: Overview of the generation of one Phy section for mode 1

4.3.1.2 Overview of mode 2, 3 and 4

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

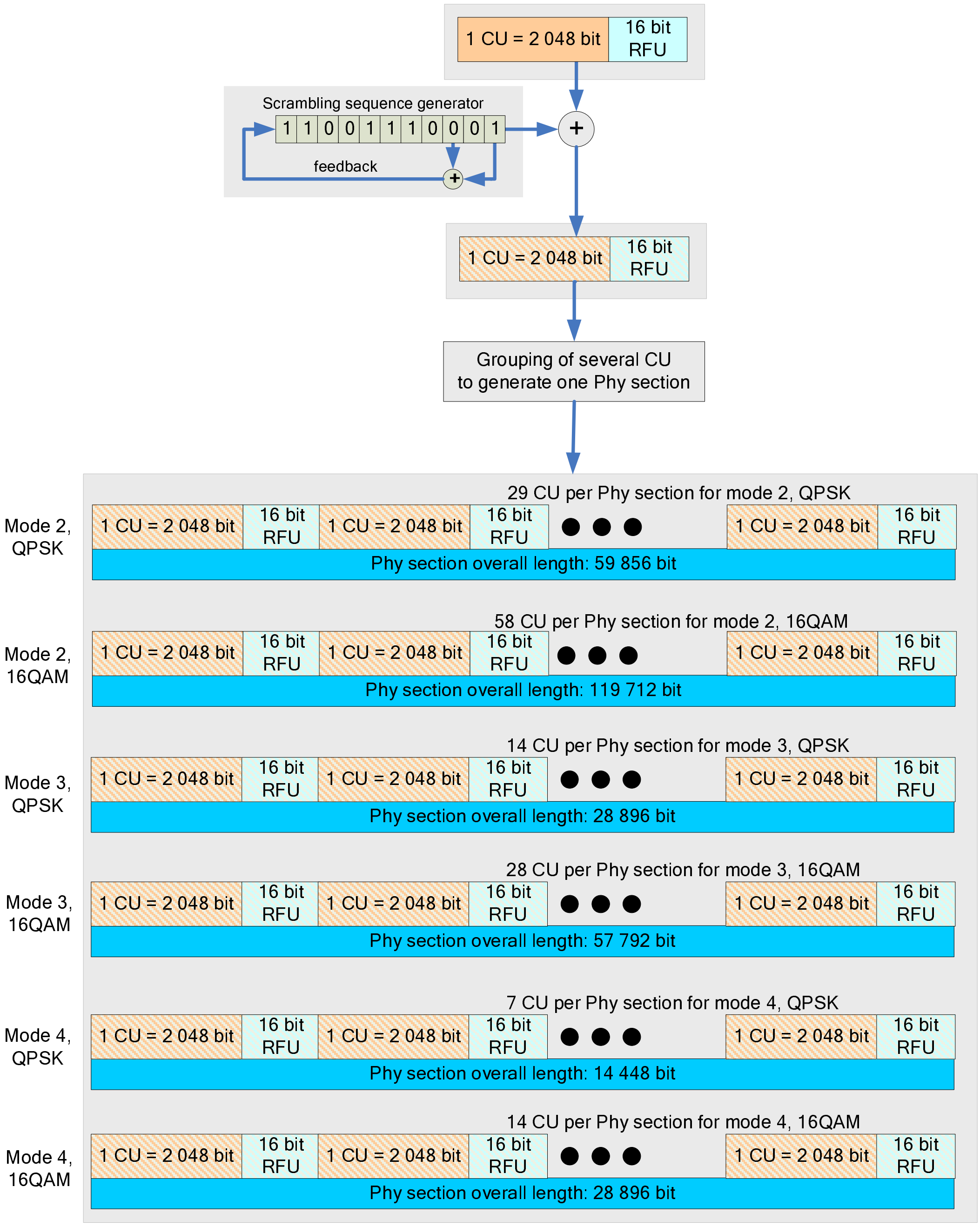


Figure 4: Overview of the generation of one Phy section for modes 2, 3 and 4

4.3.2 RFU section insertion and Bit padding

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. Therefore, the block size for one CU after bit padding is 2 056 bits in mode 1 and 2 064 bits for modes 2, 3 and 4. See also Figure 3 and Figure 4.

Bit padding at the end of each Phy section is only relevant for mode 1: As the capacity of the IPL-MC is denoted in CU per IPL-MC frame, additional bit padding has to be applied to match the exact number of symbols of each Phy section. The number of bits to be inserted can be derived from Table 1 and Table 2. The padding is performed by inserting zeros. This has no impact on the transmission as additional scrambling is introduced afterwards.

Please note that Table 1 and Table 2 display different modulation indices, thus using QPSK instead of 16QAM / 16QAM-hierarchical results in different numbers of padding bits.

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.

4.3.3 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 5):

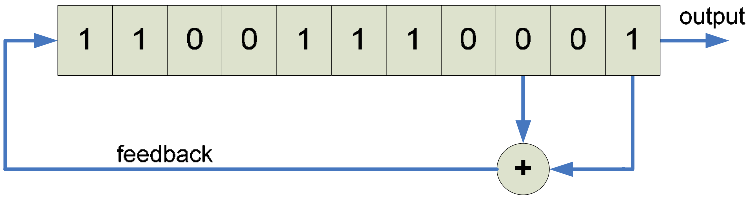


Figure 5: Scrambler used for energy dispersal

The output of the scrambler of length 2 056 or 2 064 is XOR-ed with the first 2 056 bit or 2 064 bit of the bitstream as depicted in Figure 3 and Figure 4. The scrambler is initialized at each start of one CU and at each start of the padding section. If the size of the data that has to be scrambled exceeds one cycle of the scrambler, then the scrambler just continues periodically.

4.4 Pilot tone insertion and signalling

This clause specifies the reference signals for the different modes.

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

4.4.1.1 Reference to EN 300 744

Each Phy section forms together with the scattered and continuous pilots as well as the TPS carriers a group of 68 OFDM symbols. Four of these groups (with slight variation in the creation of the TPS) form one IPL-MC frame.

Mode 1 is directly adapted from [1]. The following clauses are reused:

- **4.3.5: Signal constellation and mapping**; QPSK, 16QAM and 16QAM hierarchical shall apply with all possible values for α in the hierarchical mode.
- **4.4: OFDM frame structure**; 2k mode using 1 705 active carriers with an elementary period of 40/7 MHz. Boosted pilots (scattered and continuous) shall apply as described in this clause. TPS carriers and normalization of the data symbols are reused in the same way.
- **4.5: Reference signals**; only 2k mode shall apply.
- **4.5.1: Functions and derivation**; only 2k mode shall apply.
- **4.5.2: Definition of reference sequence**; the complete clause shall apply.
- **4.5.3: Location of scattered pilot cells**; only 2k mode shall apply; K_{max} is set to 1 704.
- **4.5.4: Location of continual pilot carriers**; only table for 2k mode shall apply.
- **4.5.5: Amplitudes of all reference information**; the complete clause shall apply.

- **4.6: TPS transmission format**; this clause (including clauses 4.6.X and 4.6.X.Y) shall apply with slight changes: Bits s_{30} to s_{35} (defining the code rates) are not relevant and should be set to "111".

However, due to the transport of CU instead of MPEG-TS, the adaptation layer between the SES SDR OPL and the IPL of DVB-T is redefined. According to Table 1 and Table 2, mode 1 is capable of transporting 100 CU per Phy section (in [1] denoted "OFDM frame") and 400 CU per IPL-MC frame (in [1] denoted "OFDM super frame") using QPSK. These values change to 200 CU per Phy section and 800 CU per IPL-MC frame if 16QAM was used instead.

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`.

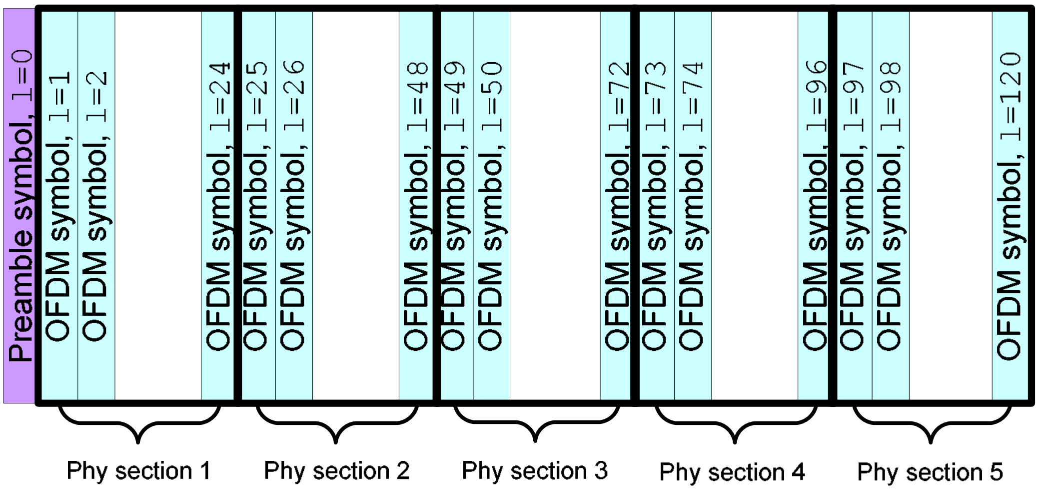


Figure 6: Framing structure of one IPL-MC frame consisting of one preamble and five Phy sections

An illustration of the scattered and continuous pilots is given in Figure 7.

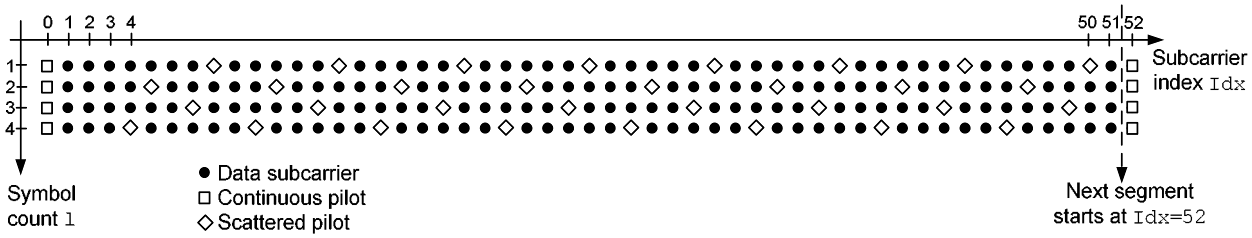


Figure 7: Pilot pattern (scattered and continuous pilots) for the first segment and the first symbols `l=1` to `l=4`

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. Either the "extended AMSS preamble" is inserted, or the so-called "frequency domain preamble".

NOTE: The extended AMSS preamble is under study.

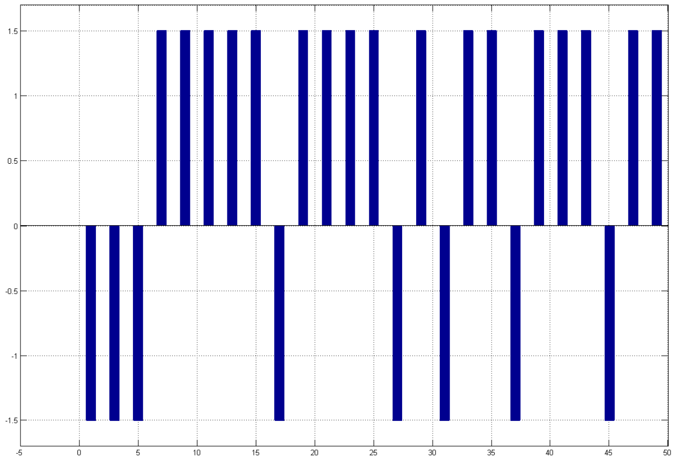
Using the so-called "frequency domain preamble", the following sequence is inserted. The notation is made in the frequency domain. Each subcarrier of this preamble is a priori known to the receiver.

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

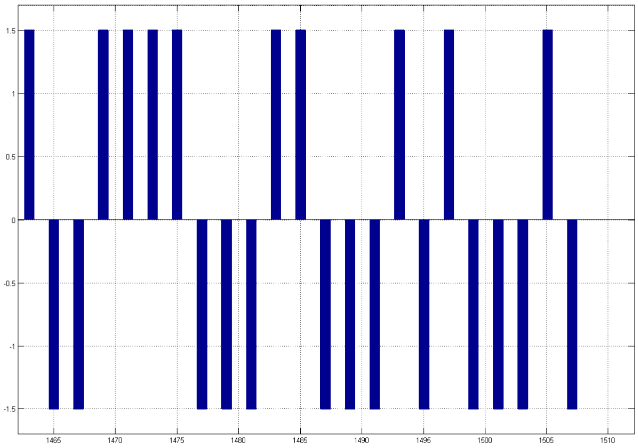
First active carrier: **Kmin** = 0;
Last active carrier: **Kmax** = 1508;

The preamble is set to the following values in the frequency domain; the amplitude of each active subcarrier is then boosted by 3/2. The average power of one active subcarrier of the preamble symbol is $E_C=9/4$.

```
0, -1, 0, -1, 0, -1, 0, 1,     0, 1, 0, 1, 0, 1, 0, 1,        0, -1, 0, 1, 0, 1, 0, 1,       0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, -1, 0, 1,       0, 1, 0, 1, 0, -1, 0, 1,       0, 1, 0, 1, 0, -1, 0, 1,       0, 1, 0, 1, 0, 1, 0, 1,
0, -1, 0, 1, 0, -1, 0, 1,      0, -1, 0, 1, 0, 1, 0, -1,      0, 1, 0, -1, 0, -1, 0, -1,     0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,      0, -1, 0, -1, 0, 1, 0, 1,      0, -1, 0, 1, 0, -1, 0, 1,      0, 1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, 1, 0, 1,      0, -1, 0, -1, 0, -1, 0, 1,     0, -1, 0, 1, 0, 1, 0, 1,       0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,     0, -1, 0, 1, 0, 1, 0, -1,      0, 1, 0, -1, 0, -1, 0, 1,      0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, 1, 0, -1, 0, 1,      0, -1, 0, 1, 0, -1, 0, 1,      0, 1, 0, -1, 0, -1, 0, 1,      0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, 1, 0, 1, 0, -1,      0, 1, 0, 1, 0, 1, 0, 1,        0, -1, 0, 1, 0, -1, 0, -1,     0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, 1, 0, 1, 0, -1,      0, 1, 0, 1, 0, 1, 0, -1,       0, 1, 0, -1, 0, 1, 0, -1,      0, -1, 0, 1, 0, -1, 0, -1,
0, 1, 0, -1, 0, 1, 0, -1,      0, 1, 0, -1, 0, 1, 0, 1,       0, -1, 0, -1, 0, 1, 0, -1,     0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, -1, 0, 1,      0, -1, 0, -1, 0, 1, 0, 1,      0, 1, 0, 1, 0, 1, 0, -1,       0, 1, 0, -1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, -1,      0, -1, 0, -1, 0, -1, 0, -1,    0, -1, 0, -1, 0, -1, 0, 1,     0, -1, 0, -1, 0, 1, 0, 1,
0, -1, 0, -1, 0, 1, 0, 1,      0, 1, 0, 1, 0, 1, 0, 1,        0, 1, 0, 1, 0, 1, 0, -1,       0, 1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, -1, 0, -1,    0, 1, 0, 1, 0, -1, 0, -1,      0, -1, 0, -1, 0, -1, 0, -1,    0, 1, 0, -1, 0, -1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,       0, 1, 0, -1, 0, 1, 0, -1,      0, -1, 0, 1, 0, 1, 0, -1,      0, -1, 0, -1, 0, -1, 0, 1,
0, 1, 0, -1, 0, -1, 0, -1,     0, -1, 0, 1, 0, 1, 0, -1,      0, 1, 0, 1, 0, 1, 0, 1,        0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, -1, 0, 1,      0, 1, 0, 1, 0, -1, 0, -1,      0, -1, 0, -1, 0, -1, 0, -1,    0, -1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, 1, 0, -1,       0, 1, 0, 1, 0, -1, 0, -1,      0, 1, 0, -1, 0, -1, 0, 1,      0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, -1,      0, -1, 0, -1, 0, 1, 0, -1,     0, 1, 0, 1, 0, 1, 0, -1,       0, -1, 0, 1, 0, 1, 0, -1,
0, 1, 0, 1, 0, -1, 0, -1,      0, 1, 0, 1, 0, 1, 0, 1,        0, -1, 0, 1, 0, 1, 0, 1,       0, 1, 0, -1, 0, -1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,     0, 1, 0, -1, 0, 1, 0, 1,       0, -1, 0, 1, 0, -1, 0, 1,      0, 1, 0, -1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,      0, -1, 0, -1, 0, 1, 0, -1,     0, 1, 0, -1, 0, -1, 0, 1,      0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, 1, 0, -1, 0, -1,     0, -1, 0, -1, 0, 1, 0, 1,      0, -1, 0, 1, 0, -1, 0, 1,      0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, 1, 0, 1,        0, 1, 0, 1, 0, -1, 0, -1,      0, -1, 0, 1, 0, -1, 0, 1,      0, -1, 0, 1, 0, -1, 0, -1,
0, -1, 0, 1, 0, 1, 0, 1,       0, -1, 0, 1, 0, 1, 0, 1,       0, 1, 0, 1, 0, -1, 0, -1,      0, 1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, -1, 0, -1,    0, -1, 0, 1, 0, 1, 0, -1,      0, -1, 0, -1, 0, -1, 0, 1,     0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,      0, -1, 0, -1, 0, -1, 0, 1,     0, -1, 0, 1, 0, -1, 0, -1,     0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,      0, -1, 0, 1, 0, -1, 0, -1,     0, -1, 0, 1, 0, 1, 0, -1,      0, 1, 0, 1, 0, -1, 0, -1,
0, 1, 0, -1, 0, -1, 0, -1,     0, 1, 0, -1, 0, 1, 0, -1,      0, 1, 0, -1, 0, 1, 0, -1,      0, 1, 0, 1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, -1,      0, -1, 0, -1, 0, 1, 0, -1,     0, -1, 0, -1, 0, -1, 0, 1,     0, 1, 0, -1, 0, -1, 0, -1,
0, 1, 0, 1, 0, 1, 0, 1,        0, -1, 0, 1, 0, -1, 0, -1,     0, -1, 0, 1, 0, -1, 0, 1,      0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,     0, -1, 0, 1, 0, -1, 0, -1,     0, 1, 0, -1, 0, 1, 0, 1,       0, 1, 0, -1, 0, -1, 0, 1,
0, -1, 0, 1, 0, -1, 0, 1,      0, -1, 0, 1, 0, -1, 0, -1,     0, -1, 0, -1, 0, 1, 0, 1,      0, -1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,      0, -1, 0, 1, 0, 1, 0, 1,       0, -1, 0, 1, 0, 1, 0, -1,      0, -1, 0, -1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, 1,       0, -1, 0, -1, 0, -1, 0, -1,    0, 1, 0, -1, 0, 1, 0, -1,      0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, -1, 0, -1,     0, 1, 0, -1, 0, 1, 0, -1,      0, 1, 0, 1, 0, 1, 0, 1,        0, 1, 0, 1, 0, 1, 0, 1,
0, -1, 0, 1, 0, -1, 0, -1,     0, -1, 0, 1, 0, 1, 0, -1,      0, 1, 0, -1, 0, -1, 0, -1,     0, -1, 0, 1, 0, -1, 0, -1,
0, 1, 0, 1, 0, -1, 0, -1,      0, 1, 0, 1, 0, -1, 0, -1,      0, 1, 0, 1, 0, -1, 0, -1,      0, 1, 0, 1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, 1,       0, -1, 0, -1, 0, -1, 0, 1,     0, 1, 0, -1, 0, -1, 0, 1,      0, -1, 0, -1, 0, -1, 0, -1,
0, 1, 0, -1, 0, 1, 0, -1,      0, -1, 0, -1, 0, 1, 0, -1,     0, -1, 0, 1, 0, -1, 0, -1,     0, -1, 0, 1, 0, -1, 0, -1,
0, 1, 0, 1, 0, -1, 0, 1,       0, 1, 0, 1, 0, -1, 0, 1,       0, -1, 0, 1, 0, 1, 0, 1,       0, -1, 0, 1, 0, 1, 0, 1,
0, 1, 0, -1, 0, -1, 0, 1,      0, -1, 0, 1, 0, 1, 0, 1,       0, 1, 0, 1, 0, -1, 0, 1,       0, -1, 0, 1, 0, -1, 0, 1,
0, -1, 0, -1, 0, 1, 0, -1,     0, -1, 0, -1, 0, 1, 0, -1,     0, -1, 0, -1, 0, 1, 0, 1,      0, -1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, -1,    0, -1, 0, -1, 0, 1, 0, -1,     0, 1, 0, -1, 0, 1, 0, 1,       0, -1, 0, -1, 0, -1, 0, -1,
0, -1, 0, 1, 0, -1, 0, -1,     0, -1, 0, 1, 0, -1, 0, 1,      0, -1, 0, 1, 0, -1, 0, 1,      0, -1, 0, -1, 0, -1, 0, -1,
0, 1, 0, 1, 0, 1, 0, 1,        0, -1, 0, -1, 0, -1, 0, -1,    0, 1, 0, 1, 0, 1, 0, 1,        0, -1, 0, -1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,      0, -1, 0, 1, 0, 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 = ...`
	`{7, 4, 6, 3, 5, 8, 5, 0, 2, 4, 1, 3,`
	`5, 2, 0, 3, 4, 7, 5, 3, 6, 8, 4, 1};`

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`=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 3:

Table 3: `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 ]`	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 ]`	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 ]`	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 ]`	16QAM, hierarchical, α=4

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

```
Idx = {   8    14    20    26    32    38    44    50
         60    66    72    78    84    90    96   102
        112   118   124   130   136   142   148   154
        164   170   176   182   188   194   200   206
        216   222   228   234   240   246   252   258
        268   274   280   286   292   298   304   310
        320   326   332   338   344   350   356   362
        372   378   384   390   396   402   408   414
        424   430   436   442   448   454   460   466
        476   482   488   494   500   506   512   518
        528   534   540   546   552   558   564   570
        580   586   592   598   604   610   616   622
```

```
   632   638   644   650   656   662   668   674
   684   690   696   702   708   714   720   726
   736   742   748   754   760   766   772   778
   788   794   800   806   812   818   824   830
   840   846   852   858   864   870   876   882
   892   898   904   910   916   922   928   934
   944   950   956   962   968   974   980   986
   996  1002  1008  1014  1020  1026  1032  1038
  1048  1054  1060  1066  1072  1078  1084  1090
  1100  1106  1112  1118  1124  1130  1136  1142
  1152  1158  1164  1170  1176  1182  1188  1194
  1204  1210  1216  1222  1228  1234  1240  1246
  1256  1262  1268  1274  1280  1286  1292  1298
  1308  1314  1320  1326  1332  1338  1344  1350
  1360  1366  1372  1378  1384  1390  1396  1402
  1412  1418  1424  1430  1436  1442  1448  1454
  1464  1470  1476  1482  1488  1494  1500  1506};
```

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=`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 3.

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`.

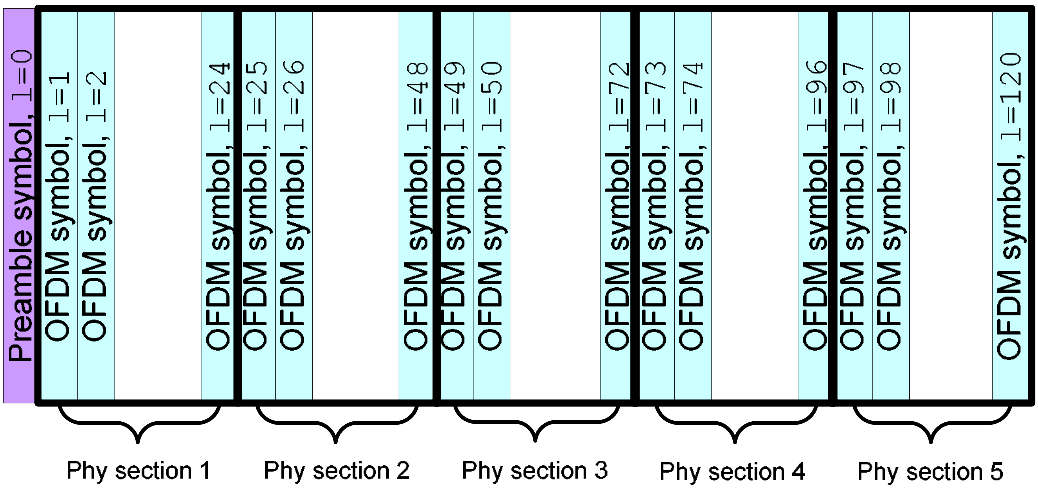


Figure 8: Framing structure of one IPL-MC frame consisting of one preamble and five Phy sections

An illustration of the scattered and continuous pilots is given in Figure 9.

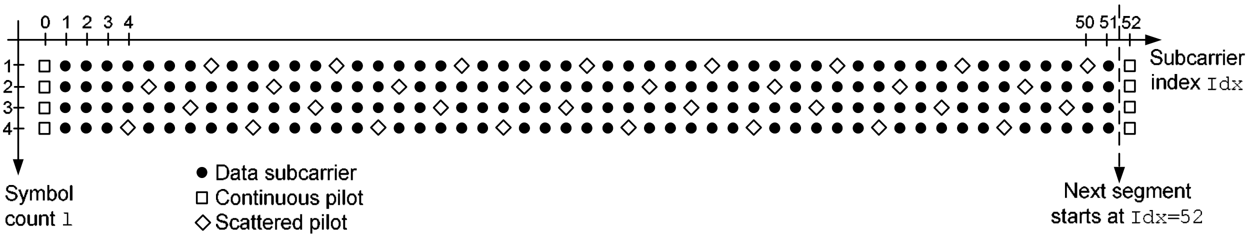


Figure 9: Pilot pattern (scattered and continuous pilots) for the first segment and the first symbols `l=1` to `l=4`

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. Either the "extended AMSS preamble" is inserted, or the so-called "frequency domain preamble".

NOTE: The extended AMSS preamble is under study.

Using 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.

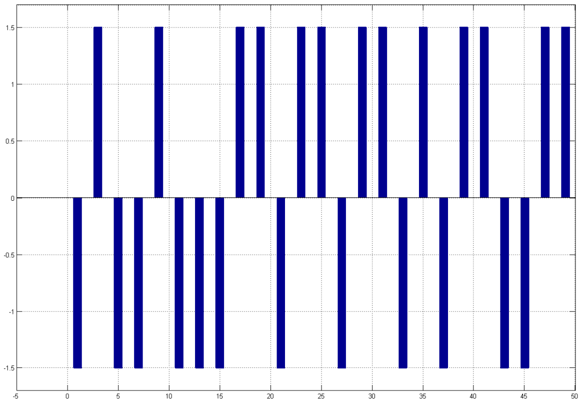
The preamble is defined as a vector of modulation symbols in the frequency domain from carrier `Kmin` to `Kmax`. The parameters are as follows:

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

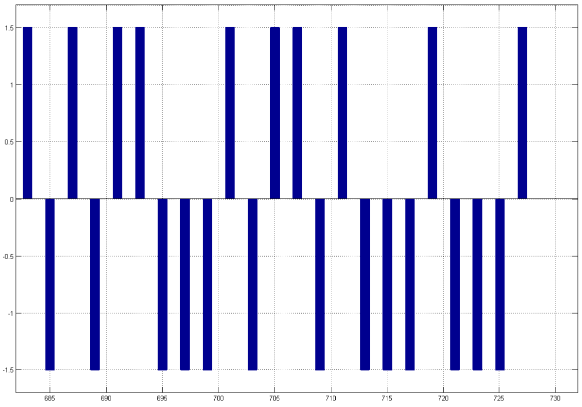
The preamble is set to the following values in the frequency domain; the amplitude of each active subcarrier is then boosted by 3/2. The average power of one active subcarrier of the preamble symbol is $E_C=9/4$.

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

```
0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,
0, -1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,
0, 1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, 1,
0, -1, 0, -1, 0, -1, 0, 1,
0, -1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, -1,
0, 1, 0, 1, 0, 1, 0, -1,
0, 1, 0, -1, 0, 1, 0, 1,
0, -1, 0, 1, 0, 1, 0, -1,
0, -1, 0, -1, 0, -1, 0, 1,
0, -1, 0, -1, 0, -1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,
0, 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`** `= ...`
	`{7, 4, 6, 3, 5, 8, 5, 0, 2, 4, 1, 3,`
	` 5, 2, 0, 3, 4, 7, 5, 3, 6, 8, 4, 1};`

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`=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 4.

Table 4: `GroupPhase` definition for mode 3

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

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

```
Idx = {  8    14    20    26    32    38    44    50
        60    66    72    78    84    90    96   102
       112   118   124   130   136   142   148   154
       164   170   176   182   188   194   200   206
       216   222   228   234   240   246   252   258
       268   274   280   286   292   298   304   310
       320   326   332   338   344   350   356   362
       372   378   384   390   396   402   408   414
       424   430   436   442   448   454   460   466
       476   482   488   494   500   506   512   518
       528   534   540   546   552   558   564   570
       580   586   592   598   604   610   616   622
       632   638   644   650   656   662   668   674
       684   690   696   702   708   714   720   726 };
```

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=`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 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`.

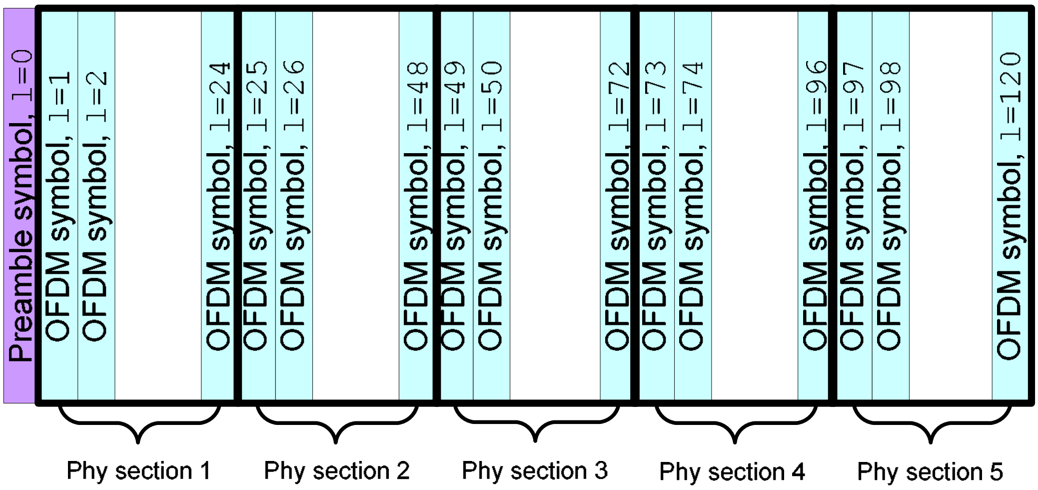


Figure 10: Framing structure of one IPL-MC frame consisting of one preamble and five Phy sections

An illustration of the scattered and continuous pilots is given in Figure 11.

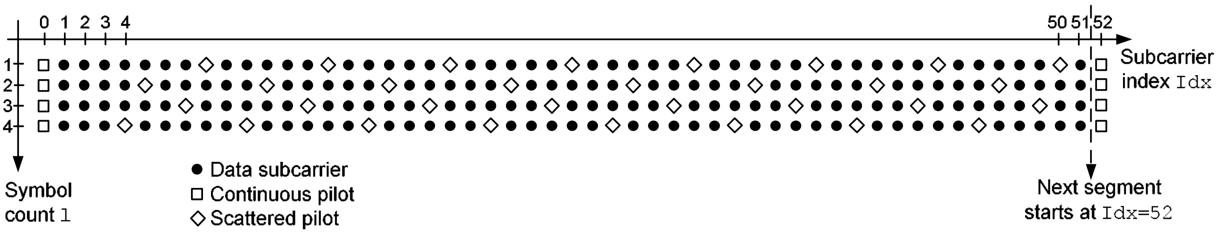


Figure 11: Pilot pattern (scattered and continuous pilots) for the first segment and the first symbols `l=1` to `l=4`

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. Either the "extended AMSS preamble" is inserted, or the so-called "frequency domain preamble".

NOTE: The extended AMSS preamble is under study.

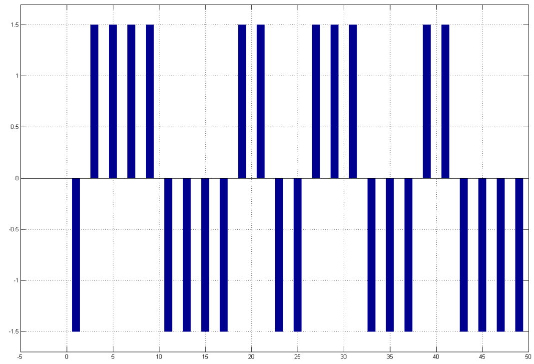
Using the so-called "frequency domain preamble", the following sequence is inserted. The notation is made in the frequency domain. Each subcarrier of this preamble is a priori known to the receiver.

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

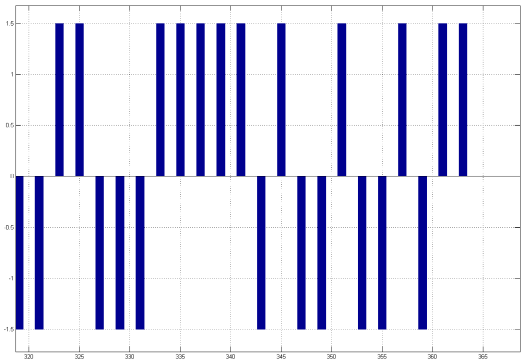
First active carrier: **`Kmin`** `= 0;`
Last active carrier: **`Kmax`** `= 364;`

The preamble is set to the following values in the frequency domain; the amplitude of each active subcarrier is then boosted by `3/2`. The average power of one active subcarrier of the preamble symbol is E_C`=9/4`.

```
0, -1, 0, 1, 0, 1, 0, 1,         0, 1, 0, -1, 0, -1, 0, -1,       0, -1, 0, 1, 0, 1, 0, -1,        0, -1, 0, 1, 0, 1, 0, 1,
0, -1, 0, -1, 0, -1, 0, 1,       0, 1, 0, -1, 0, -1, 0, -1,       0, -1, 0, -1, 0, -1, 0, -1,      0, -1, 0, 1, 0, -1, 0, 1,
0, 1, 0, 1, 0, -1, 0, 1,         0, 1, 0, -1, 0, 1, 0, 1,         0, 1, 0, -1, 0, 1, 0, 1,         0, -1, 0, -1, 0, -1, 0, 1,
0, -1, 0, 1, 0, 1, 0, 1,         0, 1, 0, -1, 0, 1, 0, -1,        0, 1, 0, 1, 0, -1, 0, 1,         0, -1, 0, -1, 0, -1, 0, 1,
0, -1, 0, -1, 0, -1, 0, 1,       0, -1, 0, 1, 0, -1, 0, -1,       0, 1, 0, 1, 0, -1, 0, 1,         0, -1, 0, 1, 0, -1, 0, -1,
0, -1, 0, -1, 0, 1, 0, -1,       0, 1, 0, -1, 0, -1, 0, 1,        0, -1, 0, -1, 0, 1, 0, 1,        0, 1, 0, 1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,        0, -1, 0, 1, 0, -1, 0, 1,        0, 1, 0, -1, 0, -1, 0, -1,       0, 1, 0, 1, 0, -1, 0, 1,
0, -1, 0, -1, 0, -1, 0, 1,       0, 1, 0, 1, 0, -1, 0, 1,         0, -1, 0, 1, 0, -1, 0, 1,        0, 1, 0, 1, 0, -1, 0, 1,
0, 1, 0, -1, 0, 1, 0, -1,        0, 1, 0, 1, 0, -1, 0, 1,         0, 1, 0, 1, 0, -1, 0, 1,         0, 1, 0, -1, 0, 1, 0, 1,
0, 1, 0, 1, 0, -1, 0, -1,        0, -1, 0, -1, 0, 1, 0, -1,       0, 1, 0, 1, 0, 1, 0, -1,         0, -1, 0, -1, 0, 1, 0, -1,
0, -1, 0, 1, 0, 1, 0, -1,        0, -1, 0, -1, 0, 1, 0, 1,        0, 1, 0, 1, 0, 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`** `= ...`
	`{7, 4, 6, 3, 5, 8, 5, 0, 2, 4, 1, 3,`
	`5, 2, 0, 3, 4, 7, 5, 3, 6, 8, 4, 1};`

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=`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 5.

Table 5: `GroupPhase` definition for mode 4

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

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

```
   Idx = {  8    14    20    26    32    38    44    50
           60    66    72    78    84    90    96   102
          112   118   124   130   136   142   148   154
          164   170   176   182   188   194   200   206
          216   222   228   234   240   246   252   258
          268   274   280   286   292   298   304   310
          320   326   332   338   344   350   356   362 };
```

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=`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 5.

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.

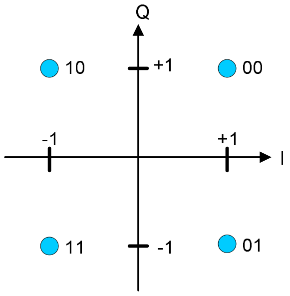


Figure 12: QPSK modulation

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.

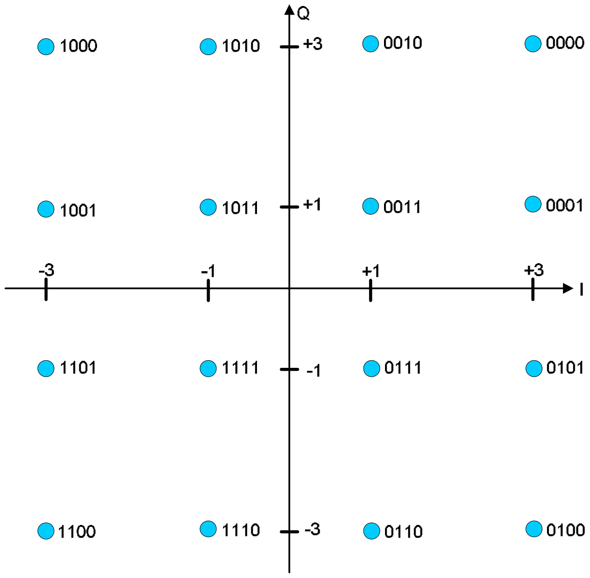


Figure 13: 16QAM modulation

4.5.3 16QAM Modulation (hierarchical)

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

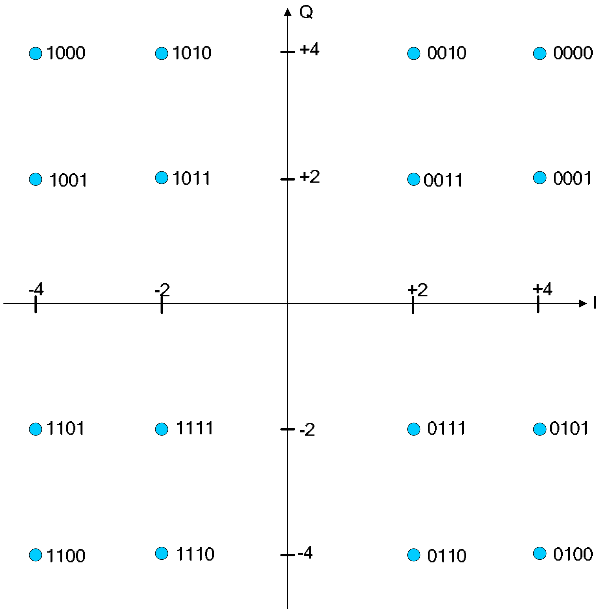


Figure 14: 16QAM hierarchical modulation with α = 2

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

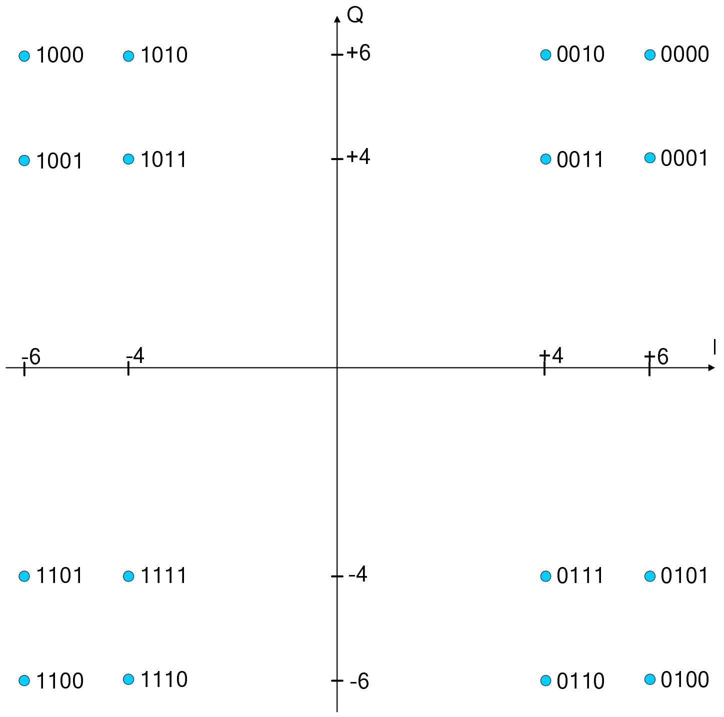


Figure 15: 16QAM hierarchical modulation with α = 4

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 6.

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

Table 6: 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 7: 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	853
2	2 048	0	1 508	1 509	755
3	1 024	0	728	729	365
4	512	0	364	365	183

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 8. Using these parameters, the following OFDM symbol lengths apply:

Table 8: 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".

History

Document history		
V1.1.1	December 2006	Publication