System Specifications

Communication Media

Powerline

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Summary

This document specifies the medium specific Physical Layer and Data Link Layer services for the Powerline medium.

Version 02.02.02 is a KNX Approved Standard.

This document is part of the KNX Specifications v2.1.

Document updates

Version	Date	Modifications
1.0 AS	2001.07.02	Finalisation of Approved Standard.
1.1 AS	2008.12.16	Finalisation of Approved Standard v1.1.
1.1.01 AS	2009.10.08	Editorial update.
1.2.00 WD	2011.01.18	Preparation for update.
2.00.00 DP	2011.10.21	Extension to PL110+. Preparation of the Draft Proposal.
2.01.00.DV	2011.11.02	Preparation of the Draft for Voting.
02.02.01	2013.10.23	Editorial update.
02.02.02	2013.10.29	Editorial update. Preparation for the inclusion in the KNX Specifications v2.1.

References

[01] Chapter 3/1/2 “Glossary”
[02] Chapter 3/3/2 “Data Link Layer General”
[03] Chapter 8/2/3 “PL110 Physical – and Data Link Layer tests”

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Contents

1 Scope

This KNX specification defines the mandatory and optional requirements for the medium specific Physical and Data Link Layer of power line Class 1 in its variations of PL110 and PL110+.

PL110+ defines a compatible extension to PL110.

Data Link Layer interface and general definitions, which are medium independent, are given in [02].

2 Normative references

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

EN 50090-1 - [1)]		*Home and Building Electronic Systems (HBES)* *Part 1: Standardization structure*
EN 50090-2-2	1996	*Home and Building Electronic Systems (HBES)* *Part 2-2: System overview - General technical requirements*
EN 50090-4-1	2004	*Home and Building Electronic Systems (HBES)* *Part 4-1: Media independent layers - Application layer for HBES Class 1*
EN 50090-4-2	2004	*Home and Building Electronic Systems (HBES)* *Part 4-2: Media independent layers - Transport layer, network layer and general parts of Data Link Layer for HBES Class 1*
EN 50090-5-1	2005	*Home and Building Electronic Systems (HBES)* *Part 5-1: Media and media dependent layers - Power line for HBES Class 1*
EN 50090-5-2	2004	*Home and Building Electronic Systems (HBES)* *Part 5-2: Media and media dependent layers - Network based on HBES Class 1, Twisted Pair*
EN 50065-1	2001	*Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz* *Part 1: General requirements, frequency bands and electromagnetic Disturbances*
EN 50065-4-6	2004	*Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz* *Part 4-6: Low voltage decoupling filters - Phase coupler*
EN 50065-7	2001	*Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz* *Part 7: Equipment impedance*
EN 50160	1999	*Voltage characteristics of electricity supplied by public distribution systems*
EN 55016-1-2	2004	*Specification for radio disturbance and immunity measuring apparatus and methods* *Part 1-2: Radio disturbance and immunity measuring apparatus - Ancillary equipment - Conducted disturbances* (CISPR 16-1-2:2003)
EN 61643-11	2002	*Low-voltage surge protective devices. Part 11: Surge protective devices connected to low-voltage power systems - Requirements and tests (IEC 61643-1:1998 + corrigendum Dec. 1998, modified)*

[1)] At draft stage.

3 Definitions and abbreviations

3.1 Definitions

For the purposes of this part the terms and definitions given in EN 50090-1 (some of which are repeated below for convenience) and the following apply.

3.1.1 Definition Home and Building Electronic Systems classes

Home and Building Electronic Systems (HBES) specification Class 1 refers to simple control and command. Class 2 refers to Class 1 plus simple voice and stable picture transmission. Class 3 refers to Class 2 plus complex video transfers.

3.1.2 Definition Differential mode

Power line signals are injected between phase and neutral [EN 50065-1].

3.1.3 Definition Coupler

A Coupler connects one Subnetwork with another Subnetwork.

3.1.4 Definition PL110

PL110 is a power line signalling using Spread Frequency Shift Keying modulation which is operating in the frequency band 95 kHz - 125 kHz according to EN 50065-1.

3.1.5 Definition PL110+

PL110+ is a power line signalling using PL110 to realize a first transmission channel and using Orthogonal Frequency Division Multiplex modulation to realize a second transmission channel. Both interoperable transmission channels are operating in the frequency band 95 kHz - 125 kHz according to EN 50065-1.

3.2 Abbreviations

Please refer to [01] for the common, communication medium independent abbreviations and acronyms.

CS	Check Sequence
CTRL	Control field
DPSK	Differential Phase Shift Keying
D2PSK	Differential 2 Phase Shift Keying (also called DBPSK)
D4PSK	Differential 4 Phase Shift Keying (also called DQPSK)
D8PSK	Differential 8 Phase Shift Keying
DBPSK	Differential Binary Phase Shift Keying
DQPSK	Differential Quadrature Phase Shift Keying
FEC	Forward Error Correction
FSK	Frequency Shift Keying
MAU	Medium Attachment Unit
MSK	Minimum Shift Keying
NAK	Not acknowledge
NPCI	Network Protocol Control Information
OFDM	Orthogonal Frequency Division Multiplex
SFSK	Spread Frequency Shift Keying
SPD	Surge Protection Devices

4 Requirements for HBES Class 1, Powerline PL110

4.1 Physical Layer type Powerline PL110

In this clause the Physical Layer characteristics of the medium powerline are specified. According to the used frequency range this Physical Layer shall be called PL110. The main characteristics of the PL110 Physical Layer shall be:

- a spread frequency shift keying signalling, and
- asynchronous transmission of data packets, and
- symbols globally synchronised to the mains frequency, and
- half duplex bidirectional communication.

The installation of the powerline depends on its initial use as an electrical power distribution network. Physical properties of the medium powerline are influenced significantly by the topology of the network, the connected loads and the cabling.

Electrical wiring in the house shall be in compliance with the current national regulations. Powerline communication is described in EN 50065-1 / Class122 (general requirements, frequency allocation and electromagnetic disturbances).

The physical topology of the powerline network is normally fixed by the electric power distribution network. The structure of this network can be 1- or 3-phase. The rated voltage between one phase and the neutral is 230 V. Signals are injected between phase and neutral. According to EN 50065-1 this kind of coupling is called “differential mode“.

General characteristics of the Physical Layer type PL110 are given in Figure 1.

Characteristic	Description
Medium	electrical power distribution network
Topology	installation dependant (e.g. linear, star, tree)
bit rate	1 200 bps
mains frequency	50 Hz (acc. EN 50160)
number of PL110 Domain Addresses	255
number of Individual Addresses	32 767
modulation type	spread frequency shift keying (SFSK)
frequency for logical “0“	105,6 kHz ± 100 ppm
frequency for logical “1“	115,2 kHz ± 100 ppm
Bit duration	833,33 µs
Maximum output level	122 dBµV [a]
Input sensitivity	≤ 60 dBµV [b]
Device class	class 122 [c]
Compliance to standards	EN 50065-1

[a] Measurement according EN 50065-1.
[b] With artificial network according EN 55016 1-2 [(50 µH + 5 Ω) / 50 Ω].
[c] Equipment manufactured to class 116 according to EN 50065-1 will now meet the requirements of class 122 and may be marked class 116 provided that its output complies with the previous standard.

Figure 1 - Features of Physical Layer Type PL110

The logical structure of the Physical Layer PL110 entity is shown in Figure 2. Each PL110 device includes one.

The PL110 entity consists of three blocks:

1. Connector
2. Medium Attachment Unit (MAU)
3. Error correction.

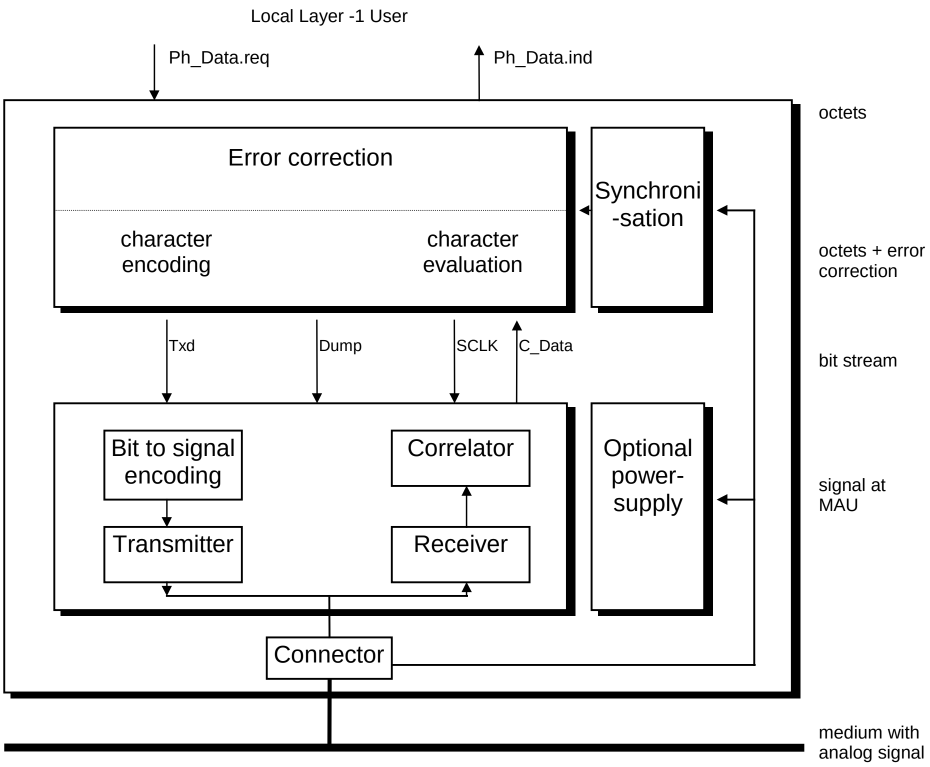


Figure 2 - Structure of the MAU (Example)

4.1.1 Transmission medium

4.1.1.1 Requirements for protection against electrical shocks and connectors

The PL110 devices are connected to the 230 V installation network. The requirements for protection against electrical shocks for human beings (and animals) and connectors must be considered within the complete device and are not subject to the Physical Layer description.

These requirements are fixed in the installation and equipment standards (safety standards).

4.1.1.2 Powerline cables

The requirements for powerline cables are defined by the use as installation wires according to national regulations. Normally the type of cable, the connected loads and the topology of the network is not known. Some widespread cables are listed in Figure 3. In contrast to the theoretical values, the impedance at one network access point is determined more by the load than by the cabling.

Typical cables for fixed electrical installation are „thermoplastic-insulated and sheathed cable“ (NYM, VDE 0250 part 204) or „PC-insulated flat cable, overall covering vulcanised rubber“ (NYIF VDE 0250 / 01.51), sheathed metal-clad wiring cable with PVC-insulated cores sheet-zinc cover with additional PVC-jacket (NYRUZY, VDE 0250 / 01.51).

Feature	Description
Cable type	NYM, NYIF, NYRUZY
Cross-section	1,5 mm² up to 4 mm²
Used wires	Phase and neutral
Resistance	25 µΩ/m to 50 mΩ/m
Capacity	15 pF/m to 100 pF/m
Inductance	1,2 µH/m to 1,5 µH/m

Figure 3 - Example of typical Cable Characteristics

NOTE 1 The use of shielded cables and cables with cross sections greater than 35 mm^2 can influence powerline signalling significantly!

4.1.2 Medium Attachment Unit (MAU)

4.1.2.1 Definition and power supply

The Medium Attachment Unit shall convert the frequency-coded signals into values representing logical ones and zeros and vice versa. In parallel, a power supply circuit may be connected to the medium. Signal converter and power supply shall be independent from each other. The requirements of the power supply are as follows:

Nominal values: RxD: 5 V @ 30 mA / 24 V @ 1 mA

TxD: 5 V @ 30 mA / 24 V @ 10 mA – 50 mA (dependent on impedance)

The power supply of the MAU may be internal or external.

Connection to the mains may be insulated or not.

4.1.2.2 Signal encoding

A signal of 105,6 kHz for a period of $833,\overline{3}$ µs corresponds to a logical „0“, a signal of 115,2 kHz for a period of $833,\overline{3}$ µs corresponds to logical „1“. See Figure 4 for illustration.

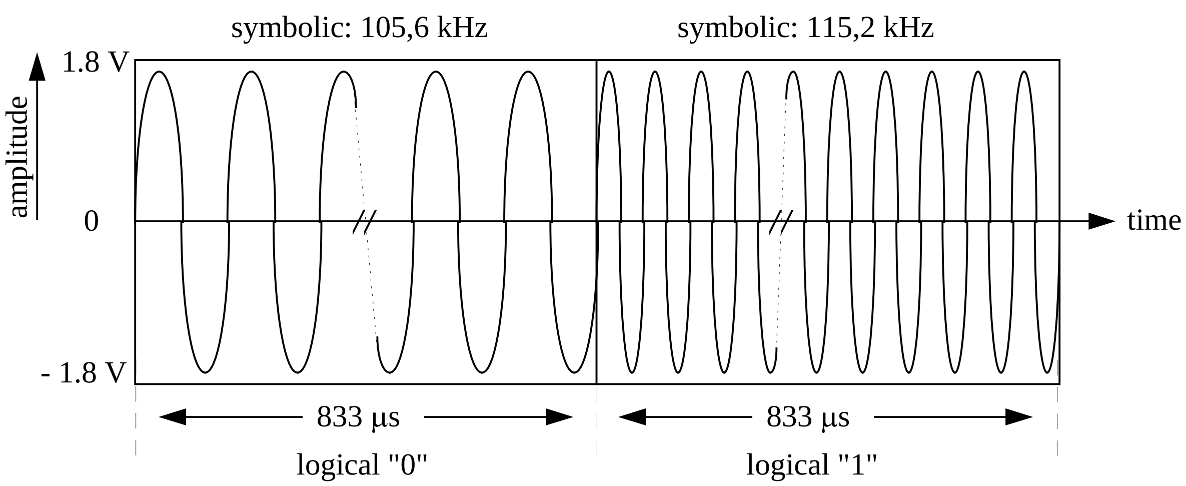


Figure 4 - Signal encoding

These NRZ-signals are superimposed to the 230 V/50 Hz mains AC-voltage. The maximum amplitude of the signal must be limited to 122 dBµV, measured with CISPR 16-1 artificial mains network according EN 50065-1. The sensitivity of the receiver shall be better than 60 dBµV, measurements according [03].

For lowest disturbances, the change between adjacent symbols shall be phase continuous.

4.1.2.3 Overlapping of logical "0" or "1"

Overlapping of logical "0" or "1"-symbols, e.g. the simultaneous transmission of equal information at the same time from several MAUs (e.g. common ACK), will result in fade-in / fade-out effects. Due to slight frequency deviations between several MAUs the signal will fade periodically with the difference of the MAU-frequencies. In PL110 Powerline communication this case is avoided by setting a unique Group Response Flag to each assigned Group Address.

4.1.2.4 Overlapping of logical "0" and "1"

Overlapping of logical "0" and "1"-symbols, e.g. the simultaneous transmission of different information at the same time from several MAU's, will result in a collision. While there is no indication of collision for any MAU, the probability of this state is minimised by special bus access mechanism.

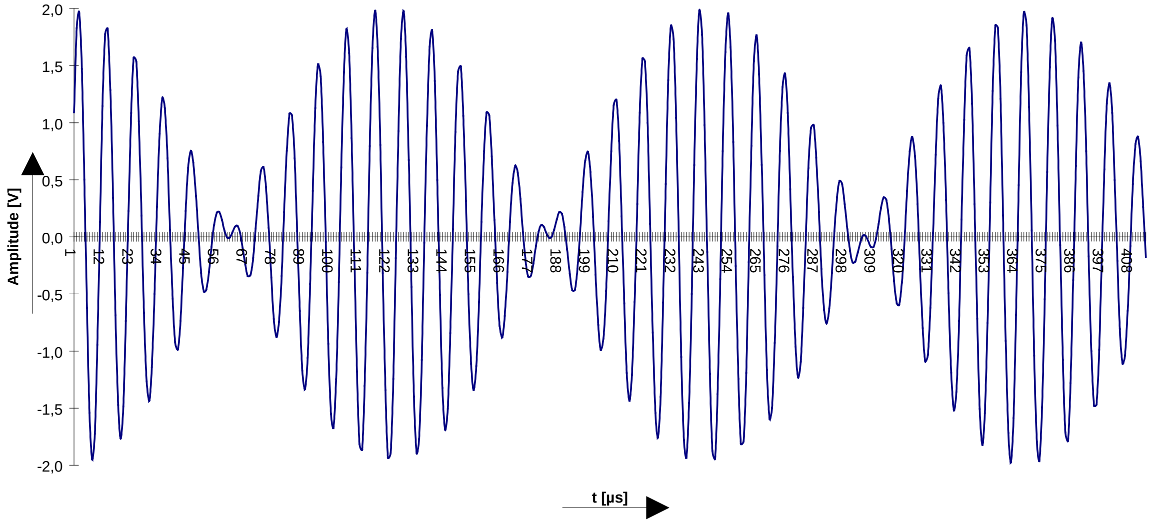


Figure 5 - Idealised overlapping of 105,4 kHz and 115,2 kHz

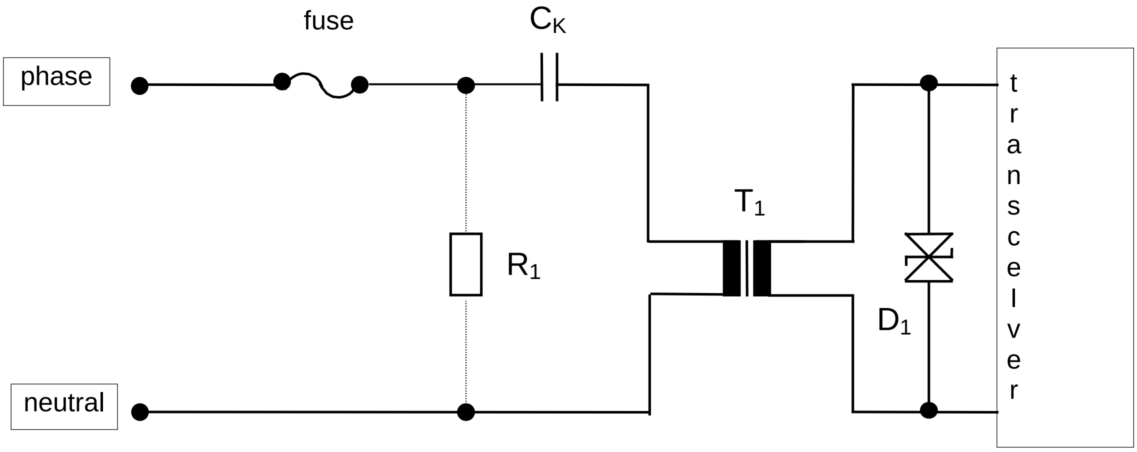
4.1.2.5 Impedance of the MAU

To limit the influence of connected MAUs on the characteristic of the Powerline bus the impedance in receiving mode must be high. For signal injection with minimum losses, the impedance in transmitting mode must be low. The limits for PL110 are:

RxD: $|Z_{in}| \geq 80\ \Omega$ @ 100 kHz to 125 kHz

TxD: $|Z_{out}| \leq 20\ \Omega$ @ 100 kHz to 125 kHz

4.1.2.6 PL bus coupling



C_K: coupling capacitor, X2-type
T_1: coupling transformer
D_1: transient voltage protection diode
R_1: resistor for discharging C_K (optional)

Figure 6 - Example of a PL inductive coupling circuit

Electrical coupling of signals to the Powerline has to be done by special circuits. In general, capacitive or inductive coupling can be used. Inductive coupling may be combined with electrical insulation or not.

4.1.3 Installation topology

The structure of an electrical installation can be linear, star, ring, tree or any combination. Referring to the electrical distribution board as the centre, the topology normally has a star structure. Each branch of the electrical distribution network can have its own different structure.

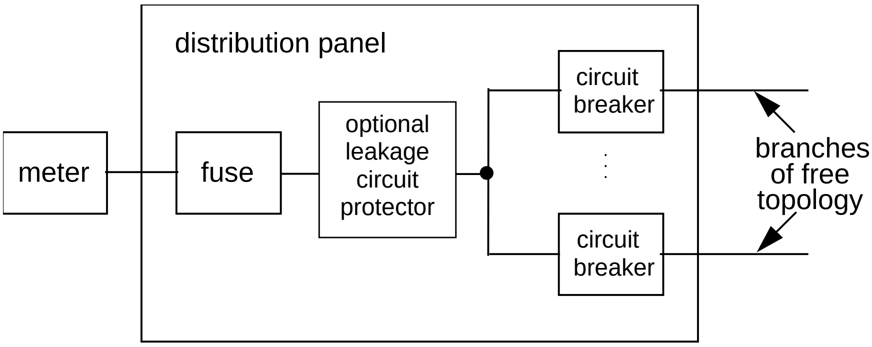


Figure 7 - Example of a typical PL topology

If voltage interruptions in one branch occur, the behaviour of the devices shall be as follows:

< 200 ms: continuous operation

≥ 200 ms: Power-On-Reset (POR), no idle

4.1.4 Installation requirements

The installation of the powerline network is subject to national and international regulations and standards. Additional instructions about the communication aspects of the network shall be given in the manufacturers instruction sheet.

4.1.5 Surge protection

Primary or secondary protection can be used. SPD´s of class B (for primary protection) or of class C (for secondary protection) according to draft DIN VDE 0675-6 have to be provided.

4.1.6 PL Physical Layer services and protocol

4.1.6.1 Physical Layer services at the Data Link Layer / Physical Layer interface

There are two services at the data link / Physical Layer interface:

Ph_Data.req (p_class, p_data)

Ph_Data.ind (p_class, p_data)

Ph_Data.req shall be called by the Data Link Layer. Each Ph_Data.req() service primitive shall transfer a single octet to the Physical Layer. class parameter -_Class shall contain timing information.

p_class:	start_of_sys.prio_frame:	transmit Training Seq, Preamble I, Preamble II and character after at least 58 bit times idle line since the last bit of the proceeding Data Link Layer message cycle.
	start_of_of_prio_frame:	transmit Training Seq, Preamble I, Preamble II and character after at least 74 + (n*16) $\vert$ $0 \leq n \leq 6$ bit times idle line since the last bit of proceeding data link message cycle.
	start_of_repeated_frame:	transmit Training Seq, Preamble I, Preamble II and character after exactly 40 bit times since the last bit of the proceeding L_Data request.
	inner_frame_char:	transmit character without any time gap after the last bit of the proceeding character.
	ack_char:	transmit Training Seq, Preamble I, Preamble II and character after exactly 4 bit times after the last bit of the proceeding L_Data request.
	nak_char:	transmit Training Seq, Preamble I, Preamble II and character after exactly 22 bit times after the last bit of the proceeding L_Data request.
p_data:	octet:	the octet to be expanded for 4 error correction to a character and to be transmitted.[1]

Ph_Data.ind shall be called by the Physical Layer. Each Ph_Data.ind() service primitive shall transfer a single octet to the Data Link Layer.

Ph_Data.ind (p_class, p_data)

p_class:	start_of_frame:	after detection of preamble I + preamble II a character is received
	inner_frame_char:	Character received immediately after the proceeding bit
	ack_char:	after detection of preamble I + preamble II a character is received
	bit_error:	uncorrectable bit error detected in received character. Receiving terminated.
p_data:	octet:	the data octet error corrected and extracted from the received character

1 Due to the fact that there is no collision-detection during transmission the return value of a Ph_Data.con will always be "Ok".

4.1.7 Features of Powerline PL110 Physical Layer

4.1.7.1 PL110 character overview

Each PL110 frame shall start with a training sequence and a preamble. Training sequence and preamble shall not be coded. Each Data Link Layer octet shall be coded to a 12 bit character (8 bits data + 4 bits error correction).

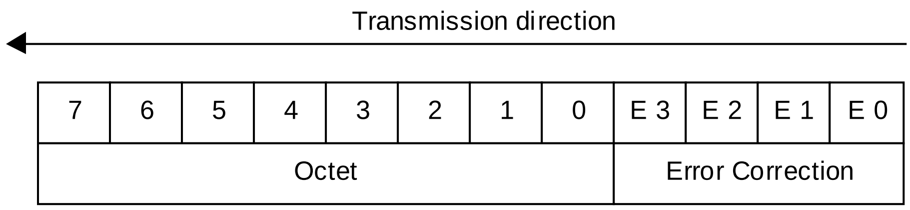


Figure 8 - Character

During transmission and reception no time gaps are allowed between the bits of a character.

4.1.7.2 Frame structure

The datagram shall consist of training sequence, preamble I / II, LPDU+CS and the Domain Address. Frame Check Sequence CS shall only be calculated with respect to TP LPDU, which is identical to the Twisted Pair LPDU. This shall lead to identical CS for Physical Layer Twisted Pair 1 and Powerline 110.

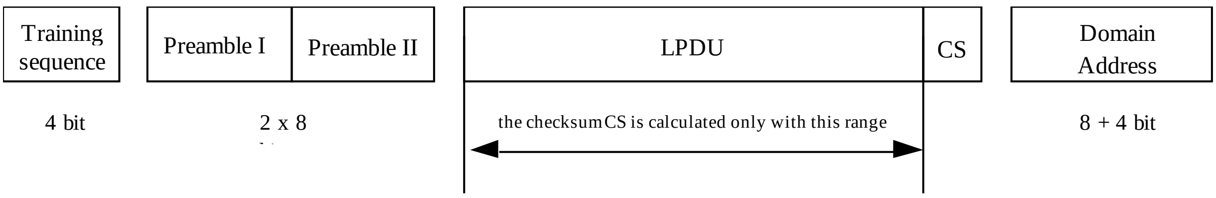


Figure 9 - Structure of a Datagram

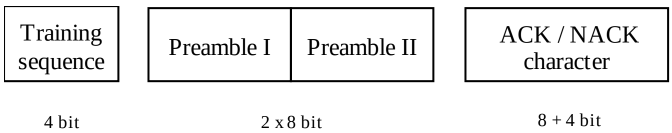


Figure 10 - Structure of an Acknowledge Frame

4.1.7.3 The Training Sequence

After switching into the status start_of_pdu the Physical Layer shall transmit a training sequence of 4 bit duration. The bit sequence is [0 1 0 1].

4.1.7.4 The Preamble Transmission start

The next 16 bit shall be the preamble I and II. This preamble shall allow the receiver to start. The sequence of each preamble shall be B0h.

4.1.7.5 Faulty transmission detection

The error correction of the PL110 Physical Layer shall be done by Powerline (12,8) block - coding. Generation is calculated with the following matrix:

$$G = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} E \\ T \end{bmatrix}$$

Figure 11 - Generation Matrix of PL110

Coding shall result in an overhead of 4 bit referring to one octet. The hamming - distance of this coding shall be 3 (min). With this (12,8) - coding it shall be possible to correct every single bit error in a 12 bit character and to recognise some multiple errors.

The code shall be calculated by determining redundancy r as the function of the transformation matrix T and the octet x:

$$r = T \cdot x$$

For decoding an estimation r` of the redundancy dependant on the incoming data d must be performed. The estimated redundancy shall be subtracted by the received redundancy d_u. The result shall be a syndrome with the value of s indicating the column of the error. Correction can be done by inverting this bit. For an error - free transmission the difference of r´ and d_u is 0.

$$d = \begin{bmatrix} d_0 & d_u \end{bmatrix}^T$$

$$r' = T \cdot d_0$$

$$s = d_u - r'$$

value of the syndrome	3	5	6	7	9	10	11	12	8	4	2	1	13	14	15	0
error location	1	2	3	4	5	6	7	8	9	10	11	12	error			Error-free

Figure 12 - Table of Syndromes related to errors

For all calculations, GF2 arithmetic shall to be used:

a	b	$a+b$	$a\times b$	$a-b$	$\frac{a}{b}$
1	1	0	1	0	1
0	1	1	0	1	0
1	0	1	0	1	–
0	0	0	0	0	–

Figure 13 - Operations of Galois-Field GF2

Example

$x := \begin{bmatrix}1 & 0 & 1 & 0 & 1 & 0 & 1 & 0\end{bmatrix}^T$ octet to be transmitted

$$r = T \cdot x = \begin{bmatrix}0 & 0 & 0 & 0 & 1 & 1 & 1 & 1\\0 & 1 & 1 & 1 & 0 & 0 & 0 & 1\\1 & 0 & 1 & 1 & 0 & 1 & 1 & 0\\1 & 1 & 0 & 1 & 1 & 0 & 1 & 0\end{bmatrix} \cdot x = \begin{bmatrix}0\\1\\1\\1\end{bmatrix}$$ redundancy

$c = \begin{bmatrix} x, r \end{bmatrix}^T = \begin{bmatrix}1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \mid 0 & 1 & 1 & 1\end{bmatrix}$ character to be transmitted

$\downarrow$ Transmission $\downarrow$ error

$d = \begin{bmatrix} d_o, d_u \end{bmatrix}^T = \begin{bmatrix}1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \mid 0 & 1 & 1 & 1\end{bmatrix}$ received character

$r' = T \cdot d_o = \ldots = \begin{bmatrix}0 & 0 & 0 & 1\end{bmatrix}^T$ estimated redundancy

$s = d_u - r' = \begin{bmatrix}0 & 1 & 1 & 0\end{bmatrix}^T = 6_{10}$

Referring to Figure 12 a syndrome value of 6 corresponds to an error in column 3. Inverting bit number 3 leads to the corrected frame.

4.1.7.6 Synchronisation

The mains zero-crossing period is 10 ms in single phase systems and $3.\overline{3}$ ms in triple phase systems (for nominal mains frequency). Dividing the $3.\overline{3}$ ms time base by an integer leads to the set of possible bit widths (and bit rates respectively) in triple phase systems:

$$bit\ rate = n \cdot 300\ bps \qquad n \in \mathbb{N}$$

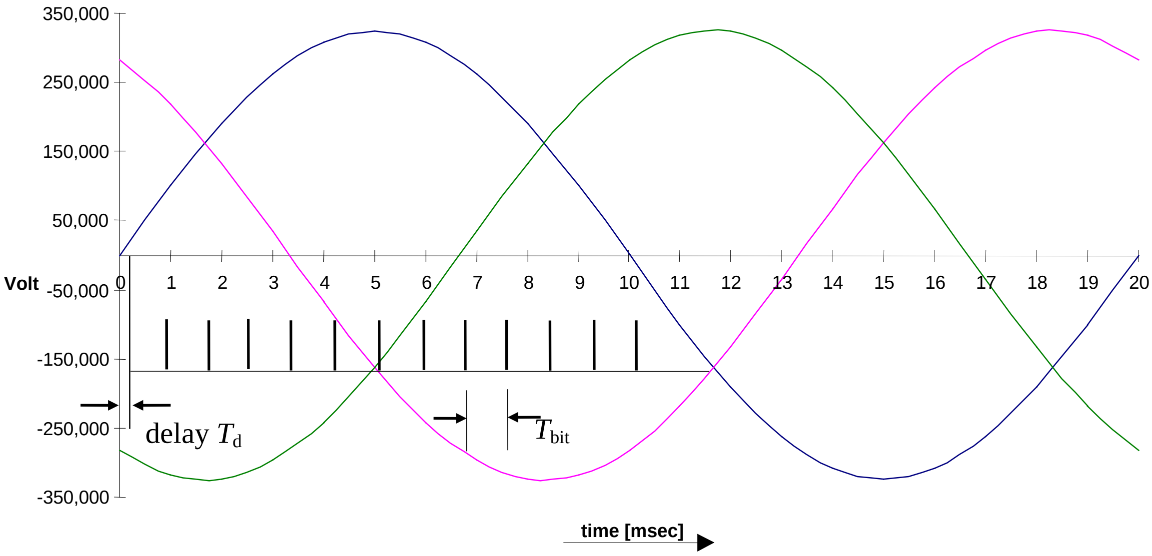


Figure 14 - Three Phase System

The start of a Transmission cannot be placed exactly at the mains zero-crossing due to internal delays of the coupling circuit. The delay must not exceed the value shown below.

$$T_d \leq 40\ \mu s$$

In order to compensate deviations of mains frequencies PL110 MAUs shall detect the zero crossing of the mains voltage and measure the current mains frequency. If the mains frequency (received by the described way) is placed within the permissible tolerance the bit width shall be calculated by the following formula:

$$\text{actual bit width} = \frac{\dfrac{1}{\text{actual mains frequency}}}{\dfrac{1}{\text{nominal mains frequency}} * 1200}$$

With the help of the first transmitted bit the transmitter shall fix its bit width to the nominal bit width of $833.\overline{3}$ µsec. Receiving the first preamble the receiver shall also fix its bit width to the nominal bit width of $833.\overline{3}$ µsec and shall correct the beginning of the following bit by:

12 * (actual bit width - nominal bit width)

4.2 Data Link Layer type Powerline 110

4.2.1 Name

The Data Link Layer described in this clause is called Data Link Layer type Powerline 110.

4.2.2 Domain Address/Individual Address/Group Address

Every PL110 BAU shall have a PL110 Domain Address. PL110 BAUs sharing the same PL110 Domain Address will belong to the same installation. The PL110 Domain Address shall be a two octet number. The most significant octet shall be set to zero, the lower significant octet shall contain the number of the PL110 Domain Address.

Every PL110 BAU shall belong to Domain Address zero, i.e. request frames with Domain Address zero shall be system-broadcasts.

PL110 Domain Address															
Octet 0								Octet 1							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	number							

Figure 15 – PL110 Domain Address

Every PL110 BAU, i.e. a Coupler or an end device shall have a unique Individual Address in a network. Please refer to [02] for the specification of the Individual Address. The Device Address shall be unique within a Subnetwork. PL110 Media Couplers shall have the Device Address zero, i.e. PL110 end devices may have the Device Address 1 to 255. The Subnetwork Address shall be unique within a network.

Please refer to [02] for the specification of the Group Address.

Group Address															
Dest Addr. (high)								Dest Addr. (low)							
Octet 0								Octet 1							
7[2]	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
	Main Group				Sub Group										

Figure 16 - Group Address

The Group Address shall be a 15 bit value that doesn't need to be unique. An end device may have more than one Group Address.

Every end device shall belong to group zero, i.e. request frames with Group Address zero as Destination Address shall be broadcasts.

4.2.3 Frame formats

4.2.3.1 General

There shall be two frame formats: the L_Data frame and the Acknowledge frame. Other frame formats shall not be received.

Each frame shall be sent as a sequence of characters. The character that corresponds to octet 0 shall be sent firstly, the octet with the highest number shall be the last character sent. The individual bits of an octet shall be sent in descending order, i.e. the most significant bit (bit 7) shall be sent firstly. The different frame formats shall differ in the control field.

4.2.3.2 L_Data frame

Two L_Data frame formats shall be available on the PL110 medium:

1. the L_Data_Standard frame format, and
2. the L_Data_Extended frame format.

The usage of the different formats shall depend on the value of the frame format parameter to the Data Link Layer (see [02]). The L_Data_Standard frame format shall be used if the frame format parameter is 0, otherwise the L_Data_Extended frame format shall be used.

[2] The most significant bit is the group-responder-flag. If this bit is set all incoming messages with this destination Group Address are acknowledged. There shall be at least one end device within one network with this bit set.

4.2.3.3 L_Data_Standard frame format

4.2.3.3.1 Structure

The structure of the variable length L_Data_Standard frame shall comply with Figure 17 below.

CTRL	SA	DA	AT, NPCI, LG	TPDU (L_Data)	FCS	DOA
8	16	16	8		8	8

Figure 17 - Frame fields with standard fieldname abbreviations

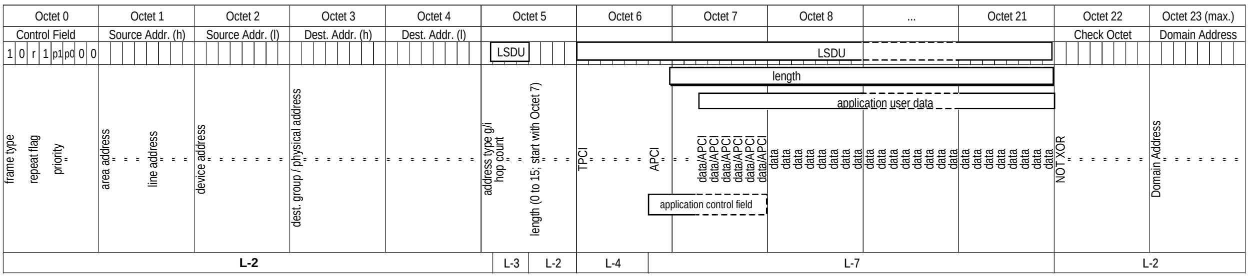


Figure 18 - L_Data_Standard frame format

4.2.3.3.2 Control field

The first character of each frame shall be the Control field (CTRL). The Control field shall contain the information about the Data Link Layer service, its priority, the Repeat Flag containing the information whether the LPDU is a repeated one or not and the Frame Type flag, as specified in Figure 19.

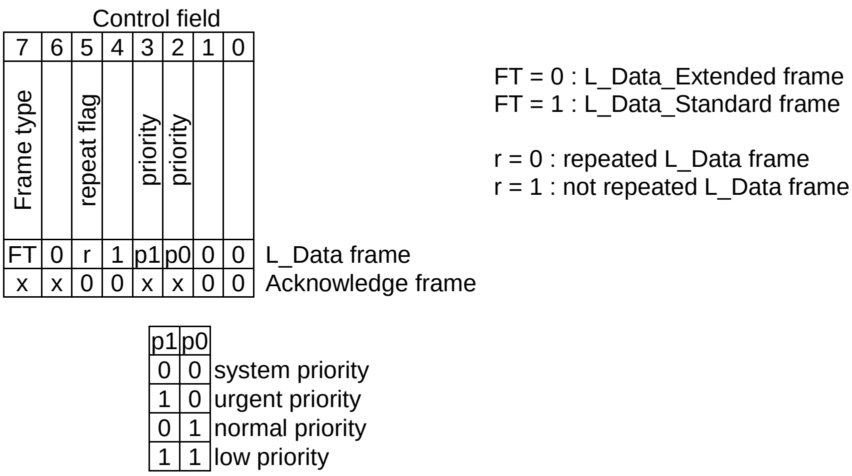


Figure 19 - Control field

The Control field shall indicate the type of the request frame: L_Data_Standard frame, L_Data_Extended frame, or Acknowledgment frame.

The Frame Type flag shall be mapped to the Frame Type Parameter of the L_Data-service. (Please refer to the specification of the L_Data-service in [02] clause "Usage of Frame Format".)

FTP parameter in L_Data-service	FT flag in L_Data-frame	
0	1	The L_Data frame shall be an L_Data_Standard frame.
1	0	The L_Data frame shall be an L_Data_Extended frame.

If Frame Type flag FT = 0 in CTRL field, an Extended Control Field CTRLE shall follow on octet 1.

The two priority bits of the Control field shall control the priority of the frame.

Repeated L_Data frames shall have the Repeat flag set to zero, non-repeated ones shall have it set to one.

4.2.3.3.3 Source Address

The octets one and two of an L_Data_Standard frame shall be the high and low octet of the Source Address. This shall be the Individual Address of the end device that causes the transmission of the frame.

4.2.3.3.4 Destination Address and Address Type (AT)

The Destination Address (octets three and four) shall define the end device(s) that shall receive the L_Data_Standard frame. For L_Data_Standard frames, the Destination Address can either be an Individual Address (AT = 0) or a Group Address (AT = 1), depending on the Address Type flag (AT) of octet five.

4.2.3.3.5 Length

The L_Data_Standard frame shall have a variable length; the maximum length shall be 24 characters. The Length field shall indicate the number of characters (0 characters to 15 characters) transported by the L_Data_Standard frame starting with the seventh octet. That means that an L_Data_Standard frame with length 0 shall end after the sixth octet.

4.2.3.3.6 Check Octet

The last but one octet of an L_Data_Standard frame shall be the Check Octet. This octet shall make an odd parity over the set of corresponding bits belonging to the preceding octets of the frame. This shall represent a logical NOT XOR function over the individual bits of the preceding octets of the frame.

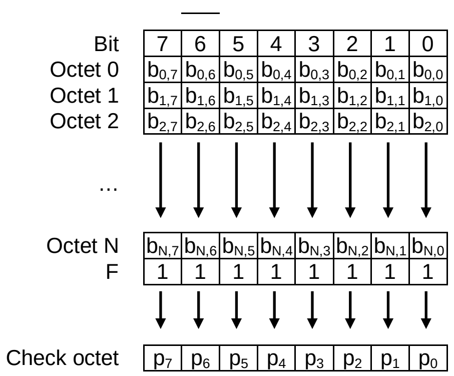


Figure 20 - Check Octet

4.2.3.3.7 Domain Address

The last octet of an L_Data_Standard request frame shall represent the lower significant octet of the Domain Address. It shall determine the devices that shall receive the frame.

4.2.3.4 L_Data_Extended frame format

4.2.3.4.1 Use and frame format

The L_Data_Extended frame format shall be used for:

- messages with APDU > 15 octets (long messages) that do not fit into L_Data_Standard frame because of its limited length, and
- messages with extended addressing capabilities used in LTE-Mode.

The L_Data_Extended frame shall not be used instead of the L_Data_Standard frame if the encoding capabilities of L_Data_Standard frame are sufficient (e.g. for short frames).

The structure of the variable length L_Data_Extended frame shall comply with Figure 21 below.

CTRL	CTRLE	SA	DA	LG	TPDU (L_Data)	FCS	DOA
8	8	16	16	8		8	8

Figure 21 - Frame fields with standard fieldname abbreviations

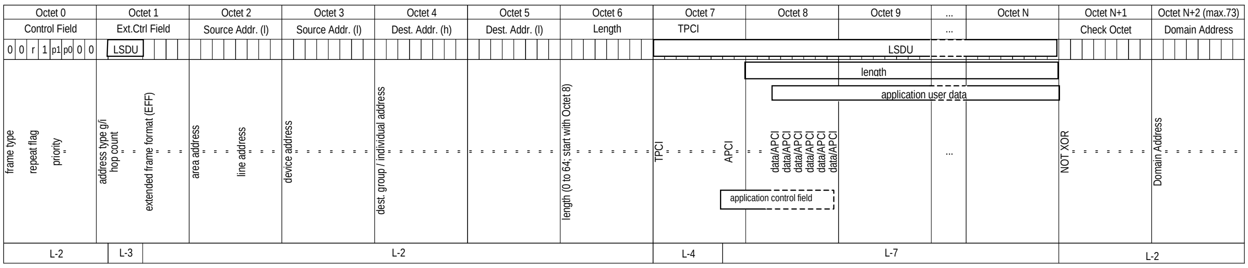


Figure 22 - L_Data_Extended frame format

4.2.3.4.2 Control field (CTRL)

The common encoding of the Control field is specified in clause 4.2.3.3.2 above.

4.2.3.4.3 Extended Control field (CTRLE)

If the Frame Type flag FT = 1 in the CTRL field, the extended control field CTRLE shall follow octet 1.

The Extended Control fields shall contain the Extended Frame Format parameter EFF and the Hop Count parameter. Bit 7 shall contain the Destination Address Type (AT) flag g/i.

Details are specified in [02].

Extended Control Field

7	6	5	4	3	2	1	0	
Address Type	Hop Count			Extended Frame Format (EFF)				
AT	r	r	r	t	t	t	t	
0	r	r	r	0	0	0	0	Point-to-point addressed L_Data_Extended frame
1	r	r	r	0	0	0	0	Standard Group Addressed L-Data_Extended frame
1	r	r	r	0	1	x	x	LTE-Mode extended address type
								All other codes are reserved for future use

Figure 23 - Extended Control Field

4.2.3.4.4 Source Address (SA)

The octets one and two of an L_Data_Extended frame shall be the high and lower octet of the Source Address. This shall be the Individual Address of the device that causes the initial transmission of the frame.

4.2.3.4.5 Destination Address (DA)

In the L_Data_Extended frame, the type of the Destination Address shall depend next to the Address Type (AT) also on the Extended Frame Format parameter (EFF) of the Extended Control field (CTRLE). With EFF = 0000b the same Address Type shall be used as in the L_Data_Standard frame format. With EFF ≠ 0000b dedicated address formats and tables shall be used.

4.2.3.4.6 Length (LG)

The L_Data_Extended frame shall have a variable length. The length information shall indicate the number of characters (0 characters to 64 characters) transported by the L_Data_Extended frame starting after the TPCI octet (octet 8). This means that a L_Data_Extended frame with length 0 shall end after the TPCI octet.

The length information shall be encoded by the combination of the Frame Type field (FT) in the Control Field and the Length field, as specified in [02].

NOTE 2 The possible encoding space (0 to 255) of the Length field is larger than the allowed usable range of 0 to 64. This limitation of the APDU to 64 octets results from limitations of the Physical Layer (probability for collisions, acceptable response time for all devices).

4.2.3.4.7 Check Octet

This shall be the same as in the L_Data_Standard frame format (see 4.2.3.3.6).

4.2.3.4.8 Domain Address

This shall be the same as in the L_Data_Standard frame format (see 4.2.3.3.7).

4.2.3.5 Acknowledge frame

Octet 0								
Acknowledge								
7	6	5	4	3	2	1	0	
1	1	0	0	1	1	0	0	ACK
0	0	0	0	1	1	0	0	NAK

Figure 24 - Acknowledge frame format

The Acknowledge frame format shall consist of a single character that shall be used to acknowledge an L_Data frame.

The Acknowledgement frame shall comply with the coding is specified in Figure 24.Any other than the shown figures shall be treated as NAK. Figure 24 shows the corresponding codes of the acknowledgment.

4.2.4 Data Link Layer protocol

4.2.4.1 Assemble/Disassemble Frame

Before transmitting a frame on the line, the Data Link Layer shall assemble service parameters into an LPDU.

It shall also ensure the following mapping.

- The Frame Type shall be calculated from the Frame Format parameter as defined in [02] and put into FT flag in the CTRL field.
- For the Extended Frame Format the EFF field shall be taken from the Frame Format parameter as defined in [02] and put into EFF field in CTRLE.
- The length information shall be calculated from octet_count parameter and put into Length field (LG) in octet 5 of the L_Data_Standard frame format or in octet 6 of the L_Data_Extended frame format.
- The fields Priority and Repeat flag shall be set in the CTRL field.
- The Destination Address and LSDU parameters shall be introduced in the frame.
- The Address Type flag (AT) shall be set in the AT field in octet 5 of the L_Data_Standard frame format or in the CTRLE field of the L_Data_Extended frame format.
- The Network Layer information shall be set in octet 5 of the L_Data_Standard frame format or in the CTRLE field of the L_Data_Extended frame format.
- Source Address, Domain Address and Check octet shall be introduced.

When receiving a PDU, the Data Link Layer does the reverse operation:

- It shall disassemble the frame into parameters to be transmitted in an L_Data.ind.
- It shall regenerate the Address Type from the AT field in octet 5 in case of an L_Data_Standard formatted frame or in the AT field of the CTRLE field in case of an L_Data_Extended formatted frame.
- It shall regenerate the octet_count parameter from the Length field in octet 5 in case of an L_Data_Standard formatted frame or from the CTRL field and the LG field in case of an L_Data_Extended formatted frame.

4.2.4.2 Medium Access Control

There is no absolutely collision free multiple access control in a frequency modulated medium. Therefore PL-BAUs shall use a slotted access technique as described below.

Before a device may start a transmission it shall wait for at least 58 bit times idle line since the last bit of the preceding Data Link Layer message cycle. The structure of a Data Link Layer message cycle depends on the architecture of the installation (installation with or without Repeater). In general a Data Link Layer message cycle consists of a Data Link Layer request frame and a subsequent Data Link Layer acknowledgment or a subsequent Data Link Layer response frame.

If several devices want to start a transmission simultaneously, then there is an access conflict. To solve this conflict a priority dependent time slot system is used:

1. Repetitions shall have the highest priority and shall gain access to the bus before any other device with a pending transmission request.
2. If the bus is not locked by a repetition, an acknowledgment- or a not acknowledgment-frame, then a system- or urgent L_Data-request frame shall gain access to the bus.
3. If the bus is not locked by a repetition, system- or urgent L_Data-request frames normal/ low operational priority request frames shall gain access to the bus. Supposed that most of all L_Data-request frames are operational priority frames there are 7 time slots chosen at random to start the transmission.

If a device once gained control of the bus it will continue transmission until the last bit is transmitted.

During reception the Data Link Layer of the receiving device checks if the device is addressed and controls the immediate acknowledgment mechanism. If a transmission error occurs, the transmitting Data Link Layer shall repeat the L_Data-request frame. Errors can occur in either direction, i.e. an L_Data-request frame or an acknowledgment frame can be destroyed.

4.2.4.3 L_Data-request Message Cycle without Repeater

After a specified idle time a PL-BAU shall initiate a message cycle transmitting an L_Data-request frame. If this L_Data-request is received by another PL-BAU it shall check the consistency of the frame and whether it is addressed.

After a time gap of 4 bit after the last bit of the L_Data-request frame it shall start the transmission of an acknowledgment frame. The acknowledgment frame shall have a duration of 32 bit times. By now the message cycle shall be terminated and the next L_Data-request message cycle may gain access to the bus after at least 58 bit times after the last L_Data-request frame.

If either the L_Data-request frame or the acknowledgment frame has been destroyed and thus an acknowledgment frame has not been received within 39 bit times after the last bit of the L_Data-request frame, the PL-BAU that initiated the message cycle shall start a retransmission with the next bit slot. If the addressed PL-BAU received the repeated L_Data-request frame properly it shall start the transmission of its acknowledgment frame after a time gap of 4 bit after the last bit of the repeated L_Data-request frame. Even if either the repeated L_Data-request frame or the acknowledgment frame has been destroyed the message cycle shall be terminated. There are no further repetitions. The next L_Data-request message cycle (system priority) shall not be started after at least 58 bit times after the last bit of the repeated L_Data-request cycle.

4.2.4.4 L_Data-request Message Cycle with Repeater

After a specified idle time a PL-BAU shall initiate a message cycle transmitting an L_Data-request frame. If this L_Data-request is received by another PL-BAU it shall check the consistency of the frame and whether it is addressed. After a time gap of 4 bit after the last bit of the L_Data-request frame it shall start the transmission of an acknowledgment frame. The acknowledgment frame shall have a duration of 32 bit times.

If the repeater receives an acknowledgment frame within 39 bit times after the last bit of the L_Data-request frame it shall not start a repetition of the L_Data-request frame. By now the message cycle shall be terminated and the next L_Data-request message cycle may gain access to the bus after at least 58 bit times after the last L_Data-request frame.

If the acknowledgment frame has been destroyed and thus the repeater has not received an acknowledgment frame within 39 bit times after the last bit of the L_Data-request frame the repeater shall start a retransmission with the next bit slot. If the addressed PL-BAU received the repeated L_Data-request frame properly it shall start the transmission of its acknowledgment frame after a time gap of 4 bit after the last bit of the repeated L_Data-request frame.

If the repeater does not detect bus access (receiving of at least preamble 1) within 22 bit times after the last bit of the repeated L_Data-request frame it shall start the transmission of a not acknowledgment frame to inform the source device that the message cycle is not successful. Even if either the repeated L_Data-request frame or the acknowledgment frame is destroyed the message cycle shall be terminated. There shall be no further repetitions. The next L_Data-request message cycle (system priority) shall not be started after at least 58 bit times after the last bit of the repeated L_Data-request cycle.

4.2.4.5 L_Data-request access Priorities

There are 8 different priority dependent time slots to start the transmission of L_Data-request frames. The first slot is reserved for system priority L_Data-requests only. The slots 2 to 8 are reserved for operational priority L_Data-request frames. Each device with a pending operational priority L_Data-request will choose one slot (2 ≤ selection ≤ 8) by random.

Slot number	**Priority**	**Start** (bit times after the last bit of the last L_Data-request frame)
0	repeated L_Data-request frame	40
1	system priority	58
2	operational priority Slot I	74
3	operational priority Slot II	90
4	operational priority Slot III	106
5	operational priority Slot IV	122
6	operational priority Slot V	138
7	operational priority Slot VI	154
8	operational priority Slot VII	170

Figure 25 - L_Data frame priorities

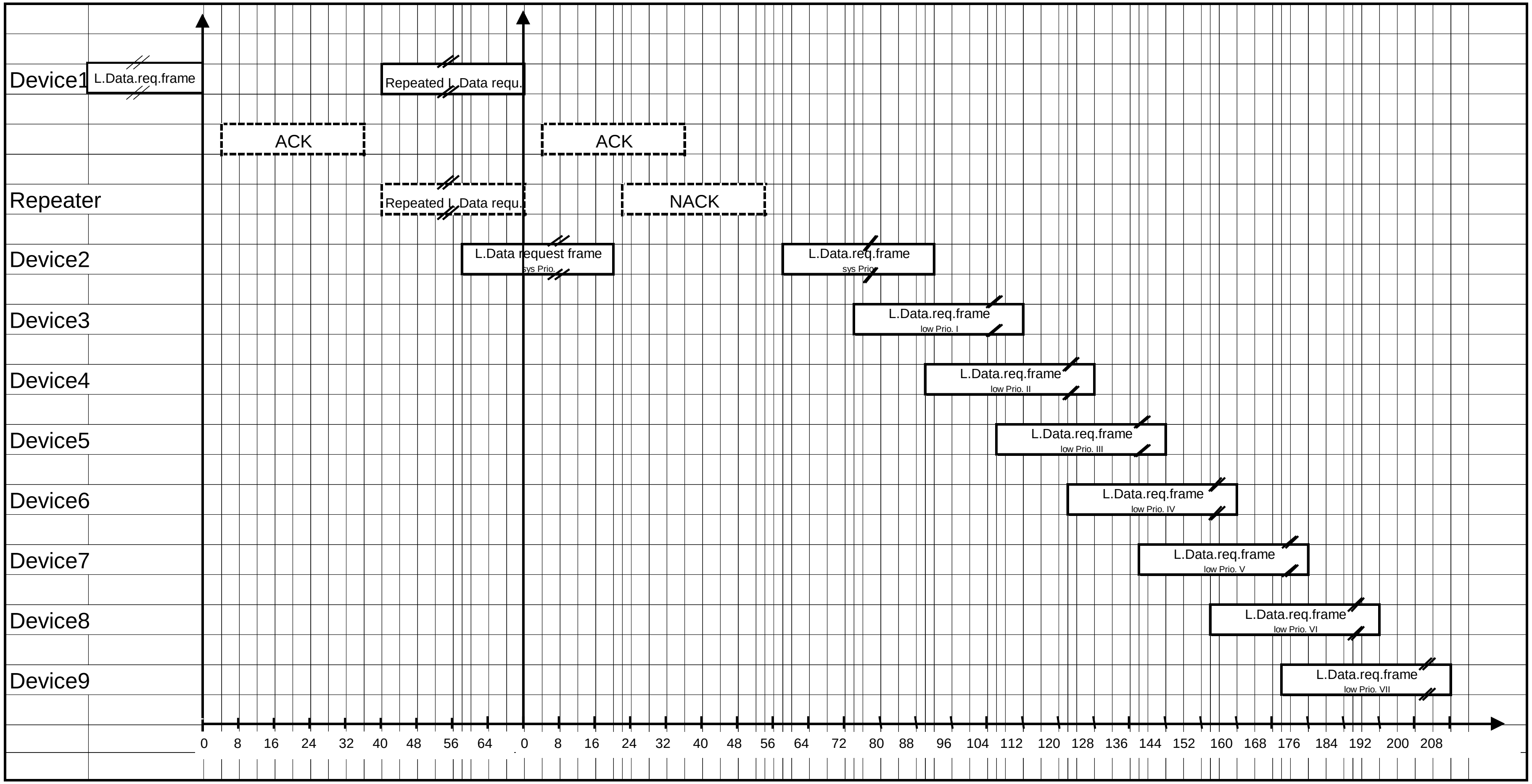


Figure 26 - Timing Diagram of an L_Data-request Frame

4.2.4.6 Checking for correct Request Frames

If the received Domain Address matches the own Domain Address and the Destination Address of a request frame corresponds to the Individual Address or one of the Group Addresses of a PL-BAU, the receiver of the frame shall check if the frame is correct. A frame is correct if:

- every character is correct or at least correctable
- the Check Octet has the correct value
- the Control Field has the correct value

The receiver of a frame shall acknowledge a repeated frame. The receiver shall discard it, if it has been received correctly before. A repeated frame shall have the same Source Address as the preceding frame (that applies to the repeater, too) with the repeat_flag set to 0.

4.2.5 Data Link Layer Services

4.2.5.1 L_Data Services

The L_Data service is a service, in case of a single destination in the same physical segment it is even an acknowledged datagram service. The local user of Layer-2 shall prepare an LSDU for the remote user by filling in the local Individual Address as Source Address and the local Domain Address as source Domain Address. The local user of Layer-2 shall apply the L_Data.req primitive to pass the LSDU to the local Layer-2. The local Layer-2 shall accept the service request and shall try to send the LSDU to the remote Layer-2 with frame format 1. The Destination Address may be an Individual Address or a Group Address (multicast or broadcast). The local Layer-2 shall pass an L_Data.con primitive to the local user that shall indicate either a correct or an erroneous data transfer.

Prior to passing the confirmation to the local user, the local Layer-2 shall need an acknowledgment from the remote Layer-2 (frame format 2). If the acknowledgment is a positive acknowledgment (ACK), the local Layer-2 shall pass an L_Data.con with l_status = ACK to the local user. If the acknowledge fails the local Layer-2 shall pass an L_Data.con with l_status = not_ok to the local user. In all other cases, i.e. acknowledgment is NAK or invalid or time-out after 36 bit times the local Layer-2 shall repeat once after 40 bit times. If it fails, the local Layer-2 shall pass an L_Data.con with l_status = not_ok to the local user.

If the request frame received is correct (see 4.2.4.6 ”Checking for correct Request Frames”), the remote Layer-2 shall send an acknowledge and shall pass the LSDU with an L_Data.ind primitive to the remote user. If the request frame received is not correct the remote Layer-2 shall not send an acknowledge.

L_Data.req(domain_address, destination_address, DAF, priority, lsdu)

domain_address:	Source and Destination Domain Address
Destination Address:	either an Individual Address or a Group Address
DAF:	destination_address flag indicates whether destination_address is an Individual Address or Group Address
priority:	system, urgent, normal or low operational priority
lsdu:	this is the user data to be transferred by Layer-2

L_Data.con(l_status)

l_status:	ok,	requested frame sent successfully
	not_ok	transmission of the frame did not succeed.

L_Data.ind(domain_address, source_address, destination_address, DAF, priority, lsdu)

domain_address:	Source and Destination Domain Address
source_address:	Individual Address of the end device that requested the L_Data service
Destination Address:	Individual Address of this device or a Group Address of this device
DAF:	destination_address flag indicates whether destination_address is an Individual (0) or Group Address (1)
priority:	system, urgent, normal or low operational priority
lsdu:	this is the user data that has been transferred by Layer-2

A Coupler (e.g.: a Media Coupler) connects one Subnetwork with another Subnetwork. It has a unique Individual Address. A Coupler shall acknowledge Layer-2 services and transmits the Layer-2 request frames to the other side, if the end device associated with the Destination Address of the frame is located on the other side. Thus receiving an acknowledge does not guarantee that the destination (the end device) has received the L_Data-request, but it indicates that at least one destination or a Coupler did receive it.

4.2.5.2 L_Sys_Data service

The L_Sys_Data service shall be an unacknowledged datagram service. The local user of Layer-2 shall prepare a LSDU for the remote user by filling in the local Individual Address as Source Address and the system-broadcast Domain Address (0000h) as source Domain Address. The local user of Layer-2 shall apply the L_Sys_Data.req primitive to pass the LSDU to the local Layer-2. The local Layer-2 shall accept the service request and shall try to send the LSDU to the remote Layer-2 with frame format 1. The Destination Address shall be a broadcast Group Address. The local Layer-2 shall pass an L_Sys_Data.con primitive to the local user that shall indicate a correct data transfer. The local Layer-2 shall always repeat the L_Sys_Data.req once before passing a positive confirmation to the local user.

If the request frame received is correct (see 4.2.4.6 “Checking for correct Request Frames”), the remote Layer-2 shall pass the LSDU with an L_Sys_Data.ind primitive to the remote user. If the request frame received is not correct the remote Layer-2 shall not send an acknowledge.

L_Sys_Data.req(system_broadcast, source_address, destination_address, DAF, priority, lsdu)

domain_address:	system broadcast Domain Address 0000h
source_address:	Individual Address of the end device that requests the L_Data service
destination_address:	broadcast Group Address 0000h
DAF:	destination_address flag indicates always a Group Address (1)
priority:	system, urgent, normal or low operational priority
lsdu:	this is the user data to be transferred by Layer-2

L_Data.con(l_status)

l_status: ok:	requested frame sent successfully

L_Data.ind(system_broadcast, source_address, destination_address, DAF, priority, lsdu)

domain_address:	system broadcast domain_address 0000h
source_address:	Individual Address of the end device that requested the L_Data service
destination_address:	broadcast Group Address
DAF:	destination_address flag indicates a Group Address (1)
priority:	system, urgent, normal or low operational priority
lsdu:	this is the user data that has been transferred by Layer-2

4.2.6 Parameters of Layer-2

The following parameters influence the behavior of Layer-2 and are required inside Layer-2 in order to operate correctly:

Domain Address	address shared by all devices belonging to the same installation
Individual Address:	unique Individual Address of this device
Group Address Table	Address Table with Group Address(es) of this end device

4.2.7 The Layer-2 of a Repeater

There are three different modes in Data Link Layer:

1. Data Link Layer without Repeater
2. Data Link Layer with a Repeater
3. Data Link Layer of a Repeater

The Data Link Layer differs in the timing and in the structure of a Data Link Layer message cycle. A message cycle shall consist of at least an L_Data.request frame followed by an acknowledgement frame. If the acknowledgement frame fails to come within its timeslot the L_Data.request frame shall be repeated (depending on the Data Link Layer mode by the PL-BAU itself or by the Repeater) in a specified timeslot. If the acknowledgement frame fails to come again within its timeslot the repeater shall transmit a not-acknowledgement frame to signal the loss of the L_Data.request frame.

If a repeater has to repeat a received L_Data.request frame the repeat flag in the control field (transmitted Octet 0) shall be set to zero.

The Source Address shall not be modified by the Repeater. I.e. the Source Address of the transmitting PL-BAU shall remain unchanged.

The Repeater is assigned to its Domain Address, i.e. it shall repeat only L_Data.request frames within its own Domain Address [3)].

4.2.8 The Layer-2 of a Media Coupler

To be defined.

4.2.9 State Machine of Layer-2

After power on, a device does not receive or transmit frames. The Layer-2 state machine shall synchronize to the mains frequency by measuring the time between two zero crossings. After that the Layer-2 state machine shall be in the idle state where Layer-2 shall work as described in the above clauses, i.e. receive frames and transmit frames.

3) In addition the Repeater shall consider itself as member of the Domain Address 0000h. Though not recommended, several Repeaters of adjacent Domain Addresses may be installed within receiving range.

5 Requirements for HBES Class 1, Powerline PL110+

This clause defines the mandatory and optional requirements for the medium specific Physical - and Data Link Layer of power line Class 1 in its variation of PL110+.

PL110+ defines a compatible extension to PL110 for transmitting higher data rates on a separate communication channel within the same frequency band.

It shall be noted that a PL110+ device shall fulfil the specification of a PL110 device for FSK signalling according to clause 4 and additionally shall fulfil the specification according to this clause for OFDM signalling.

PL110+ devices can communicate with PL110 devices using FSK signalling (see clause 4) and can communicate with PL110+ devices using PL110 FSK (see clause 4) or OFDM signalling (see clause 5).

The following subclauses specify only the OFDM extension and presuppose that the PL110 specification is considered for PL110+. These clauses point out the significant differences compared with PL110. Identical clauses of PL110+ and PL110 are referenced to the corresponding parts of clause 4.

5.1 Physical Layer type Powerline PL110+

5.1.1 General

This clause specifies the Physical Layer characteristics of the PL110+ power line signalling that shall operate in the frequency band 95 kHz to 125 kHz band as specified in EN 50065-1 and having a nominal centre frequency of 110 kHz.

The main characteristics of the PL110+Physical Layer shall be the following:

- up to 9 active OFDM carriers, and
- differential phase shift keying signalling (DBSK, DQPSK, D8PSK), and
- asynchronous transmission of data packets, and
- OFDM symbol raw synchronization to the mains frequency and fine synchronization using an orthogonal synchronization signal, and
- half duplex bidirectional communication, and
- interoperability and full backward compatibility with PL110 (refer to clause 4).

Electrical wiring in the building/home shall be in compliance with the current national regulations. Power line communication is described in EN 50065-1 / Class122 (general requirements, frequency allocation and electromagnetic disturbances).

The electric power distribution network normally determines the physical topology of the power line network. The structure of this network may be 1- or 3-phase. The rated voltage between one phase and the neutral shall be 230 V. PL110+ signals shall be injected between phase and neutral. According to EN 50065-1 this kind of coupling is called “differential mode“.

General requirements for the Physical Layer type PL110+ are given in Figure 27.

Characteristic	Description
Medium	electrical power distribution network
Topology	installation dependant (e.g. linear, star, tree)
FSK bit rate	1 200 bps
OFDM bit rate	10 800 bps (DBPSK) [d] 21 600 bps (DQPSK) [d] 32 400 bps (D8PSK) [d]
Mains frequency	50 Hz (acc. EN 50160)
Number of Domain Addresses	255
Number of Individual Addresses	32 767
FSK modulation type	spread frequency shift keying (SFSK)
OFDM modulation type	DBPSK, DQPSK or D8PSK subcarrier modulation
FSK frequency for logical "0"	105,6 kHz ± 100 ppm
FSK frequency for logical "1"	115,2 kHz ± 100 ppm
OFDM frequency f1OFDM	98,4 kHz ± 50 ppm
OFDM frequency f2OFDM	100,8 kHz ± 50 ppm
OFDM frequency f3OFDM	103,2 kHz ± 50 ppm
OFDM frequency f4OFDM	108,0 kHz ± 50 ppm
OFDM frequency f5OFDM	110,4 kHz ± 50 ppm
OFDM frequency f6OFDM	112,8 kHz ± 50 ppm
OFDM frequency f7OFDM	117,6 kHz ± 50 ppm
OFDM frequency f8OFDM	120,0 kHz ± 50 ppm
OFDM frequency f9OFDM	122,4 kHz ± 50 ppm
OFDM preamble frequency fPre	106,8 kHz ± 50 ppm
OFDM synchronization frequency fSync1	109,2 kHz ± 50 ppm
OFDM synchronization frequency fSync2	111,6 kHz ± 50 ppm
FSK Bit duration / OFDM symbol duration	$833,\overline{3}\,\mu s$
Maximum output level	122 dBµV [a]
Input sensitivity	≤ 60 dBµV [b]
Device class	class 122 [c]
Compliance with standards	EN 50065-1

[a] Measurement according to EN 50065-1.
[b] With artificial network according to EN 55016-1-2 [(50 µH + 5 Ω) / 50 Ω].
[c] Equipment manufactured to Class 116 according to EN 50065-1 will now meet the requirements of class 122 and may be marked class 116 provided that its output complies with the previous standard.
[d] With 9 OFDM carriers active.

Figure 27 - General requirements for Physical Layer PL110+

The logical structure of the Physical Layer PL110+ entity is shown in Figure 28. Each PL110+ device includes one.

The PL110+ entity shall consist of three blocks:

1. Connector
2. Medium Attachment Unit (MAU)
3. Error correction.

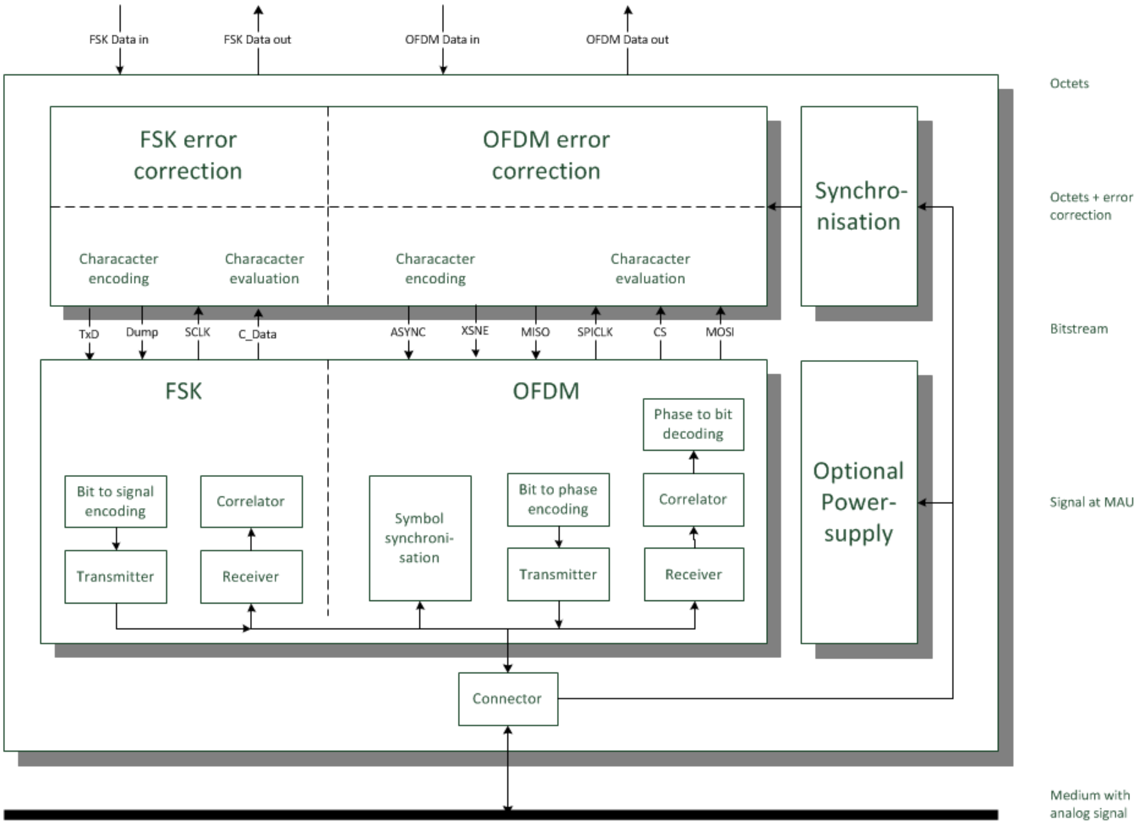


Figure 28 - Structure of the MAU PL110+ (example)

5.1.2 Transmission medium

The PL110+ and PL110 devices shall use the same transmission medium.

The requirements for protection against electrical shocks, connectors and power line cables are identical to the requirements of PL110. Please refer to clause 4.1.1 with subclauses 4.1.1.1 and 4.1.1.2.

5.1.3 Medium Attachment Unit (MAU)

5.1.3.1 General requirements

The Medium Attachment Unit shall convert the PL110 frequency - coded signals and the OFDM DPSK - coded signals into values representing logical ones and zeros and vice versa. The FSK-part shall comply with the PL110 MAU structure (refer to clause 4.1). In parallel, a power supply circuit may be connected to the medium. Signal converter and power supply shall be independent from each other. Compliance is checked by measurement.

The power supply of the MAU may be internal or external.

Connection to the mains may be insulated or not.

5.1.3.2 Signal encoding

5.1.3.2.1 PL110 FSK

Referring to clause 4.1.2.2, the PL110 FSK signals shall be defined as sine tones for a period of 833,3 µs with the following frequencies:

$f1_{fsk}$	105,6 kHz
$f2_{fsk}$	115,2 kHz

Figure 29 - PL110 FSK frequencies

The sine tones shall be SFSK modulated. Regarding the signal period, these frequencies shall also be orthogonal to each other. See Figure 30.

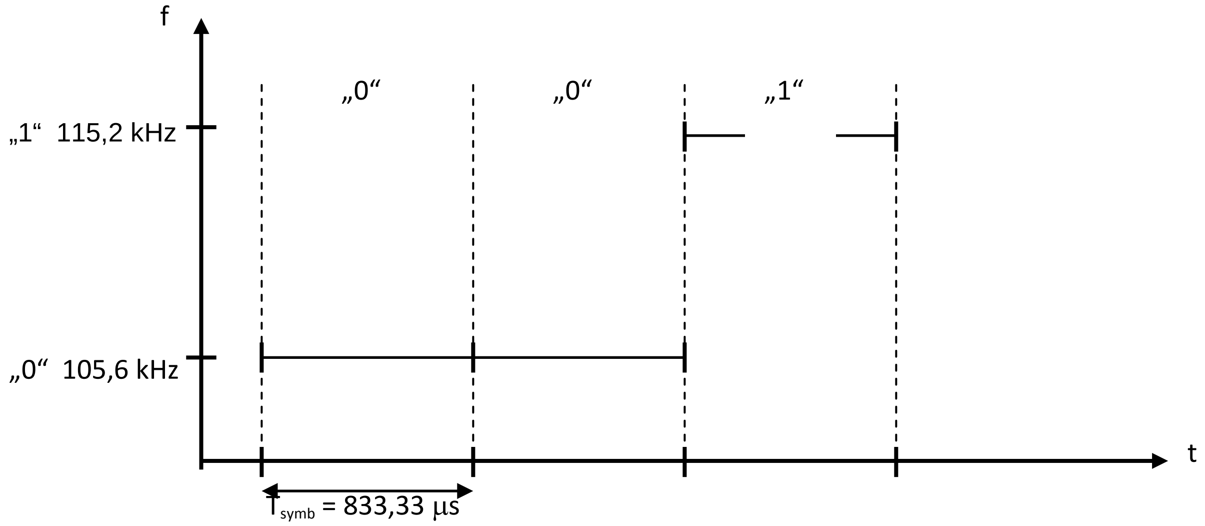


Figure 30 - Orthogonal SFSK modulation

The raw data rate with SFSK modulation shall be: Rbit = 1 bit / 833,33 µs = 1200 bit/s

These NRZ-signals shall be superimposed to the 230 V/50 Hz mains AC-voltage. The maximum amplitude of the signal shall be limited to 122 dBµV, measured with CISPR 16-1 artificial mains network according EN 50065-1. The sensitivity of the receiver shall be better than 60 dBµV, measurements according [03].

For lowest disturbances, the change between adjacent symbols shall be phase continuous.

5.1.3.2.2 OFDM

An OFDM signal shall consist of the sum from up to 9 orthogonal sine tones for a period of $833.\overline{3}$ µs that shall be orthogonal to the PL110 FSK signals (refer to 4.1.2.2). This OFDM signal shall be time limited and defined as an OFDM symbol. A transmission frame shall consist of several OFDM symbols that shall be transmitted serially without gaps between adjacent symbols. The OFDM sine tones – so called OFDM carriers – shall be defined with the frequencies as specified in Figure 31.

$f1_{OFDM}$	98,4 kHz
$f2_{OFDM}$	100,8kHz
$f3_{OFDM}$	103,2 kHz
$f4_{OFDM}$	108,0 kHz
$f5_{OFDM}$	110,4 kHz
$f6_{OFDM}$	112,8 kHz
$f7_{OFDM}$	117,6 kHz
$f8_{OFDM}$	120,0 kHz
$f9_{OFDM}$	122,4 kHz

Figure 31 - OFDM carrier frequencies

Each ODFM carrier shall be submodulated by BPSK, QPSK or 8PSK modulation. Depending on the modulation the number of bits per subcarrier varies, so that the data rate depends on the modulation. Refer to Figure 32.

Modulation	Bits per subcarrier
DBPSK	1
DQPSK	2
D8PSK	3

Figure 32 - OFDM bits per subcarrier

The BPSK, QPSK and 8PSK modulation encoding as well as the corresponding phase state diagrams shall be defined by Figure 33 to Figure 38.

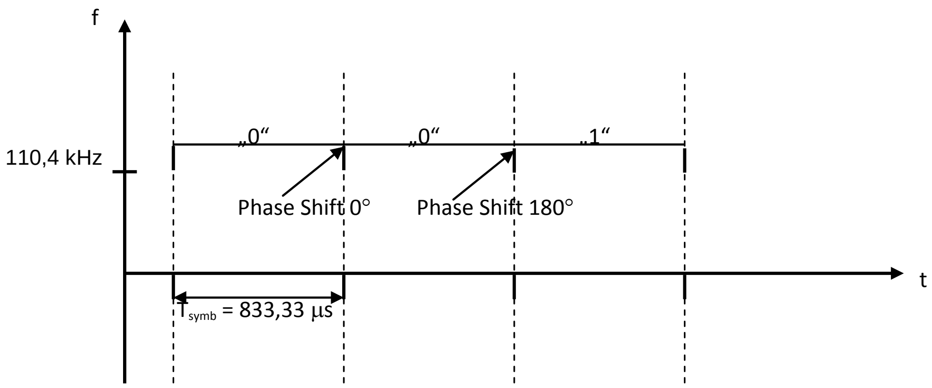


Figure 33 - Orthogonal BPSK modulation encoding at 110,4kHz

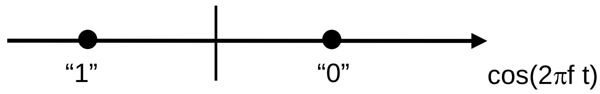


Figure 34 - BPSK Phase State Diagram

The raw data rate per active OFDM carrier with BPSK modulation shall be:

$$Rbit = 1\ bit / 833{,}33\ \mu s = 1200\ bit/s$$

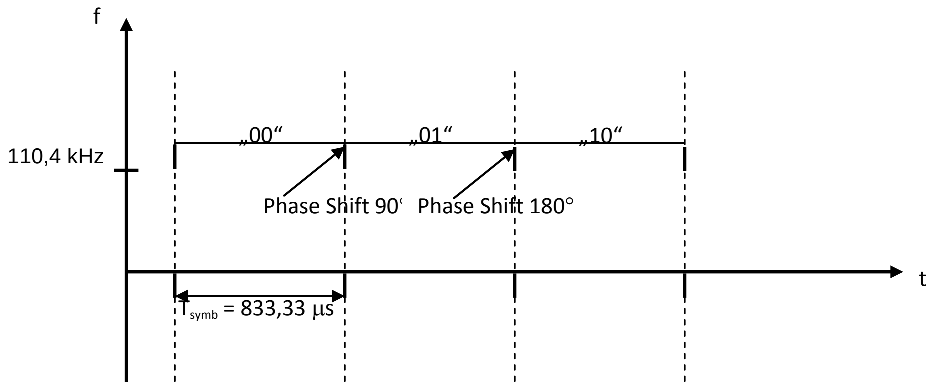


Figure 35 - Orthogonal QPSK modulation encoding at 110,4kHz

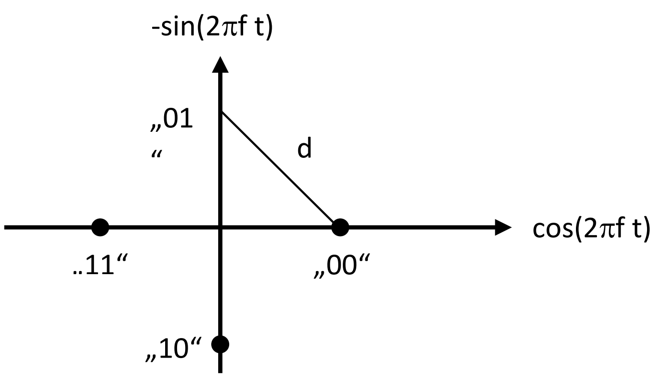


Figure 36 - QPSK Phase State Diagram

The raw data rate per active OFDM carrier with QPSK modulation shall be:

$$Rbit = 2 \text{ bit} / 833{,}33\ \mu s = 2400 \text{ bit/s}$$

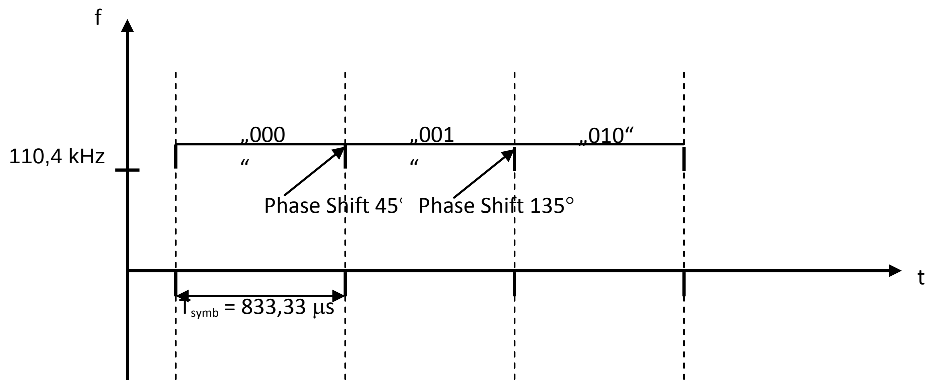


Figure 37 - Orthogonal 8PSK modulation encoding at 110,4 kHz

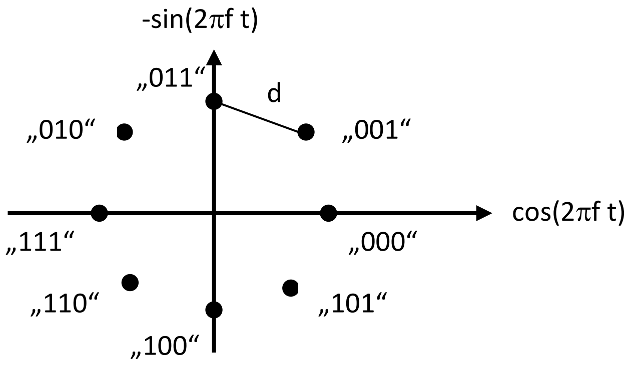


Figure 38 - 8PSK Phase State Diagram

The raw data rate per active OFDM carrier with 8-PSK modulation shall be:

Rbit = 3 bit / 833,33 µs = 3 600 bit/s

Figure 39 illustrates the unmodulated frequency carrier configuration in the frequency domain of the 9 OFDM carriers and of the embedded PL110 FSK carriers in dashed lines.

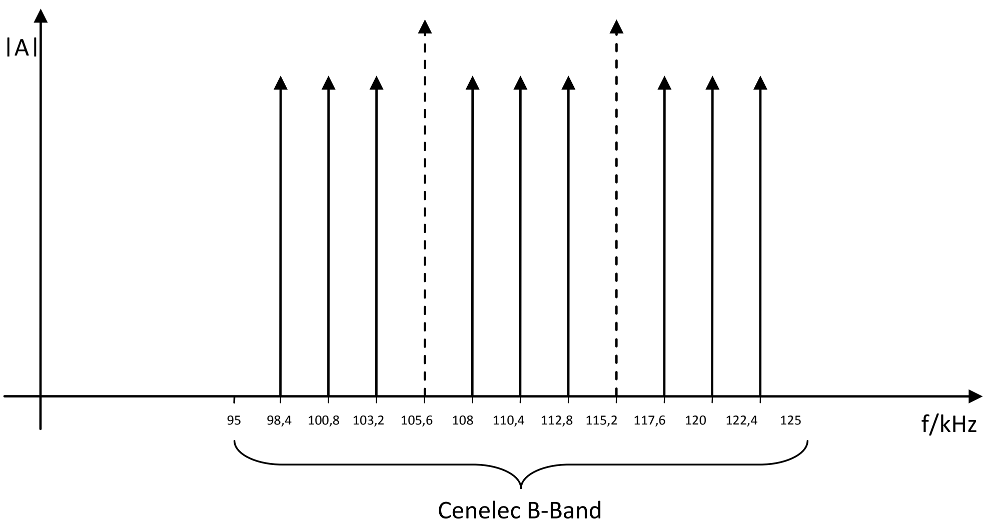


Figure 39 - Unmodulated ODFM carriers and PL110 FSK carriers

Each ODFM carrier modulation shall be done differentially by DBPSK, DQPAK and D8PSK modulation. In detail the data bits to be transmitted shall be assigned to a carrier phase offset $\Delta\varphi_m$ that shall be added to the carrier phase of the last transmitted OFDM carrier.

The definition for differential phase TX calculation shall be:

$$\boldsymbol{\varphi_m(T) = \varphi_m(T-1) + \Delta\varphi_m}$$

Where T shall represent the symbol count, $\varphi_m(T-1)$ shall be the last transmitted absolute phase of carrier m, $\varphi_m(T)$ shall be the modulation specific data assigned phase offset for carrier m and $\varphi_m(T)$ shall be the absolute carrier phase for transmission of OFDM symbol T. Refer to Figure 40.

DBPSK	
Data Input	TX Angle $\Delta\varphi_m$
"0b"	0°
"1b"	180°

DQPSK	
Data Input	TX Angle $\Delta\varphi_m$
"00b"	0°
"01b"	90°
"10b"	270°
"11b"	180°

D8PSK	
Data Input	TX Angle $\Delta\varphi_m$
"000b"	0°
"001b"	45°
"010b"	135°
"011b"	90°
"100b"	315°
"101b"	270°
"110b"	180°
"111b"	225°

Figure 40 - OFDM differential subcarrier modulation coding

EXAMPLE 1 For a transmission, in the case that the last carrier phase of a D8PSK modulated subcarrier was 45° and the new data bits for transmission are "110b", then new carrier phase offset will be 180° resulting in an absolute transmitting carrier phase of 45°+180°= 225°.

Each OFDM carrier shall be controlled individually, so that it is possible to setup variable OFDM carrier configuration. The following individual OFDM carrier configuration shall be possible for each transmission symbol:

- Carrier On/Off, and
- Differential carrier phase.

All OFDM carriers shall be pre-configured with an absolute start phase of 0°, when switching form receive mode to transmit mode.

Each OFDM carrier shall hold its actual absolute phase if it is temporarily switched off until it is switched on again, so that it is possible to allow differential phase modulation and carrier frequency hopping for each transmitted OFDM symbol.

These NRZ-signals shall be superimposed on the 230 V/50 Hz mains AC-voltage. The OFDM time signal shall be limited to 122 dBµV, measured with EN 5506-1-2 artificial mains network according EN 50065-1. The sensitivity of the receiver shall be better than 60 dBµV.

For lowest disturbances and compliance with EN 50065-1, each OFDM symbol shall be multiplied with a window filter function, which is an efficient way to realize a digital filter. The chosen window function realizes a very strong attenuation for the sideband frequencies that are generated during the OFDM modulation. It reduces the output power by approx. 6 dB.

The following window function shall be used:

$$\boldsymbol{window_{OFDM}(n) = 0,5 + 0,5 \cdot cos(2\pi f_{Symbol} n\tau + \pi)}$$

Definitions: $f_{Symbol} = 1{,}2kHz$ is the OFDM symbol frequency, $\tau = 1/f_{Sample}$ is the sample time with the sample frequency f_{Sample} and n is the sample position within the OFDM symbol.

The OFDM output signal shall be scalable for each transmitted symbol since the summation of m OFDM carriers may result in high RMS values and amplitude peaks of the time domain signal that can be up to m-times higher than the amplitude of single carrier. A typical scaling factor is $1/m$ in case of m active carriers.

OFDM output signal clipping is recommended for digital OFDM modulators to avoid register overflow due to high signal peaks.

Figure 41 shows a typical realization of a digital OFDM modulator including carrier phase modulation, signal summation, scaling, clipping, window filtering and digital to analog conversion. Alternatively, the signal scaling may be done with each carrier signal before signal summation to avoid digital clipping.

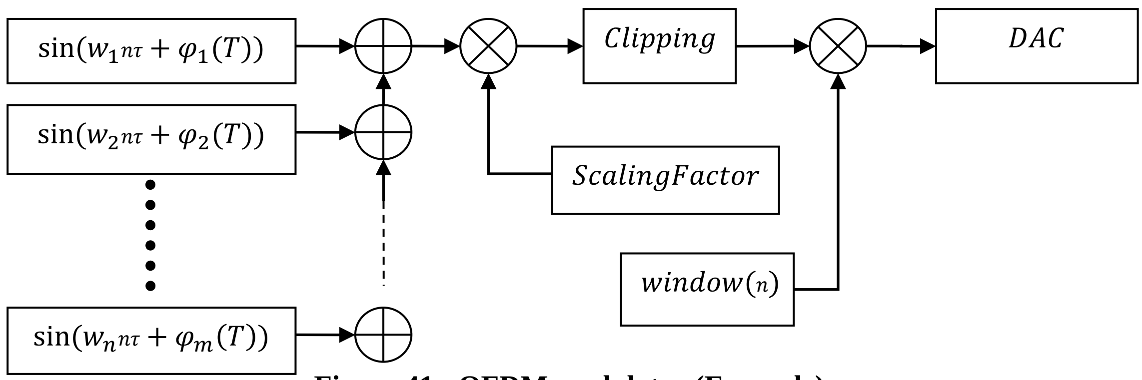


Figure 41 - OFDM modulator (Example)

Definitions: T shall be the symbol count, $\varphi_m(T)$ shall be the carrier phase and $w_1 = 2\pi f_1$ shall be the carrier angular frequency

Compliance shall be checked by measurement.

5.1.3.2.3 OFDM synchronisation signal

The OFDM signal reception requires a very good synchronisation to the signal of an OFDM PL110+ device, because the information shall be coded in the phase of each OFDM carrier. A "raw" synchronisation of transmitter and receiver shall be realized by synchronisation to the mains phase zero-crossing according to clause 5.1.8.12. This shall ensure also the synchronisation to PL110 devices according to clause 4.1.7.6.

An OFDM preamble signal shall be defined by sine tone for a period of $833.\overline{3}$ µs that shall be orthogonal to the OFDM carriers and orthogonal to the PL110 FSK carriers:

$$\boldsymbol{pre(t) = scale_{Pre} \cdot \sin(2\pi f_{Pre} t + \varphi_{Pre})}$$

Where $scale_{Pre}$ shall be the scaling factor of the amplitude and $f_{Pre} = 106{,}8\ kHz$ shall be the preamble signal frequency starting with a phase $\varphi_{Pre} = 90°$.

An OFDM sync signal shall be defined by the sum of two orthogonal sine tones for a period of $833.\overline{3}$ µs that shall be orthogonal to the other OFDM carriers and PL110 FSK carriers:

$$\boldsymbol{\begin{aligned} sync(t) &= sync_1(t) + sync_2(t) \\ &= scale_{sync} \cdot [\sin(2\pi f_{sync_1} t + \varphi_{sync}) + \sin(2\pi f_{sync_2} t + \varphi_{sync})] \end{aligned}}$$

The two frequencies of the sync signal shall be $f_{sync_1} = 109{,}2\ kHz$ and $f_{sync_2} = 111{,}6\ kHz$ with a starting phase of $\varphi_{sync} = -90°$ and $Scale_{sync}$ shall be the scaling factor of the amplitude. Compared to the preamble phase, the sine wave of the sync signal shall be shifted by 180°.

For OFDM transmission a more precise additional symbol synchronisation signal sequence shall be defined as:

$$\textbf{Synchronisation sequence}: \boldsymbol{pre - pre - sync - pre - pre - sync - pre}$$

To reach the same V_{RMS} value for preamble and sync signals the following equation shall be used:

$$\boldsymbol{scale_{sync} = scale_{Pre} / \sqrt{2}}$$

The symbols of the synchronization sequence shall not be filtered by the OFDM window function as defined in 5.1.3.2.2.

The first preamble symbol within the OFDM synchronization sequence may be multiplied by a soft ramp-up function within the first quarter of the symbol to reduce spurious emissions and allow a good tune-in phase at receiver input stage. Using a ramp-up function is not mandatory.

All symbols within an OFDM transmission frame - except the first preamble symbol - should have approx. the same V_{RMS} values to avoid problems with receiver AGC (**A**utomatic **G**ain **C**ontrol) circuits e.g. gain tuning within the transmission frame.

The following scaling factors can be used for $scale_{Pre}$ and $scale_{sync}$ depending on the active carrier count of the Data block:

Active OFDM data carriers	Scaling factor	
	$scale_{Pre}$	$scale_{sync}$
1	-	-
2	0,433	0,306
3	0,354	0,250
4	0,306	0,217
5	0,274	0,194
6	0,250	0,177
7	0,231	0,164
8	0,217	0,153
9	0,204	0,144

Figure 42 - Synchronization sequence scaling factors

Figure 43 shows the resulting synchronization signal sequence:

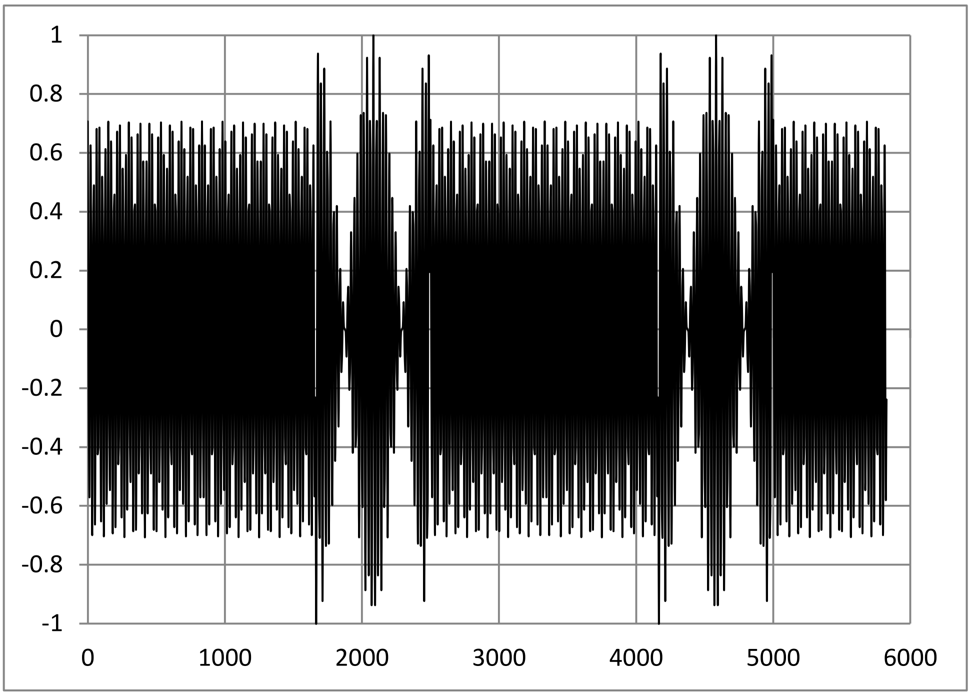


Figure 43 - OFDM synchronisation sequence (without ramp-up)

5.1.3.3 Signal decoding

5.1.3.3.1 General

A PL110+ device shall receive FSK and OFDM in parallel. So it shall be possible to synchronize and receive a power line device frame according to clause 4 during a PL110+ OFDM frame reception and vice versa.

5.1.3.3.2 PL110 FSK

Please refer to clause 4 for PL110 FSK signal decoding specification.

5.1.3.3.3 OFDM

The PL110+ OFDM demodulator shall detect the differential carrier phase of each OFDM carrier and shall assign modulation specific data bits to it.

Figure 44 shows a typical realization of a digital OFDM demodulator including analog to digital conversion, complex signal correlation, signal normalization, delta phase calculation and delta phase demodulation. The correlation may be realized by complex Fast Fourier Transformation (FFT) or matched filter techniques. The normalization is recommended to increase the following delta calculation.

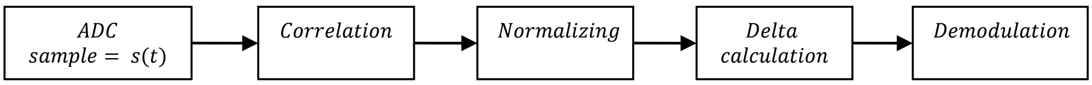


Figure 44 - OFDM demodulator (example)

After signal is analog to digital converted, the next part of the demodulation shall be the IQ-correlation, where the sine- and cosine-waves of the used frequencies shall be multiplied and accumulated over a period of 1 OFDM symbol ($833.\overline{3}$ µs) to calculate the real and imaginary part for all *m* carriers.

Figure 45 shows an IQ correlator based on matched filter techniques:

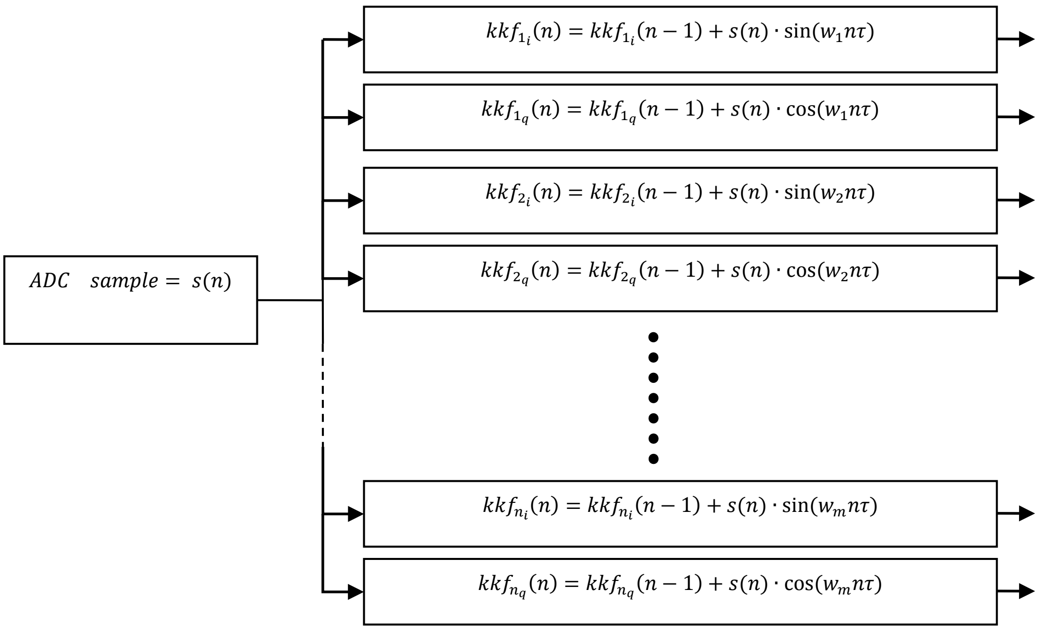


Figure 45 - OFDM correlator (example)

During the demodulation calculation the lower bits of the correlation sums get lost, due to multiplications and shifting processes. For high receiver sensitivity a normalization is recommended but not mandatory. It may be realized by the following operations: real and imaginary parts of the correlation sums are compared with each other as absolute values and the signed bits of the bigger one are counted. Finally the imaginary and real parts are multiplied with the normalizing factor $2^{signed\ bit\ count}$.

The absolute OFDM carrier phase shall be calculated by:

$$\boldsymbol{\varphi_m(T)} = \frac{180}{\pi} * \mathbf{arctan}\left(\frac{\boldsymbol{kkf_{m_q}(T)}}{\boldsymbol{kkf_{m_i}(T)}}\right)$$

The differential carrier phase (delta phase) shall be calculated by subtracting the previous phase angle from the actual phase angel of each OFDM carrier:

$$\boldsymbol{\Delta\varphi_m = \varphi_m(T) - \varphi_m(T-1)}$$

Where T shall represent the symbol count, $\varphi_m(T-1)$ shall be the last received absolute phase of carrier m, $\varphi_m(T)$ shall be the received absolute carrier phase of OFDM symbol T and $\Delta\varphi_m$ shall be the received differential phase for carrier m.

If applicable, alternative calculations of the differential carrier phase may be used.

The modulation specific RX data bits shall be assigned to $\Delta\varphi_m$. Refer to Figure 46.

RX Angle $\Delta\varphi_m$	Data Output		
	DBPSK	DQPSK	D8PSK
0,00° - 22.50°	"0b"	"00b"	"000b"
22.50°- 45.00°	"0b"	"00b"	"001b"
45.00° - 67.50°	"0b"	"01b"	"001b"
67.50° - 90.00°	"0b"	"01b"	"011b"
90.00° - 112.50°	"1b"	"01b"	"011b"
112.50° - 135.00°	"1b"	"01b"	"010b"
135.00° - 157.50°	"1b"	"11b"	"010b"
157.50° - 180.00°	"1b"	"11b"	"110b"
180.00° - 202.50°	"1b"	"11b"	"110b"
202.50° - 225.00°	"1b"	"11b"	"111b"
225.00° - 247.50°	"1b"	"10b"	"111b"
247.50° - 270.00°	"1b"	"10b"	"101b"
270.00° - 292.50°	"0b"	"10b"	"101b"
292.50° - 315.00°	"0b"	"10b"	"100b"
315.00° - 337.50°	"0b"	"00b"	"100b"
337.50° - 360.00°	"0b"	"00b"	"000b"

Figure 46 - OFDM differential subcarrier demodulation decoding

EXAMPLE 2 For reception, at receiver side the absolute carrier phase of the last OFDM signal was e.g. 67° and the absolute carrier phase of the new OFDM signal was 250°. The resulting phase difference $\Delta\varphi_m$ is then 250°-67°=183°. This differential phase angle falls in the angel segment 180°+/- 22,5° for D8PSK modulation and shall be decoded to "110b" for the received data bits. (Refer to Figure 46).

Each OFDM reception carrier shall be controlled individually, so that it is possible to setup variable OFDM carrier configuration. The following individual OFDM carrier configuration shall be possible for each reception symbol:

- carrier On/Off, and
- type of modulation (DBPSK, DQPSK, D8PSK).

All OFDM carriers shall be pre-configured with an absolute start phase of 0°, when switching from transmit to receive mode.

Each OFDM reception carrier shall hold its actual absolute received phase if it is temporary switched off until it is switched on again, so that it is possible to allow differential phase demodulation and carrier frequency hopping for each received OFDM symbol.

5.1.3.4 Overlapping of equal logical information

Overlapping of equal logical symbols, e.g. the simultaneous transmission of equal information at the same time from several MAUs (e.g. common ACK), results in fade-in / fade-out effects. Due to slight frequency deviations between several MAUs the signal fades periodically with the difference of the MAU-frequencies. In PL110+ power line communication this case can be avoided by setting a unique group response flag to each assigned Group Address.

5.1.3.5 Overlapping of different logical information

Overlapping of different logical symbols, e.g. the simultaneous transmission of different information at the same time from several MAUs, results in a collision. While there is no indication of collision for any MAU, the probability of this state is minimized by special bus access mechanism (refer to 5.2.3.2).

5.1.3.6 Impedance of the MAU

To limit the influence of connected MAUs on the characteristic of the power line bus the impedance in receiving mode shall be high. For signal injection with minimum losses, the impedance in transmitting mode shall be low. When tested according to EN 50065-7, the limits for PL110+ shall be:

Impedance on	Requirements
Receiving mode	$\lvert Z_{in} \rvert \geq 80\ \Omega$ at 95 kHz to 125 kHz
Transmitting mode	$\lvert Z_{out} \rvert \leq 20\ \Omega$ at 95 kHz to 125 kHz

Figure 47 - Requirements for the impedance of the MAU

5.1.3.7 PL bus coupling

The PL bus coupling is identical for PL110+ and PL110 (see clause 4.1.2.6).

5.1.4 Installation topology

The installation topology is identical for PL110+ and PL110 (see clause 4.1.3).

5.1.5 Installation requirements

The installation requirements are identical for PL110+ and PL110 (see clause 4.1.4).

5.1.6 Surge protection

The surge protection specification is identical for PL110+ and PL110 (see clause 4.1.5).

5.1.7 PL Physical Layer services and protocol

5.1.7.1 Physical Layer services at the Data Link Layer / Physical Layer interface

There shall be two services at the Data Link Layer / Physical Layer interface for PL110+ OFDM transmission:

Ph_Data.req (p_class, p_data)

Ph_Data.ind (p_class, p_data)

Ph_Data.req shall be called by the Data Link Layer. Each Ph_Data.req() service primitive shall transfer a single octet to the Physical Layer. Class parameter p_class shall contain timing information.

	length preamble	7 symbols for preamble 1 symbol carrier 0-phase-init 3 symbols application logical sync ⇨ 11 symbols
	length ACK frame (CONV)	11 symbols preamble (see above) (1 byte (CTRL) + 8bit CRC)*2 + 10bit tailing (with K=6) on 3ch*2bit/ch = 7 symbols, expanded to interleaving block size= 9 symbols. ⇨ 20 symbols Assuming CONV coder results in a length of 20 symbols for an ACK frame.
	min gap between frames	4 symbols. The gap length can vary depending on the phase situation (OFDM can only start at phase crossing on one of the 3 phases (50Hz system, every 4 symbols) or on one of the 2 phases (60Hz system, every 5 symbols)). To start the next transmission frame, the gap can be between 4 and 9 symbols. ⇨ 4 to 9 symbols
p_class:	start_of_sys.prio_frame:	This parameter value shall be used to start transmitting after at least 65 bit times (-0/+5) idle line since the last bit of the proceeding data link message cycle.
	start_of_of_prio_frame:	This parameter value shall be used to start transmitting after at least 81 + (n*16) $\mid 0 \leq n \leq 7$ bit times (-0/+5) idle line since the last bit of proceeding data link message cycle.
	start_of_repeated_frame:	This parameter value shall be used to start transmitting after exactly 49 bit times (-0/+5) since the last bit of the proceeding L_Data request.
	inner_frame_char:	This parameter value shall be used to start transmitting without any time gap after the last bit of the proceeding character.
	ack_char:	This parameter value shall be used to start transmitting after 4 bit times (-0/+5) after the last bit of the proceeding L_Data request.

p_data:	octet:	This parameter value shall contain the octet to be expanded by four error corrections to a character and to be transmitted. Due to the fact that no collision-detection is carried out during transmission the return value of a Ph_Data.con shall always be "Ok".

Ph_Data.ind shall be called by the Physical Layer. Each Ph_Data.ind() service primitive shall transfer a single octet to the Data Link Layer.

Ph_Data.ind (p_class, p_data)

p_class:	sync_1_detected:	This parameter value shall indicate the synchronisation on the preamble sequence was successful
	start_of_frame:	This parameter value shall indicate that a valid application sync word set (3 symbols) has been received
	bit_error:	This parameter value shall be used to indicate that an uncorrectable bit error was detected in the received character and that reception was terminated.
p_data:	octet:	This parameter value shall be used to indicate that the data octet error was corrected and extracted from the received character [4].

5.1.8 Features of Powerline PL110+ Physical Layer

5.1.8.1 Introduction

This clause describes the frame format, error correction and synchronization of PL110+ medium using OFDM modulation. Compliance with the requirements of this clause is subject to transient and logical measurement equipment.

5.1.8.2 PL110+ character overview

Each PL110+ frame shall start with an OFDM synchronization sequence. The synchronization sequence shall not be coded.

Two error correction codings shall be possible for PL110+ OFDM transmission:

- Convolutional coding
- Power line (12,8) block coding according to clause 4.1.7.5

This shall result in 2 character definitions for convolutional and (12,8) block coding:

1. Each Data Link Layer octet that has to be convolutional coded, shall be encoded to a 16 bit character (16 bit convolutional coded data).
   Hint: Each data octet bit is coded into two convolutional bits with index a and b. Additional tail bits are transmitted at the end of each data block.

Transmission direction ←

E7a	E7b	E6a	E6b	E5a	E5b	E4a	E4b	E3a	E3b	E2a	E2b	E1a	E1b	E0a	E0b
Error Correction including coded Data															

Figure 48 - Convolutional coded character

2. Each Data Link Layer octet that has to be (12,8) block coded, shall be coded to a 12 bit character (8 bits data + 4 bits error correction).

[4] Due to the fact that there is no collision-detection during transmission the return value of a Ph_Data.con will always be "Ok".

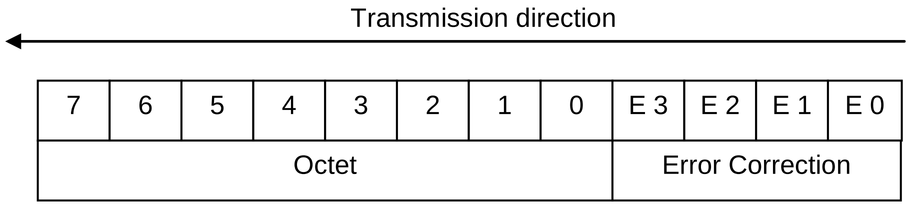


Figure 49 - (12,8) Block coded character

During transmission and reception no time gaps are allowed between the bits of a character.

5.1.8.3 OFDM frame structure

The OFDM Frame shall consist of physical OFDM synchronization sequence, carrier 0-phase init, logical sync data, CTRL block, HDR block and a variable Data block.

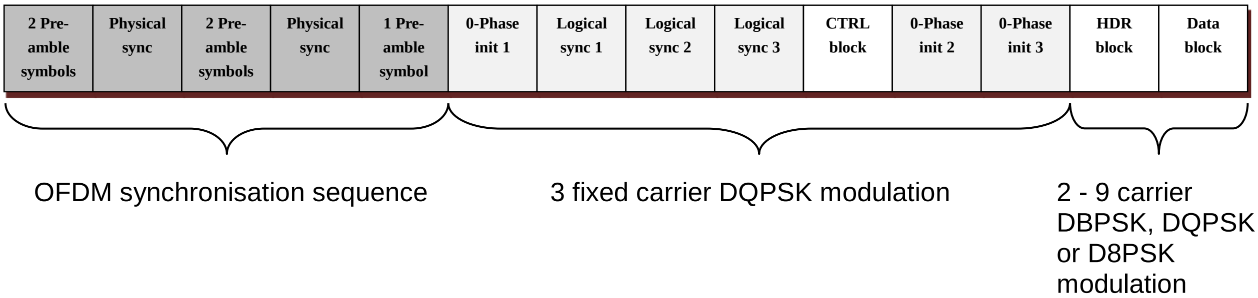


Figure 50 - OFDM frame structure

5.1.8.3.1 Block structure

The OFDM frame blocks CTRL, HDR and DATA are part of the original PL110 structure according to clause 4. Detailed information can be found in clauses 4.2.3.3 and 4.2.3.4.

For PL110+ OFDM transmission these three blocks shall be extended by additional PL110+ specific information:

Block	data contained		OFDM Coding	Data Octets
CTRL	KNX Frame:	CTRL, CTRL+	DQPSK (fixed), 3 fixed active carriers	2
	ACK Frame:	ACK	DQPSK (fixed), 3 fixed active carriers	1
HDR	extended frame:	CTRLE, SA, DA, LG	DBPSK,DQPSK,D8PSK, 2 – 9 active carriers	6
DATA	extended frame:	TPCI + n * DATA + CRC + DOA (n > 15 && n < 255)	DBPSK,DQPSK,D8PSK, 2-9 active carriers	LEN + 3

Figure 51 - OFDM frame blocks

Each block shall be protected by the FEC algorithm defined by the selected logical sync words. For the CTRL/ACK block the OFDM modulation shall be fixed to DQPSK using 3 active carries, meaning 6 bits/symbol for very robust transmission.

Within the CTRL block an additional CTRL+ octet shall be transmitted that shall include OFDM modulation information as well as the active carrier count for the following packets. So it shall be possible to transmit the HDR/DATA blocks with another OFDM modulation and different active OFDM carriers (e.g. D8PSK with 9 active carriers).

The ACK CTRL block shall have no additional data, since there is no need for the additional modulation information.

5.1.8.3.2 OFDM transmission scaling factors

All symbols within an OFDM transmission frame should have approx. the same V_{RMS} values to avoid problems with receiver AGC (**A**utomatic **G**ain **C**ontrol) circuits e.g. gain tuning within the transmission frame.

The following scaling factors can be used for the OFDM frame symbols depending on the active carrier count of the Data block:

Active OFDM Data Carriers	Scaling factor				
	Preamble	Physical sync	0-Phase init1-3	Logical sync 1-3	CTRL, HDR, Data
1	-	-	-	-	-
2	0,433	0,306	0,408	0,408	0,500
3	0,354	0,250	0,333	0,333	0,333
4	0,306	0,217	0,289	0,289	0,250
5	0,274	0,194	0,258	0,258	0,200
6	0,250	0,177	0,236	0,236	0,167
7	0,231	0,164	0,218	0,218	0,143
8	0,217	0,153	0,204	0,204	0,125
9	0,204	0,144	0,192	0,192	0,111

Figure 52 - Scaling factors for OFDM frame symbols (Example)

5.1.8.4 The OFDM synchronization sequence

After switching into the status start_of_pdu the Physical Layer shall transmit an OFDM synchronization sequence of 7 symbols duration. The sequence is fixed to “preamble-preamble-sync-preamble-preamble-sync-preamble”.

5.1.8.5 The OFDM init 1 and logical sync sequence

The following symbol shall initialize the absolute starting phase of carrier 3, 5 and 7 ($f3_{OFDM}$, $f5_{OFDM}$, $f7_{OFDM}$) at transmitter and receiver side.

Modulation	DQPSK
Active Carrier	3
Bit Alignment to Carriers	bit 5,4 : Carrier 3
	bit 3,2 : Carrier 5
	bit 1,0 : Carrier 7
Window	On

Figure 53 - Carrier selection and modulation: Init 1 symbol and logical sync symbols

	Bin Data
0-Phase Init 1	101001

Figure 54 - 0-Phase init 1 data

The next 18 bit shall consist of the 3 logical sync symbols (sync 1, sync 2 and sync 3) that shall use carrier 3, 5 and 7 with DQPSK modulation and active window filtering.

There shall be defined 2 sets of logical sync data. Depending on the transmitted logical sync set data, two different **F**orward **E**rror **C**orrection (FEC) algorithms shall be used for the next data symbols within the actual transmission frame. So the receiver can auto-detect which FEC is used by checking the received SYNC set of an incoming PL110+ OFDM signal. The transmitter shall select the FEC and the corresponding SYNC set for the transmission. The receiver then shall decode the received SYNC set and shall assign the corresponding FEC variant for further decoding of incoming data symbols.

Sync Set A (Convolutional Coder)	Bin Data
Logical sync 1	010101
Logical sync 2	010101
Logical sync 3	100110

Figure 55 - Logical sync set A data for convolutional coder / Viterbi decoder

Sync Set B (8to12 Coder)	Bin Data
Logical sync 1	101010
Logical sync 2	101010
Logical sync 3	011001

Figure 56 - Logical sync set B data for 8to12 coder / 12to8 decoder

Additionally, a valid reception of logical sync data shall ensure correct synchronization to the OFDM signal. Up to 6 bit errors shall be corrected within the 18 bit logical sync data using a simple error correction method. If logical sync data is received, the algorithm shall check for a perfect match under the two sync sets. If there is a perfect match the sync set shall be taken. If there is no perfect match the number of bit errors of every possible sync set shall be calculated. The sync set with the lowest bit error count shall be taken, but the number shall not exceed six bit errors.

This init and logical sync sequence shall be fixed to 4 OFDM symbols.

5.1.8.6 CTRL block

The control block shall contain the coded PL110 CTRL and PL110+ CTRL+ octet that shall include the modulation information and the active OFDM carrier count for the following blocks. The CTRL data shall be extended with 8 bit CRC, convolutional coded and channel coded. For transmission the 3 fixed carrier frequencies $f3_{OFDM}$, $f5_{OFDM}$, and $f7_{OFDM}$ with DQPSK modulation shall be used. Figure 57 illustrates the CTRL block structure.

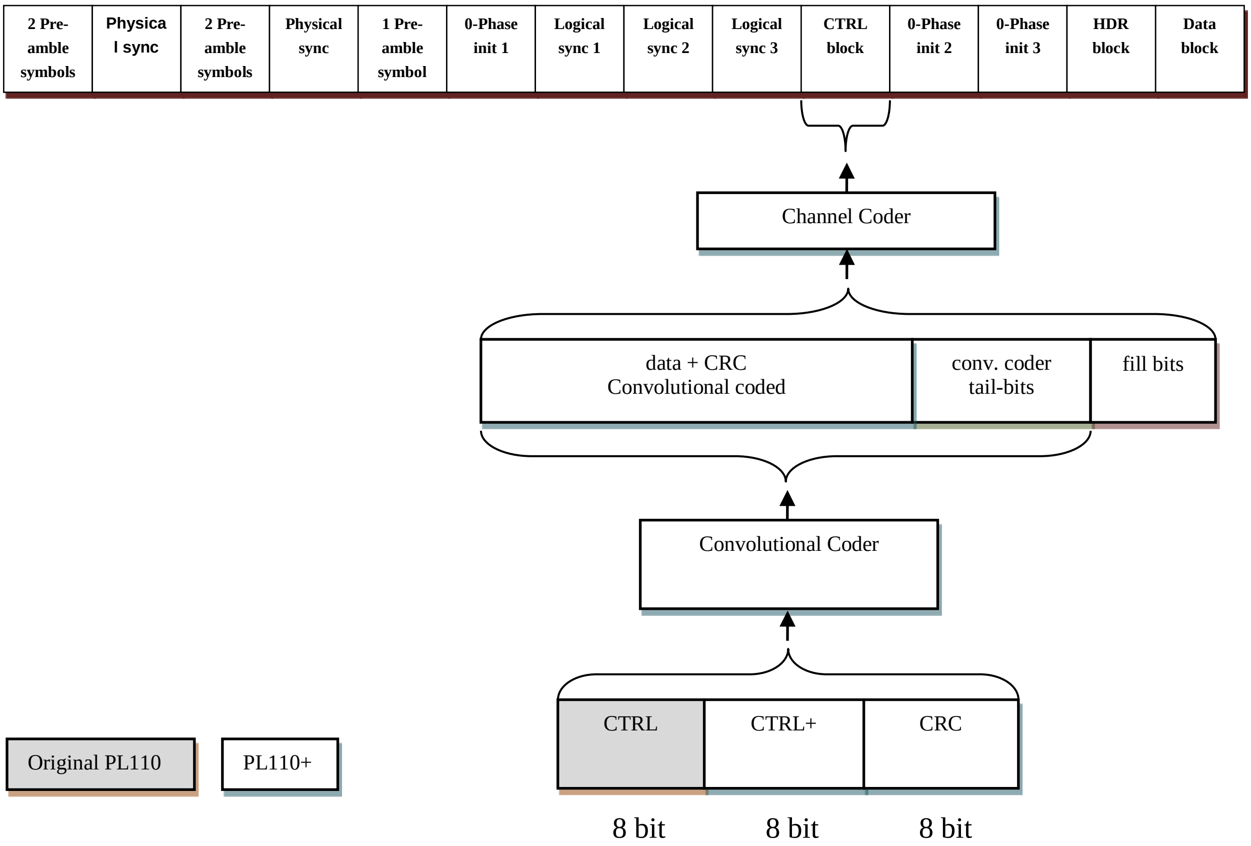


Figure 57 - CTRL block (convolutional coded)

Figure 58 - CTRL+ octet definition defines the CTRL+ octet:

CTRL+		
Identifier	bit	Remark
MOD	[1,0]	0: DBPSK modulation 1: DQPSK modulation 2: D8PSK modulation 3: Reserved
ACC	[4..2]	0: 9 active OFDM carriers 1: 8 active OFDM carriers 2: 7 active OFDM carriers 3: 6 active OFDM carriers 4: 5 active OFDM carriers 5: 4 active OFDM carriers 6: 3 active OFDM carriers 7: 2 active OFDM carriers
-	[7..5]	Reserved (bits set to zero)

Figure 58 - CTRL+ octet definition

5.1.8.7 ACK

For the OFDM ACK message, no data shall follow the CTRL octet and no additional coding information shall be added. This shall result in a reduced OFDM control block structure. The control block shall only contain the coded PL110 CTRL octet. The ACK data shall be extended with 8 bit CRC, convolutional coded and channel coded for OFDM transmission. For transmission the 3 fixed carrier frequencies $f3_{OFDM}$, $f5_{OFDM}$, and $f7_{OFDM}$ with DQPSK modulation shall be used.

Figure 59 illustrates the ACK block structure:

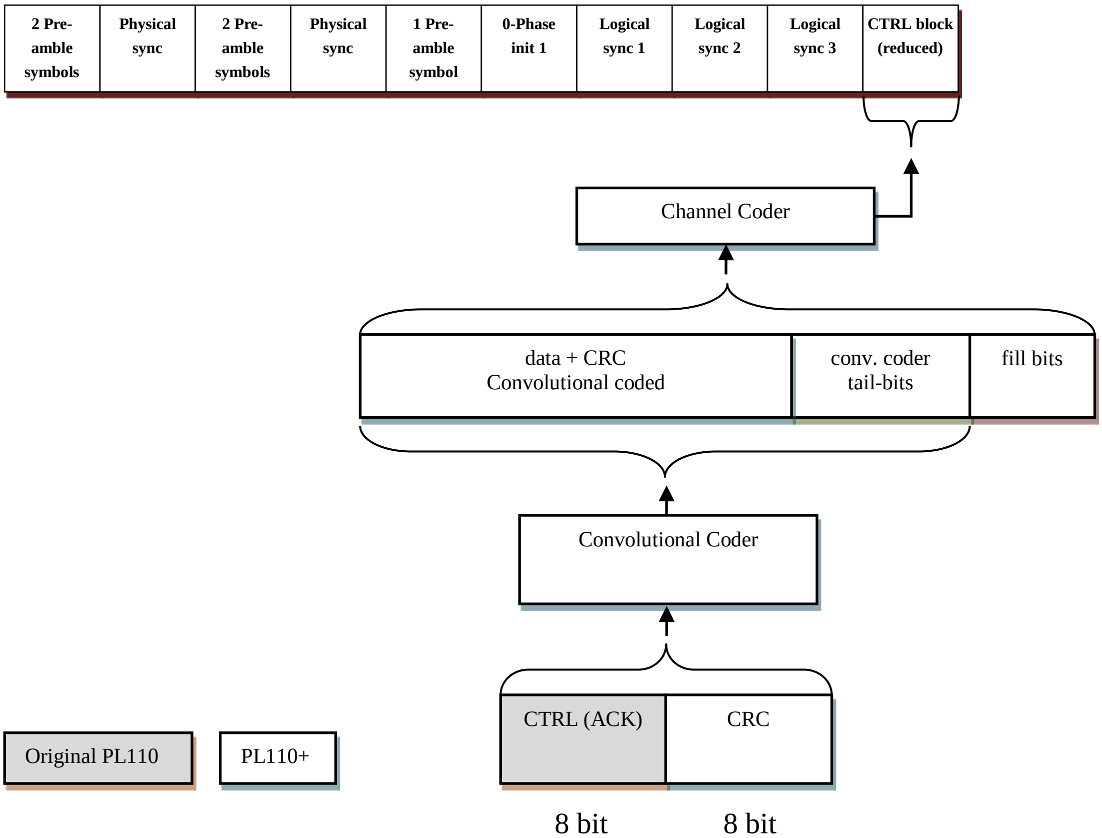


Figure 59 - ACK (convolutional coded)

5.1.8.8 The OFDM init 2 and init 3 sequence

The following init 2 symbol shall initialize the absolute starting phase of carrier 1, 4 and 8 ($f1_{OFDM}$, $f4_{OFDM}$, $f8_{OFDM}$) at transmitter and receiver side:

Modulation	DQPSK
Active Carrier	3
Bit Alignment to Carriers	bit 5,4 : Carrier 1
	bit 3,2 : Carrier 4
	bit 1,0 : Carrier 8
Window	On

Figure 60 - Carrier selection and modulation for init 2 symbol

	Bin Data
0-Phase Init 2	000011

Figure 61 - 0-Phase init 2 data

The following init 3 symbol shall initialize the absolute starting phase of carrier 2, 6 and 9 ($f2_{OFDM}$, $f6_{OFDM}$, $f9_{OFDM}$) at transmitter and receiver side.

Modulation	DQPSK
Active Carrier	3
Bit Alignment to Carriers	bit 5,4 : Carrier 2
	bit 3,2 : Carrier 6
	bit 1,0 : Carrier 9
Window	On

Figure 62 - Carrier selection and modulation for init 3 symbol

	Bin Data
0-Phase Init 3	110000

Figure 63 - 0-Phase init 3 data

5.1.8.9 HDR block

The HDR block shall contain the coded PL110 CTRLE, SA, DA and LG information. Depending on the selected FEC, two different HDR block codings shall be defined:

5.1.8.9.1 HDR block (convolutional coded)

In case of convolutional FEC selection at transmitter side, the HDR data shall be extended with 16 bit CRC, convolutional coded and channel coded for OFDM transmission. For transmission 2 - 9 carrier frequencies with DBPSK, DQPSK or D8PSK modulation can be used.

Figure 64 shows the HDR block structure:

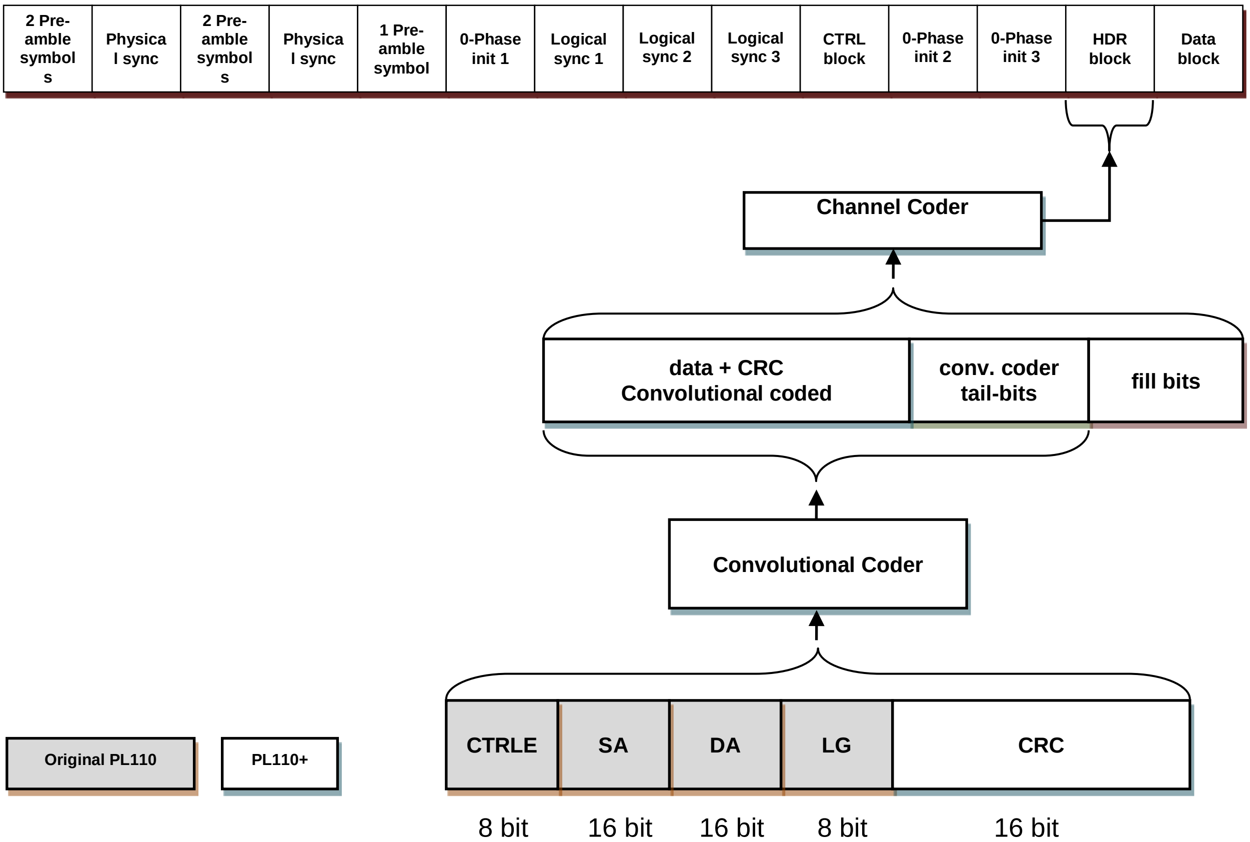


Figure 64 - HDR block (convolutional coded)

5.1.8.9.2 HDR block ((12,8) block coded)

In case of (12,8) block FEC selection at transmitter side, the HDR data shall be (12,8) block coded and channel coded for OFDM transmission. For transmission 2 - 9 carrier frequencies with DBPSK, DQPSK or D8PSK modulation can be used.

Figure 65 shows the HDR block structure:

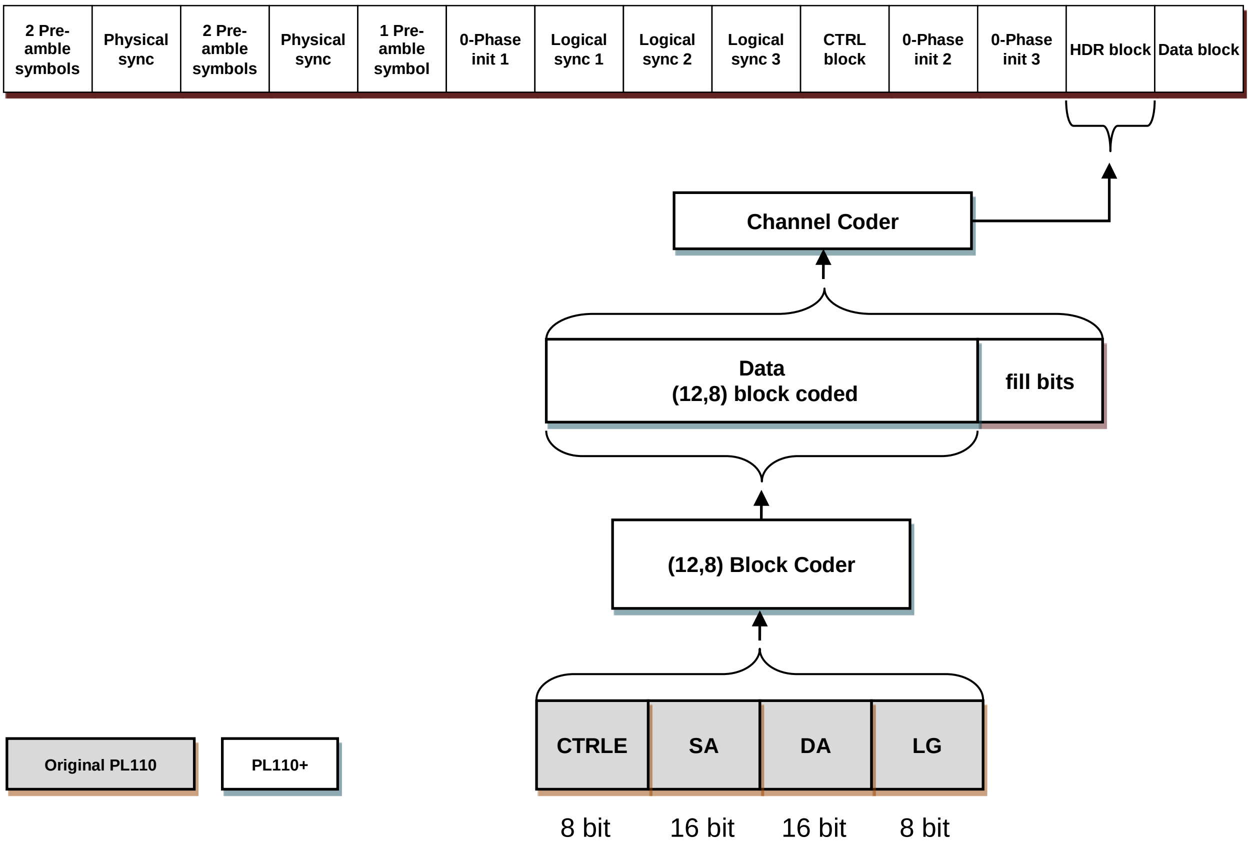


Figure 65 - HDR block ((12,8) block coded)

5.1.8.10 Data block

5.1.8.10.1 Contents

The Data block shall contain the coded PL110 TPCI, Data, CRC and DOA information. The net data payload shall be variable in the range 16 byte to 254 byte. Depending on the selected FEC, two different Data block codings shall be defined.

5.1.8.10.2 Data block (convolutional coded)

In case of convolutional FEC selection at transmitter side, the Data shall be extended with 16 bit CRC, convolutional coded and channel coded. For transmission 2 - 9 carrier frequencies with DBPSK, DQPSK or D8PSK modulation can be used.

Figure 66 shows the Data block structure:

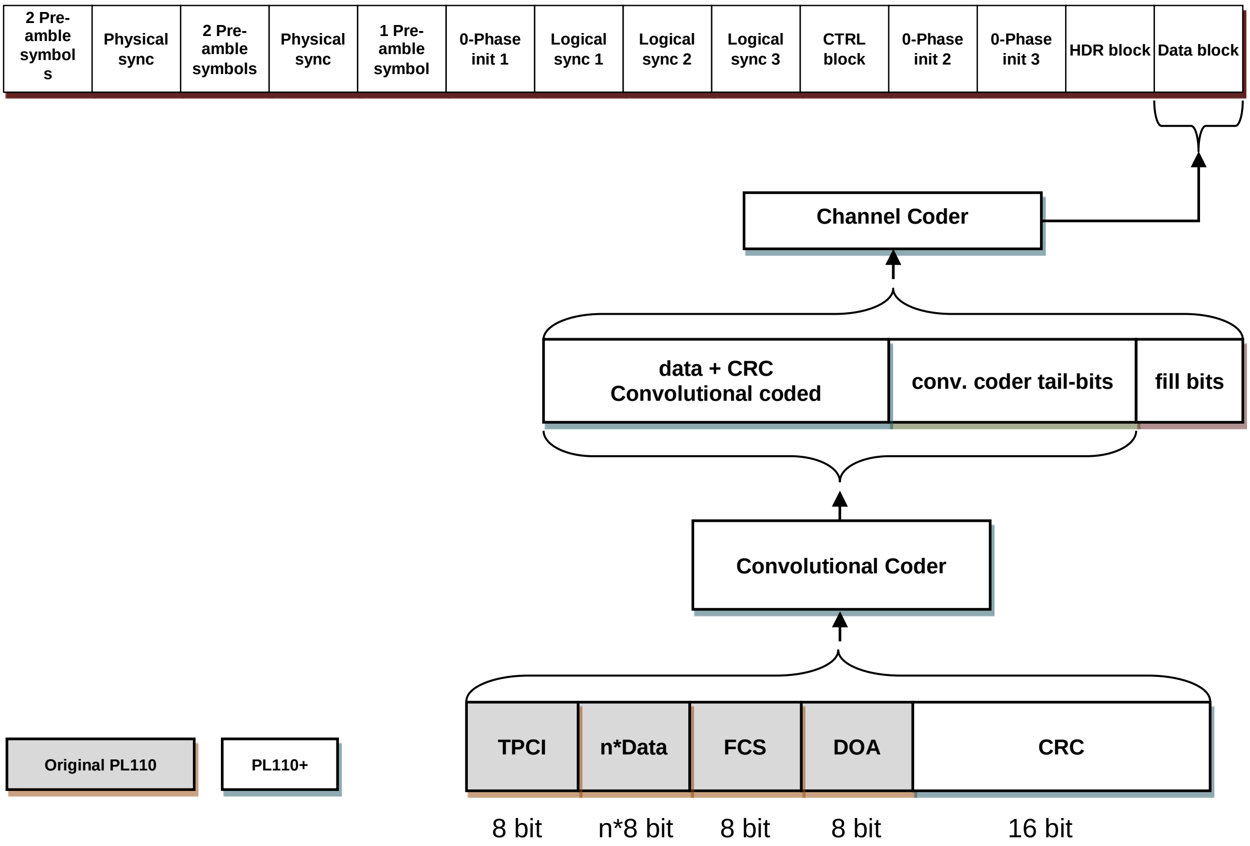


Figure 66 - Data block (convolutional coded)

5.1.8.10.3 Data block ((12,8) block coded)

In case of (12,8) block FEC selection at transmitter side, the Data shall be (12,8) block coded and channel coded for OFDM transmission. For transmission 2 - 9 carrier frequencies with DBPSK, DQPSK or D8PSK modulation can be used.

Figure 67 shows the Data block structure:

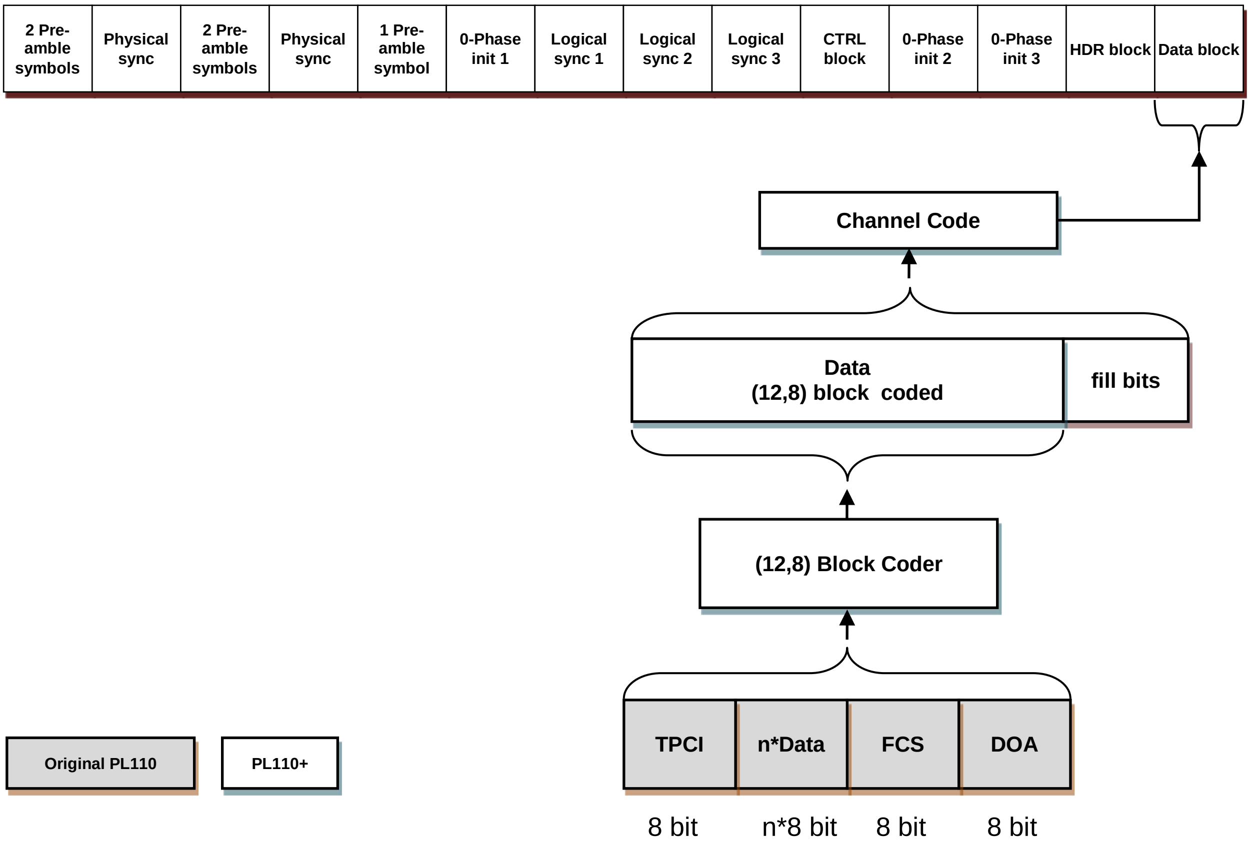


Figure 67 - Data block ((12,8) block coded)

5.1.8.11 Faulty transmission detection

5.1.8.11.1 Definition

The **F**orward **E**rror **C**orrection (FEC) of the PL110+ Physical Layer shall be done by convolutional coding or power line (12,8) block – coding, depending on the selected logical sync set data at transmitter side.

The faulty transmission detection shall be done by Viterbi decoding or power line (12,8) block decoding, depending on the transmitted logical sync set data.

Additionally further channel coding shall be done to improve the OFDM transmission robustness against interferers. Therefore an interframe bit interleaving, a bit scrambling and a frequency hopping shall be realized.

Figure 68 visualizes the complete coding path for a PL110+ transmitter and receiver:

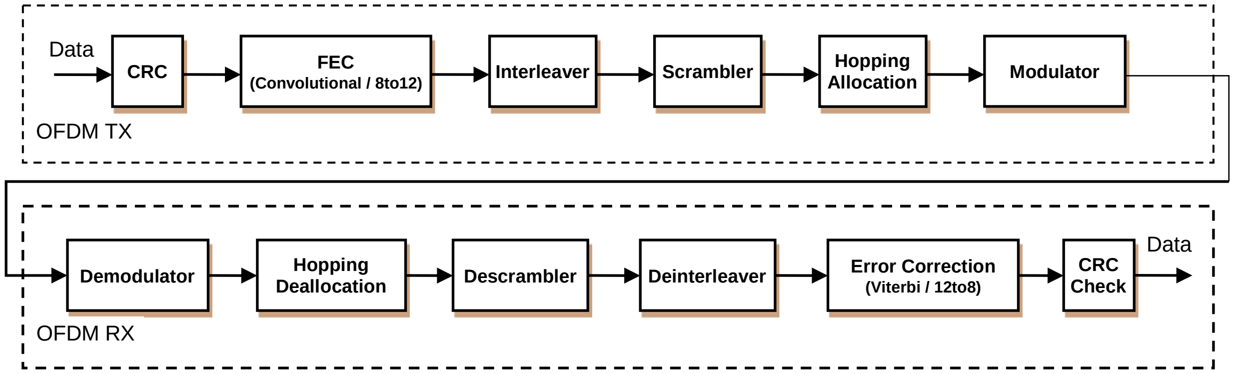


Figure 68 - PL110+ coding path

5.1.8.11.2 Convolutional coding

The convolutional coder shall have a code rate of 50 % and a constraint length of k = 6. The convolutional code shall be non-systematic and non-recursive. The following polynomials shall be used:

$$\boldsymbol{G_A = 1 + D_1 + D_3 + D_4 + D_5}$$

$$\boldsymbol{G_B = 1 + D_2 + D_4 + D_5}$$

Figure 69 shows the convolutional coder structure:

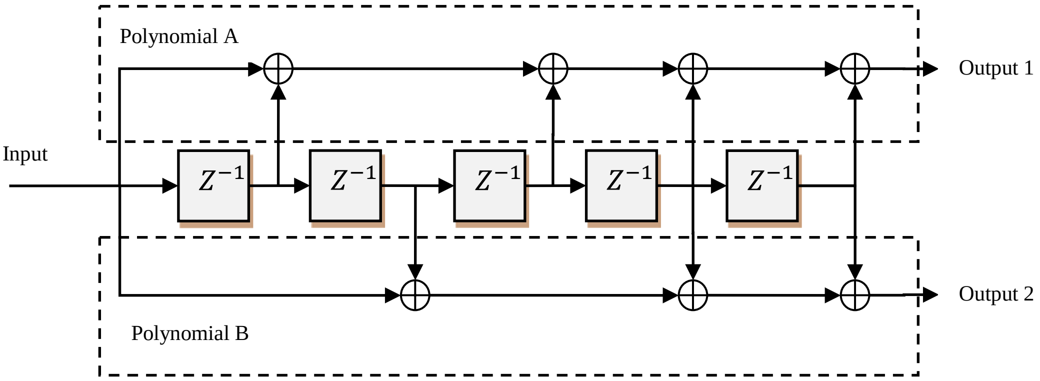


Figure 69 - Convolutional coder structure

Data octets shall be shifted bit-wise into the convolutional coder with MSB first. Data shall be shifted out of the coder with the order {Output 1, Output 2}. Output 1 shall represent the MSB and Output 2 shall represent the LSB.

The convolutional coder produces tail-bits that shall be transmitted additionally at the end of every convolutional coded data block. The number of tail-bits shall be calculated with (K-1)*2. The number depends on the code rate and the constraint length of the convolutional coder. Additionally fill bits (typically 0) shall be added to fill up the current 833µs symbol and/or fill up the actual interleaving block size. This is especially necessary after the CTRL block since the coding can be changed at this point.

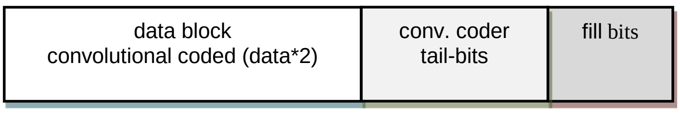


Figure 70 - Convolutional coded data block, tail- and fill- bits

Every data block that will be convolutional coded, shall first be protected by a CRC to ensure the data validity after decoding. The CRC shall always be the last information in a data block and shall cover the whole block except the CRC itself. The CTRL block (refer to clause 5.1.8.3.1) shall be protected by an 8 bit CRC. All other data blocks shall be protected by a 16 bit CRC. It shall be transmitted high byte first and then low byte. The following CRC-CCITT polynomials and initial values shall be used:

Polynomial	$x^8 + x^2 + x + 1$
CRC order	8
Initial value	FFh

Figure 71 – CRC-8 polynomial and initial value for convolutional coded data block

EXAMPLE 3 For CRC-8: The CRC calculation of the data sequence {3Ch, E0h, FFh, FFh, 17h, D0h, 20h} shall have the CRC-8 result 0Eh.

Polynomial	$x^{16} + x^{12} + x^5 + 1$
CRC order	16
Initial value	FFFFh

Figure 72 – CRC-16 polynomial and initial value for convolutional coded data block

EXAMPLE 4 For CRC-16: The CRC calculation of the data sequence {3Ch, E0h, FFh, FFh, 17h, D0h, 20h} shall have the CRC-16 result 97AAh.

The typical block structure for convolutional coded data with16 bit CRC is shown in Figure 73.

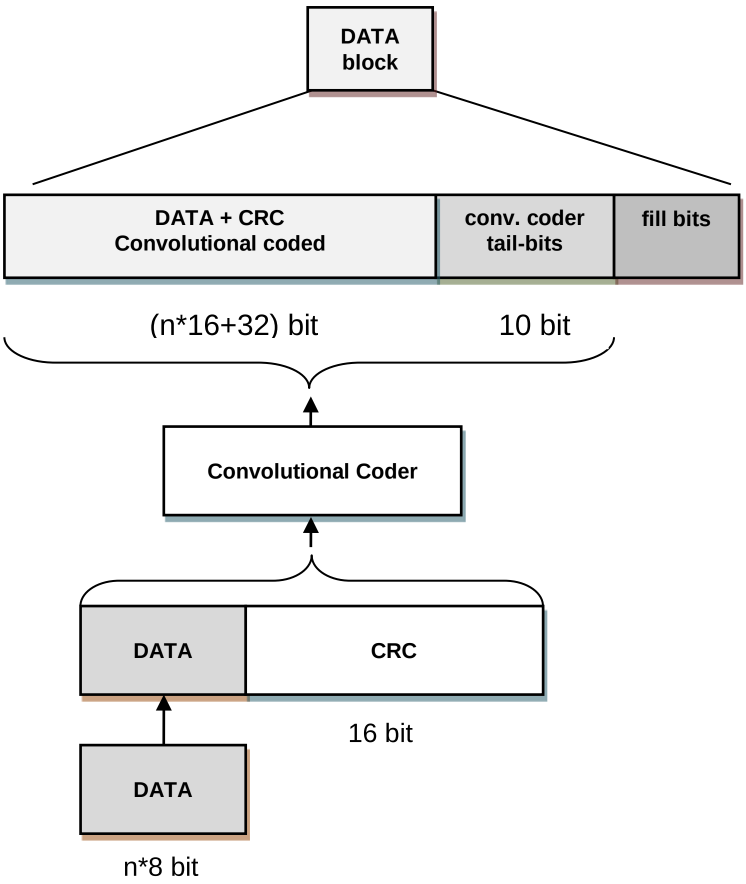


Figure 73 - Block structure for convolutional coded data (16 bit CRC)

Any block (CTRL, HDR, DATA) shall be adapted into this block structure.

The convolutional coder shall work together with a Viterbi decoder at receiver side and shall be able to correct different kinds of error patterns. It is more flexible than the 8to12 block FEC of the PL110 standard and is recommended for OFDM long-frame data transmission.

The Viterbi decoder shall be the implementation of a trellis diagram construction with traceback functionality. The trellis diagram shall represent a linear time sequencing of events, while the x-axis is discrete, the y-axis shows all states.

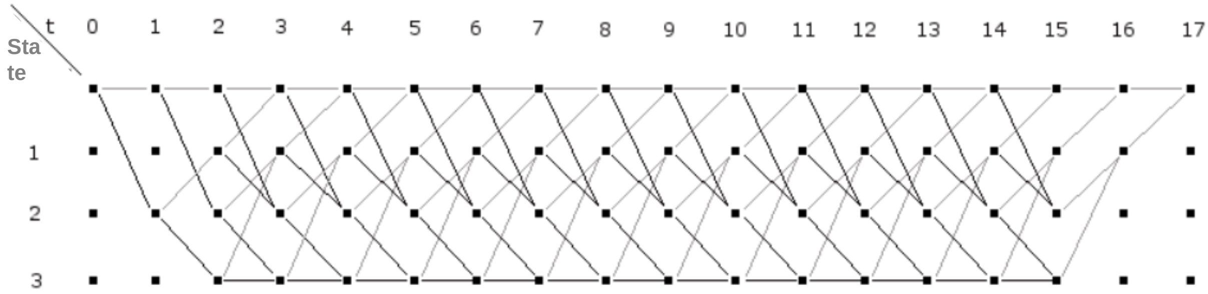


Figure 74 - Trellis diagram (example)

Figure 74 demonstrates just a small trellis as an example for decoding a convolutional code with the constraint length k = 3. For PL110+ devices a constraint length k = 6 shall be used and the trellis shall have 32 states on the y-axis. The x-axis shall depend on the block length. The start situation and the end situation shall be known, because of the used tail-bits in the convolutional encoder. There shall only be two possible next states from every point in the trellis. Using the mentioned two facts, the Viterbi algorithm shall find the most likely sequence of states through the trellis. More information about the Viterbi algorithm and its way of finding the right bit sequence through the trellis will follow in the next clauses.

The Viterbi algorithm shall consist of three main parts that shall calculate the branch metric: the path metric and finally the traceback.

In every received tuple of bits the distance between the tuple and every possible symbol in the code alphabet shall be calculated. This is called the branch metric. In case of the shown trellis (see Figure 74), 2 times 4 branch metrics shall be calculated. The branch metric shall be compared and the one with the smallest value shall be taken (survivor).

The path metrics shall be the accumulated branch metrics for all 2^{k-1} paths, while one path can be selected as the perfect path through the trellis.

The traceback shall start at the end of the trellis and shall follow the path with the minimum path metric and so the bit sequence that is most likely sent shall be found.

5.1.8.11.3 (8,12) block coding

This coding complies fully with PL110 EN (12,8) block coding definitions. Please refer to clause 4.1.7.5.

The typical block structure for (12,8) block coded data shows Figure 75:

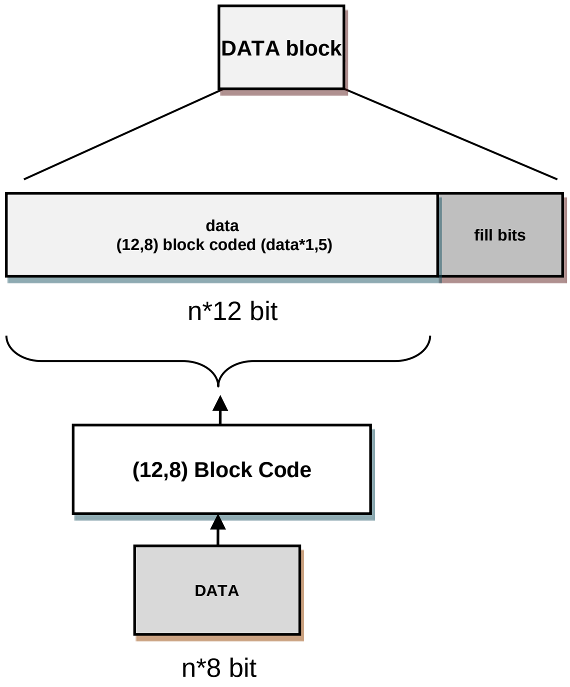


Figure 75 - Block structure for (12,8) block coded data

Additionally fill bits (typically 0) shall be added to fill up the current 833 µs symbol and/or fill up the actual interleaving block size. This is especially necessary after the CTRL block since the coding can be changed at this point.

5.1.8.11.4 Interframe bit interleaving and frequency hopping

The main purpose of the interframe interleaver together with the frequency hopping bit allocation is to avoid burst errors in the received data stream. This is an additional OFDM feature to have a better probability to fix occurred errors with the convolutional encoder and the Viterbi decoder. Typical problems in the power line channel are interferences in the spectrum that may cause groups of subcarriers to be disturbed. To reduce the appearance of having many bit errors in row that cannot be fixed especially for the higher modulations like the D8PSK, interframe interleaving shall be performed.

The interleaver shall work using interleaving tables that shall describe the assignment of individual TX data bits to OFDM modulation bits and OFDM symbols. The interleaver shall interleave the data within up to 9 OFDM symbols. Additionally the interleaver shall use fill bits (typically 0 bits) if there is no more incoming data and the interleaving symbols are not completely assigned.

The frequency hopping bit allocation shall assign the interleaved bits to active OFDM carriers. Depending on the hopping scheme in the tables, the active carrier selection of an OFDM symbol shall change from transmitted symbol to symbol. If a carrier is not assigned, it shall be switched off.

The following tables will define the interleaving patterns and frequency hopping schemes for the used modulations and in detail which bit number / numbers are assigned to the symbols and related active OFDM carriers:

Carriers	Modulation	bits/ Carrier	Inter-leaved bits	Symbol No.	Assigned bits Carrier 1	Assigned bits Carrier 2	Assigned bits Carrier 3	Assigned bits Carrier 4	Assigned bits Carrier 5	Assigned bits Carrier 6	Assigned bits Carrier 7	Assigned bits Carrier 8	Assigned bits Carrier 9
2	DBPSK	1	16	1	0				9				-
				2		10				3			-
				3			4				13		-
				4				14				7	-
				5	8				1				-
				6		2				11			-
				7			12				5		-
				8				6				15	-
2	DQPSK	2	32	1	0, 8				17, 25				-
				2		18, 26				3, 11			-
				3			4, 12				21, 29		-
				4				22, 30				7, 15	-
				5	16, 24				1, 9				-
				6		2, 10				19, 27			-
				7			20, 28				5, 13		-
				8				6, 14				23, 31	-
2	D8PSK	3	48	1	0, 8, 16				25, 33, 41				-
				2		26, 34, 42				3, 11, 19			-
				3			4, 12, 20				29, 37, 45		-
				4				30, 38, 46				7, 15, 23	-
				5	24, 32, 40				1, 9, 17				-
				6		2, 10, 18				27, 35, 43			-
				7			28, 36, 44				5, 13, 21		-
				8				6, 14, 22				31, 39, 47	-

Figure 76 - 2 Carrier bit interleaving and frequency hopping for BPSK, QPSK and 8PSK

Carriers	Modulation	bits/ Carrier	Inter-leaved bits	Symbol No.	Assigned bits Carrier 1	Assigned bits Carrier 2	Assigned bits Carrier 3	Assigned bits Carrier 4	Assigned bits Carrier 5	Assigned bits Carrier 6	Assigned bits Carrier 7	Assigned bits Carrier 8	Assigned bits Carrier 9
3	DBPSK	1	27	1	0					19	11		
				2		12			4			23	
				3			24	16					8
				4	9					1	20		
				5		21			13			5	
				6			6	25					17
				7	18					10	2		
				8		3			22			14	
				9			15	7					26
3	DQPSK	2	54	1	0, 9					37, 46	20, 29		
				2		21, 30			4, 13			41, 50	
				3			42, 51	25, 34					8, 17
				4	18, 27					1, 10	38, 47		
				5		39, 48			22, 31			5, 14	
				6			6, 15	43, 52					26, 35
				7	36, 45					19, 28	2, 11		
				8		3, 12			40, 49			23, 32	
				9			24, 33	7, 16					44, 53
3	D8PSK	3	81	1	0, 9, 18					55, 64, 73	29, 38, 47		
				2		30, 39, 48			4, 13, 22			59, 68, 77	
				3			60, 69, 78	34, 43, 52					8, 17, 26
				4	27, 36, 45					1, 10, 19	56, 65, 74		
				5		57, 66, 75			31, 40, 49			5, 14, 23	
				6			6, 15, 24	61, 70, 79					35, 44, 53
				7	54, 63, 72					28, 37, 46	2, 11, 20		
				8		3, 12, 21			58, 67, 76			32, 41, 50	
				9			33, 42, 51	7, 16, 25					62, 71, 80

Figure 77 - 3 Carrier bit interleaving and frequency hopping for BPSK, QPSK and 8PSK

Carriers	Modulation	bits/ Carrier	Inter- leaved bits	Symbol No.	Assigned bits Carrier 1	Assigned bits Carrier 2	Assigned bits Carrier 3	Assigned bits Carrier 4	Assigned bits Carrier 5	Assigned bits Carrier 6	Assigned bits Carrier 7	Assigned bits Carrier 8	Assigned bits Carrier 9
4	DBPSK	1	32	1			0	25		18	11		
				2		12			5			30	23
				3			16	9		2	27		
				4		28			21			14	7
				5			8	1		26	19		
				6	31	20			13			6	
				7			24	17		10	3		
				8	15	4			29			22	
4	DQPSK	2	64	1			0, 8	49, 57		34, 42	19, 27		
				2		20, 28			5, 13			54, 62	39, 47
				3			32, 40	17, 25		2, 10	51, 59		
				4		52, 60			37, 45			22, 30	7, 15
				5			16, 24	1, 9		50, 58	35, 43		
				6	55, 63	36, 44			21, 29			6, 14	
				7			48, 56	33, 41		18, 26	3, 11		
				8	23, 31	4, 12			53, 61			38, 46	
4	D8PSK	3	96	1			0, 8, 16	73, 81, 89		50, 58, 66	27, 35, 43		
				2		28, 36, 44			5, 13, 21			78, 86, 94	55, 63, 71
				3			48, 56, 64	25, 33, 41		2, 10, 18	75, 83, 91		
				4		76, 84, 92			53, 61, 69			30, 38, 46	7, 15, 23
				5			24, 32, 40	1, 9, 17		74, 82, 90	51, 59, 67		
				6	79, 87, 95	52, 60, 68			29, 37, 45			6, 14, 22	
				7			72, 80, 88	49, 57, 65		26, 34, 42	3, 11, 19		
				8	31, 39, 47	4, 12, 20			77, 85, 93			54, 62, 70	

Figure 78 - 4 Carrier bit interleaving and frequency hopping for BPSK, QPSK and 8PSK

Carriers	Modulation	bits/ Carrier	Inter- leaved bits	Symbol No.	Assigned bits Carrier 1	Assigned bits Carrier 2	Assigned bits Carrier 3	Assigned bits Carrier 4	Assigned bits Carrier 5	Assigned bits Carrier 6	Assigned bits Carrier 7	Assigned bits Carrier 8	Assigned bits Carrier 9
5	DBPSK	1	45	1		20		12	4		36		28
				2	9	1		42		34		26	
				3	29		21		13	5		37	
				4	0		41		33		25		17
				5		30		22		14	6		38
				6	19		11	3		44		27	
				7	39		31		23		15	7	
				8		10	2		43		35		18
				9		40		32		24		16	8
5	DQPSK	2	90	1		38, 47		21, 30	4, 13		72, 81		55, 64
				2	18, 27	1, 10		78, 87		61, 70		44, 53	
				3	56, 65		39, 48		22, 31	5, 14		73, 82	
				4	0, 9		77, 86		60, 69		43, 52		26, 35
				5		57, 66		40, 49		23, 32	6, 15		74, 83
				6	37, 46		20, 29	3, 12		80, 89		54, 63	
				7	75, 84		58, 67		41, 50		24, 33	7, 16	
				8		19, 28	2, 11		79, 88		62, 71		36, 45
				9		76, 85		59, 68		42, 51		25, 34	8, 17
5	D8PSK	3	135	1		56, 65, 74		30, 39, 48	4, 13, 22		108,117,126		82, 91,100
				2	27, 36, 45	1, 10, 19		114,123,132		88, 97,106		62, 71, 80	
				3	83, 92,101		57, 66, 75		31, 40, 49	5, 14, 23		109,118,127	
				4	0, 9, 18		113,122,131		87, 96,105		61, 70, 79		35, 44, 53
				5		84, 93,102		58, 67, 76		32, 41, 50	6, 15, 24		110,119,128
				6	55, 64, 73		29, 38, 47			116,125,134		81, 90, 99	
				7	111,120,129		85, 94,103		59, 68, 77		33, 42, 51	7, 16, 25	
				8		28, 37, 46	2, 11, 20		115,124,133		89, 98,107		54, 63, 72
				9		112,121,130		86, 95,104		60, 69, 78		34, 43, 52	8, 17, 26

Figure 79 - 5 Carrier bit interleaving and frequency hopping for BPSK, QPSK and 8PSK

Carriers	Modulation	bits/ Carrier	Inter-leaved bits	Symbol No.	Assigned bits Carrier 1	Assigned bits Carrier 2	Assigned bits Carrier 3	Assigned bits Carrier 4	Assigned bits Carrier 5	Assigned bits Carrier 6	Assigned bits Carrier 7	Assigned bits Carrier 8	Assigned bits Carrier 9
6	DBPSK	1	54	1	0				49	41	33	16	8
				2		46	38	30	22	14	6		
				3	27	19	11	3				43	35
				4	36				31	23	15	52	44
				5	9	1	47	39				25	17
				6		28	20	12	4	50	42		
				7	18				13	5	51	34	26
				8		10	2	48	40	32	24		
				9	45	37	29	21				7	53
6	DQPSK	2	108	1	0, 9				94,103	77, 86	60, 69	25, 34	17, 44
				2		91,100	74, 83	57, 66	40, 49	23, 32	6, 15		
				3	54, 63	37, 46	20, 29	3, 12				79, 88	71, 98
				4	72, 81				58, 67	41, 50	24, 33	97,106	8, 89
				5	18, 27	1, 10	92,101	75, 84				43, 52	35, 62
				6		55, 64	38, 47	21, 30	4, 13	95,104	78, 87		
				7	36, 45				22, 31	5, 14	96,105	61, 70	53, 80
				8		19, 28	2, 11	93,102	76, 85	59, 68	42, 51		
				9	90, 99	73, 82	56, 65	39, 48				7, 16	26,107
6	D8PSK	3	162	1	0, 9, 18				139,148,157	113,122,131	87, 96,105	34, 43, 52	26, 62, 71
				2		136,145,154	110,119,128	84, 93,102	58, 67, 76	32, 41, 50	6, 15, 24		
				3	81, 90, 99	55, 64, 73	29, 38, 47	3, 12, 21				115,124,133	107,143,152
				4	108,117,126				85, 94,103	59, 68, 77	33, 42, 51	142,151,160	8, 17,134
				5	27, 36, 45	1, 10, 19	137,146,155	111,120,129				61, 70, 79	53, 89, 98
				6		82, 91,100	56, 65, 74	30, 39, 48	4, 13, 22	140,149,158	114,123,132		
				7	54, 63, 72				31, 40, 49	5, 14, 23	141,150,159	88, 97,106	80,116,125
				8		28, 37, 46	2, 11, 20	138,147,156	112,121,130	86, 95,104	60, 69, 78		
				9	135,144,153	109,118,127	83, 92,101	57, 66, 75				7, 16, 25	35, 44,161

Figure 80 - 6 Carrier bit interleaving and frequency hopping for BPSK, QPSK and 8PSK

Carriers	Modulation	bits/ Carrier	Inter-leaved bits	Symbol No.	Assigned bits Carrier 1	Assigned bits Carrier 2	Assigned bits Carrier 3	Assigned bits Carrier 4	Assigned bits Carrier 5	Assigned bits Carrier 6	Assigned bits Carrier 7	Assigned bits Carrier 8	Assigned bits Carrier 9
7	DBPSK	1	63	1	0		57	49	41	33		25	17
				2	37	29		21	13	5		62	54
				3	9	1		58	50	42	34		26
				4	46	38	30		22	14	6		60
				5	18	10	2		59	51	43	35	
				6	55	47	39	31		23	15	7	
				7		19	11	3		27	52	44	36
				8		56	48	40	32		24	16	8
				9	28		20	12	4		61	53	45
7	DQPSK	2	126	1	0, 9		111,120	94,103	77, 86	60, 69		43, 52	26, 35
				2	73, 82	56, 65		39, 48	22, 31	5, 14		116,124	99,108
				3	18, 27	1, 10		112,121	95,104	78, 87	61, 70		44, 53
				4	91,100	74, 83	57, 66		40, 49	23, 32	6, 15		117,125
				5	36, 45	19, 28	2, 11		113,122	96,105	79, 88	62, 71	
				6	109,118	92,101	75, 84	58, 67		41, 50	24, 33	7, 16	
				7		37, 46	20, 29	3, 12		54,114	97,106	80, 89	63, 72
				8		110,119	93,102	76, 85	59, 68		42, 51	25, 34	8, 17
				9	55, 64		38, 47	21, 30	4, 13		115,123	98,107	81, 90
7	D8PSK	3	189	1	0, 9, 18		165,174,183	139,148,157	113,122,131	87, 96,105		61, 70, 79	35, 44, 53
				2	109,118,127	83, 92,101		57, 66, 75	31, 40, 49	5, 14, 23		170,179,187	144,153,162
				3	27, 36, 45	1, 10, 19		166,175,184	140,149,158	114,123,132	88, 97,106		62, 71, 80
				4	136,145,154	110,119,128	84, 93,102		58, 67, 76	32, 41, 50	6, 15, 24		171,180,188
				5	54, 63, 72	28, 37, 46	2, 11, 20		167,176,185	141,150,159	115,124,133	89, 98,107	
				6	163,172,181	137,146,155	111,120,129	85, 94,103		59, 68, 77	33, 42, 51	7, 16, 25	
				7		55, 64, 73	29, 38, 47	3, 12, 21		81,168,177	142,151,160	116,125,134	90, 99,108
				8		164,173,182	138,147,156	112,121,130	86, 95,104		60, 69, 78	34, 43, 52	8, 17, 26
				9	82, 91,100		56, 65, 74	30, 39, 48	4, 13, 22		169,178,186	143,152,161	117,126,135

Figure 81 - 7 Carrier bit interleaving and frequency hopping for BPSK, QPSK and 8PSK

Carriers	Modulation	bits/ Carrier	Inter-leaved bits	Symbol No.	Assigned bits Carrier 1	Assigned bits Carrier 2	Assigned bits Carrier 3	Assigned bits Carrier 4	Assigned bits Carrier 5	Assigned bits Carrier 6	Assigned bits Carrier 7	Assigned bits Carrier 8	Assigned bits Carrier 9
8	DBPSK	1	72	1	0		65	57	49	41	33	25	17
				2	45	37	29	21	13	5		70	62
				3	9	1		66	58	50	42	34	26
				4	54	46	38	30	22	14	6		71
				5	18	10	2		67	59	51	43	35
				6	63	55	47	39	31	23	15	7	
				7	27	19	11	3		68	60	52	44
				8		64	56	48	40	32	24	16	8
				9	36	28	20	12	4		69	61	53
8	DQPSK	2	144	1	0, 9		128,137	111,120	94,103	77, 86	60, 69	43, 52	26, 35
				2	90, 99	73, 82	56, 65	39, 48	22, 31	5, 14		133,142	116,125
				3	18, 27	1, 10		129,138	112,121	95,104	78, 87	61, 70	44, 53
				4	108,117	91,100	74, 83	57, 66	40, 49	23, 32	6, 15		134,143
				5	36, 45	19, 28	2, 11		130,139	113,122	96,105	79, 88	62, 71
				6	126,135	109,118	92,101	75, 84	58, 67	41, 50	24, 33	7, 16	
				7	54, 63	37, 46	20, 29	3, 12		131,140	114,123	97,106	80, 89
				8		127,136	110,119	93,102	76, 85	59, 68	42, 51	25, 34	8, 17
				9	72, 81	55, 64	38, 47	21, 30	4, 13		132,141	115,124	98,107
8	D8PSK	3	216	1	0, 9, 18		191,200,209	165,174,183	139,148,157	113,122,131	87, 96,105	61, 70, 79	35, 44, 53
				2	135,144,153	109,118,127	83, 92,101	57, 66, 75	31, 40, 49	5, 14, 23		196,205,214	170,179,188
				3	27, 36, 45	1, 10, 19		192,201,210	166,175,184	140,149,158	114,123,132	88, 97,106	62, 71, 80
				4	162,171,180	136,145,154	110,119,128	84, 93,102	58, 67, 76	32, 41, 50	6, 15, 24		197,206,215
				5	54, 63, 72	28, 37, 46	2, 11, 20		193,202,211	167,176,185	141,150,159	115,124,133	89, 98,107
				6	189,198,207	163,172,181	137,146,155	111,120,129	85, 94,103	59, 68, 77	33, 42, 51	7, 16, 25	
				7	81, 90, 99	55, 64, 73	29, 38, 47	3, 12, 21		194,203,212	168,177,186	142,151,160	116,125,134
				8		190,199,208	164,173,182	138,147,156	112,121,130	86, 95,104	60, 69, 78	34, 43, 52	8, 17, 26
				9	108,117,126	82, 91,100	56, 65, 74	30, 39, 48	4, 13, 22		195,204,213	169,178,187	143,152,161

Figure 82 - 8 Carrier bit interleaving and frequency hopping for BPSK, QPSK and 8PSK

Carriers	Modulation	bits/ Carrier	Inter-leaved bits	Symbol No.	Assigned bits Carrier 1	Assigned bits Carrier 2	Assigned bits Carrier 3	Assigned bits Carrier 4	Assigned bits Carrier 5	Assigned bits Carrier 6	Assigned bits Carrier 7	Assigned bits Carrier 8	Assigned bits Carrier 9
9	DBPSK	1	81	1	0	73	65	57	49	41	33	25	17
				2	45	37	29	21	13	5	78	70	62
				3	9	1	74	66	58	50	42	34	26
				4	54	46	38	30	22	14	6	79	71
				5	18	10	2	75	67	59	51	43	35
				6	63	55	47	39	31	23	15	7	80
				7	27	19	11	3	76	68	60	52	44
				8	72	64	56	48	40	32	24	16	8
				9	36	28	20	12	4	77	69	61	53
9	DQPSK	2	162	1	0, 9	145,154	128,137	111,120	94,103	77, 86	60, 69	43, 52	26, 35
				2	90, 99	73, 82	56, 65	39, 48	22, 31	5, 14	150,159	133,142	116,125
				3	18, 27	1, 10	146,155	129,138	112,121	95,104	78, 87	61, 70	44, 53
				4	108,117	91,100	74, 83	57, 66	40, 49	23, 32	6, 15	151,160	134,143
				5	36, 45	19, 28	2, 11	147,156	130,139	113,122	96,105	79, 88	62, 71
				6	126,135	109,118	92,101	75, 84	58, 67	41, 50	24, 33	7, 16	152,161
				7	54, 63	37, 46	20, 29	3, 12	148,157	131,140	114,123	97,106	80, 89
				8	144,153	127,136	110,119	93,102	76, 85	59, 68	42, 51	25, 34	8, 17
				9	72, 81	55, 64	38, 47	21, 30	4, 13	149,158	132,141	115,124	98,107
9	D8PSK	3	243	1	0, 9, 18	217,226,235	191,200,209	165,174,183	139,148,157	113,122,131	87, 96,105	61, 70, 79	35, 44, 53
				2	135,144,153	109,118,127	83, 92,101	57, 66, 75	31, 40, 49	5, 14, 23	222,231,240	196,205,214	170,179,188
				3	27, 36, 45	1, 10, 19	218,227,236	192,201,210	166,175,184	140,149,158	114,123,132	88, 97,106	62, 71, 80
				4	162,171,180	136,145,154	110,119,128	84, 93,102	58, 67, 76	32, 41, 50	6, 15, 24	223,232,241	197,206,215
				5	54, 63, 72	28, 37, 46	2, 11, 20	219,228,237	193,202,211	167,176,185	141,150,159	115,124,133	89, 98,107
				6	189,198,207	163,172,181	137,146,155	111,120,129	85, 94,103	59, 68, 77	33, 42, 51	7, 16, 25	224,233,242
				7	81, 90, 99	55, 64, 73	29, 38, 47	3, 12, 21	220,229,238	194,203,212	168,177,186	142,151,160	116,125,134
				8	216,225,234	190,199,208	164,173,182	138,147,156	112,121,130	86, 95,104	60, 69, 78	34, 43, 52	8, 17, 26
				9	108,117,126	82, 91,100	56, 65, 74	30, 39, 48	4, 13, 22	221,230,239	195,204,213	169,178,187	143,152,161

Figure 83 - 9 Carrier bit interleaving and frequency hopping for BPSK, QPSK and 8PSK

The deinterleaver shall work using the same interleaving tables as the interleaver. These shall describe the assignment of OFDM modulation bits and OFDM symbols to individual TX data bits. The deinterleaver shall interleave the data within up to 9 OFDM symbols.

The frequency hopping bit deallocation shall assign the active OFDM carriers to interleaved bits. Depending on the hopping scheme in the tables, the active reception carrier selection of an OFDM symbol shall change from received symbol to symbol. If a carrier is not assigned, it shall not receive and hold the carrier absolute phase of last active carrier reception.

5.1.8.11.5 Bit scrambler

The purpose of data bit scrambling is to reduce the probability of symbols consisting of carriers that all have the same phase and/or multiple identical symbols in case of identical data (e.g. zero data patterns).

The scrambler shall be realized with a Fibonacci LFSR (**L**inear **F**eedback **S**hift **R**egister). Its random output shall be XOR'd with the input data. The LFSR shall be implemented with an order of 7, which will generate a pseudo random sequence with the period of 127. The LFSR shall be initialized with the value 4Dh

The characteristic polynomial shall be: $x^7 + x^6 + 1$

Figure 84 shows the structure of the bit scrambler:

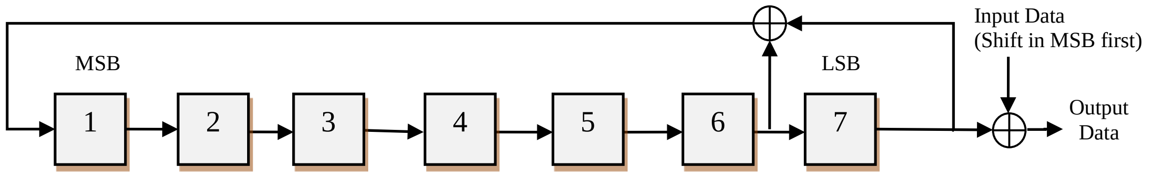


Figure 84 - Structure of the Scrambler

The descrambler shall be identical to the scrambler.

5.1.8.12 Synchronization to mains phase

This synchronization to the mains phase shall comply mostly with PL110 synchronization definitions (see clause 4.1.7.6), but with the following additions.

- The start of a transmission shall be placed at the mains zero-crossing of one of the 3 phases.
- The actual symbol width shall be averaged and aligned to the mains zero-crossing.

This synchronisation is still valid for PL110 devices since the resulting timing signal has a higher accuracy than required according clause 4.1.7.6. For PL110+ devices it shall also be used for a raw synchronisation to the starting time of the OFDM synchronisation sequence as well as the starting time of a reception search time-window. The search time-window length shall be defined by 2 OFDM symbol times and shall start 4 875 OFDM symbol times after mains zero-crossing of each mains phase is detected. An OFDM signal reception shall only be expected during this time-window. The OFDM synchronization sequence transmission shall start at the moment of mains zero-crossings. Regarding all 3 mains phases in a 50 Hz system, the OFDM transmission and reception shall be allowed on each phase in a grid of 4 symbol times ($3.\overline{3}$ ms period). This raw synchronisation to the mains zero-crossing shall ensure interoperability and backwards compatibility of PL110+ signalling to PL110 signalling.

5.1.8.13 OFDM symbol synchronization

For OFDM symbol synchronization digital matched filter techniques shall be used. The analog to digital converted incoming signal shall be correlated with the expected sine waves of the sync signal (*109,2 kHz* and *111,6 kHz*) over a time window of $833.\overline{3}$ µs. This correlation time window of the OFDM synchronization shall be then shifted over the incoming signal for the next $833.\overline{3}$ µs (= 1 OFDM symbol time). In case of a present synchronization signal, both correlation summation values (*109,2 kHz* and *111,6 kHz*) will show a maximum when the sync window is located directly above the sync signal. For a protection of the sync signal and for improving accuracy and sensibility, the preamble sine wave (*106,8 kHz*) and a second sine wave (*114,0 kHz*) shall be correlated additionally in parallel and then subtracted from the sync correlation.

The following equations illustrate the synchronization calculations.

$$|\boldsymbol{kkf}_{sync1}(\boldsymbol{pos})|^2 = (\sum_{n=pos}^{l+pos-1} s(n) \cdot \sin(w_{sync1} n\tau))^2 + (\sum_{n=pos}^{l+pos-1} s(n) \cdot \cos(w_{sync1} n\tau))^2$$

$$|\boldsymbol{kkf}_{sync2}(\boldsymbol{pos})|^2 = (\sum_{n=pos}^{l+pos-1} s(n) \cdot \sin(w_{sync2} n\tau))^2 + (\sum_{n=pos}^{l+pos-1} s(n) \cdot \cos(w_{sync2} n\tau))^2$$

$$\boldsymbol{pre1}(\boldsymbol{pos}) = |\boldsymbol{kkf}_{pre1}(\boldsymbol{pos})|^2 = (\sum_{n=pos}^{l+pos-1} s(n) \cdot \sin(w_{pre1} n\tau))^2 + (\sum_{n=pos}^{l+pos-1} s(n) \cdot \cos(w_{pre1} n\tau))^2$$

$$\boldsymbol{pre2}(\boldsymbol{pos}) = |\boldsymbol{kkf}_{pre2}(\boldsymbol{pos})|^2 = (\sum_{n=pos}^{l+pos-1} s(n) \cdot \sin(w_{pre2} n\tau))^2 + (\sum_{n=pos}^{l+pos-1} s(n) \cdot \cos(w_{pre2} n\tau))^2$$

$s(n)$ shall be the sample value, pos shall be the position in the synchronization window, n shall be the sample count, $\tau = 1/f_{Sample}$ shall be the sample rate and $l = f_{Sample} * 833.\overline{3}$ µs shall be the number of samples per OFDM symbol. The peak of the two sync signals shall be based on these correlation square sums and shall be calculated with the following equations:

$$\boldsymbol{sync1}(\boldsymbol{pos}) = |\boldsymbol{kkf}_{sync1}(\boldsymbol{pos})|^2 - |\boldsymbol{kkf}_{pre1}(\boldsymbol{pos})|^2 - |\boldsymbol{kkf}_{pre2}(\boldsymbol{pos})|^2$$

$$\boldsymbol{sync2}(\boldsymbol{pos}) = |\boldsymbol{kkf}_{sync2}(\boldsymbol{pos})|^2 - |\boldsymbol{kkf}_{pre1}(\boldsymbol{pos})|^2 - |\boldsymbol{kkf}_{pre2}(\boldsymbol{pos})|^2$$

The maximum peak value of $sync1(pos)$ and $sync2(pos)$ shall define the symbol synchronization position.

$$\max(\boldsymbol{sync1}(\boldsymbol{pos})) \Rightarrow \boldsymbol{pos}_{sync1}$$

$$\max(\boldsymbol{sync2}(\boldsymbol{pos})) \Rightarrow \boldsymbol{pos}_{sync2}$$

$$\boldsymbol{pos}_{sync} = \frac{\boldsymbol{pos}_{sync1} + \boldsymbol{pos}_{sync2}}{\boldsymbol{2}}$$

A valid OFDM synchronization shall be found if:

$$\boldsymbol{f}_{Sample} * 833{,}\overline{3}\ \mu s \le \boldsymbol{pos}_{sync} \le \boldsymbol{1{,}25} * \boldsymbol{f}_{Sample} * 833{,}\overline{3}\ \mu s$$

Since the number of samples per OFDM symbol have a direct relation to the symbol synchronization precision and at least have influence to the receiver sensitivity, the minimum number of samples per OFDM symbol shall be 250 which results in a minimum required sample rate of 300 kHz.

Figure 85 shows the correlation values and resulting peak value during the symbol synchronization (example).

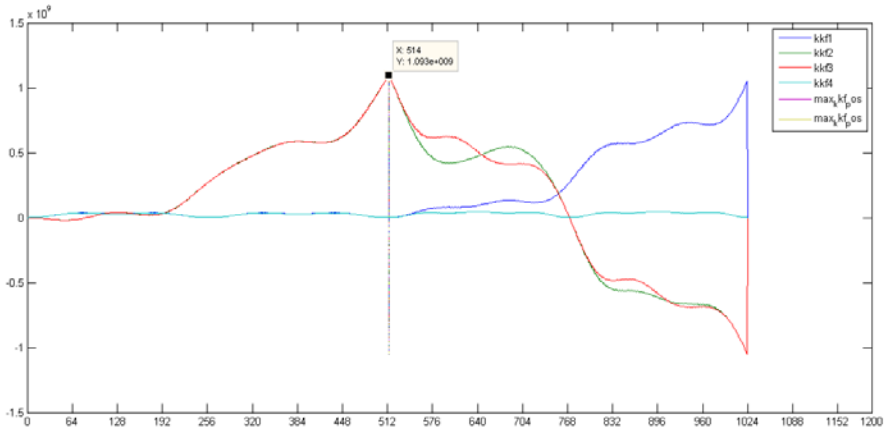


Figure 85 - Peak detection at sample position at pos_{sync} = 514 (example)

Figure 86 shows the synchronization sequence alignment to the mains phase zero-crossing.

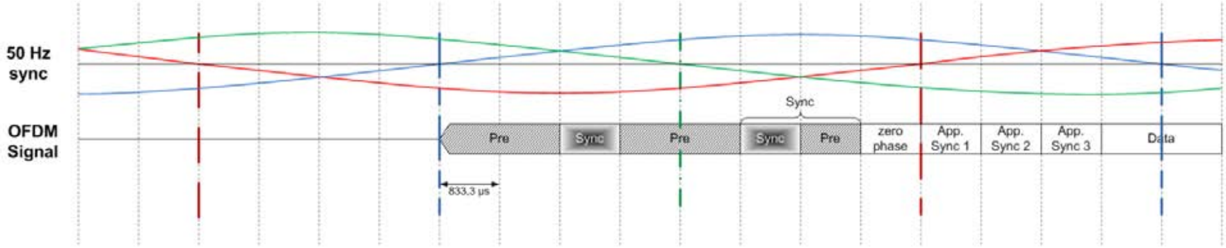


Figure 86 - Synchronization sequence alignment to mains phase zero-crossing

5.2 Data Link Layer type Powerline 110+

This clause describes the addressing, frame formats and access control of PL110+ medium. Compliance to the requirements of this sub clause is subject to transient and logical measurement equipment.

5.2.1 Domain Address/Individual Address/Group Address

Domain Address, Individual Address and Group Address are identical for PL110+ and PL110 (see clause 4.2.2).

5.2.2 Frame formats

5.2.2.1 General

General specifications of Frame formats are identical for PL110+ and PL110 (see clause 4.2.3.1).

5.2.2.2 L_Data frame

Two L_Data frame formats shall be available on the PL110+ medium:

1. the L_Data_Standard frame format, and
2. the L_Data_Extended frame format.

The usage of the different formats shall depend on the value of the frame format parameter to the Data Link Layer (see [02]). The L_Data_Standard frame format shall be used with PL110 signalling if the frame format parameter is 0 and the message APDU is less than 16 octets (short messages), otherwise the L_Data_Extended frame format shall be used with PL110+ OFDM signalling (long messages).

5.2.2.3 L_Data_Standard frame format

For PL110+ there shall be a L_Data_Standard frame available for PL110 FSK signalling. Please refer to clause 4.2.3.3.

5.2.2.4 L_Data_Extended-frame

5.2.2.4.1 Use and frame format

The use and the frame format shall be identical for PL110+ and PL110 (see clause 4.2.3.4.1).

The encoding of the fields in the frame is specified in the next clauses.

5.2.2.4.2 Control field (CTRL)

The Control field (CTRL) shall be identical for PL110+ and PL110 (see clause 4.2.3.4.2).

5.2.2.4.3 Extended Control field (CTRLE)

The Extended Control field (CTRLE) shall be identical for PL110+ and PL110 (see clause 4.2.3.4.3).

5.2.2.4.4 Source Address (SA)

The Source Address (SA) shall be identical for PL110+ and PL110 (see clause 4.2.3.4.4).

5.2.2.4.5 Destination Address (DA)

The Destination Address (DA) shall be identical for PL110+ and PL110 (see clause 4.2.3.4.5).

5.2.2.4.6 Length

The L_Data_Extended frame shall have a variable length. The length information shall indicate the number of characters (0 characters to 254 characters) transported by the L_Data_Extended frame starting after the TPCI octet (octet 8). This means that an L_Data_Extended frame with length 0 shall end after the TPCI octet.

The length information shall be encoded by the combination of the Frame Type field (FT) in the Control Field and the Length field, as specified in [02].

5.2.2.4.7 Check Octet

The Check Octet shall be identical for PL110+ and PL110 (see clause 4.2.3.4.7).

5.2.2.4.8 Domain Address

The Domain Address shall be identical for PL110+ and PL110 (see clause 4.2.3.4.8).

5.2.2.5 Acknowledge-frame

Octet 0								
Short Ack								
b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0	
1	1	0	0	1	1	0	0	ACK

Figure 87 - Format 2, short acknowledgement frame format

The Acknowledge frame format for OFDM transmission shall consist of a single character that shall be used to acknowledge an L_Data frame.

This Acknowledgement frame shall comply with the coding is specified in Figure 87. Any other than the shown figures shall be treated as not acknowledged.

5.2.3 Data Link Layer protocol

5.2.3.1 Assemble/Disassemble Frame

The Assemble/Disassemble Frame Specification shall be identical for PL110+ and PL110 (see clause 4.2.4.1).

5.2.3.2 Medium Access Control

There is no absolutely collision free multiple access control in a frequency modulated medium. Therefore PL-BAUs shall use a slotted access technique as described below.

Before a device may start a transmission it shall wait for at least 65 bit times idle line since the last bit of the preceding Data Link Layer message cycle. The structure of a Data Link Layer message cycle depends on the architecture of the installation (installation with or without repeater). In general a data link message cycle consists of a Data Link Layer request frame and a subsequent Data Link Layer acknowledgement or a subsequent Data Link Layer response frame.

If several devices want to start a transmission simultaneously, then an access conflict arises. To solve this conflict a priority dependent time slot system shall be used:

1. Repetitions shall have the highest priority and shall gain access to the bus, before any other device with a pending transmission request;
2. If the bus is not locked by a repetition or an acknowledgment frame, then the repeater L_Data-request frame shall gain access to the bus;
3. if the bus is not locked by a repetition, an acknowledgment or a repeater frame, then a system- or urgent L_Data-request frame shall gain access to the bus;
4. if the bus is not locked by a repetition, system- or urgent L_Data-request frames normal / low operational priority, request frames shall gain access to the bus. Supposed that most of all L_Data-request frames are operational priority frames there are 7 time slots chosen at random to start the transmission.

If a device once gained control of the bus it shall continue transmission until the last bit is transmitted.

During reception the Data Link Layer of the receiving device shall check if the device is addressed and control the immediate acknowledgement mechanism. If a transmission error occurs, the transmitting Data Link Layer shall repeat the L_Data-request frame. Errors may occur in either direction, i.e. an L_Data-request frame or an acknowledgement frame may be destroyed.

5.2.3.3 L_Data-request Message Cycle without Repeater

After a specified idle time a PL-BAU shall initiate a message cycle transmitting an L_Data-request frame. If this L_Data-request is received by another PL-BAU it shall check the consistency of the frame and whether it is addressed.

After a time gap of 4 bit (-0/+5) after the last bit of the L_Data-request frame it shall start the transmission of the acknowledgement frame. The acknowledgement frame shall have a duration of 20 bit times (3ch, QPSK, Convolutional coding). By now the message cycle shall be terminated and the next L_Data-request message cycle may gain access to the bus after at least 65 bit times (-0/+5) after the last L_Data-request frame.

If either the L_Data-request frame or the acknowledgement frame has been destroyed and thus an acknowledgement frame has not been received within 33 bit times after the last bit of the L_Data-request frame, the PL-BAU that initiated the message cycle shall start a retransmission with the next bit slot. If the addressed PL-device received the repeated L_Data-request frame properly it shall start the transmission of its acknowledgement frame after a time gap of 4 bits (-0/+5) after the last bit of the repeated L_Data-request frame. Even if either the repeated L_Data-request frame or the acknowledgement frame is destroyed the message cycle shall be terminated. There shall be no further repetitions. The next L_Data-request message cycle (system priority) shall not be started after at least 65 bit times after the last bit of the repeated L_Data-request cycle (see Figure 88 and Figure 89).

5.2.3.4 L_Data-request Message Cycle with Repeater

After a specified idle time a PL-BAU shall initiate a message cycle transmitting an L_Data-request frame including the configured number of repetitions (see 5.2.3.3) the repeater shall gain access to the bus after at least 49 bit times (-0/+5). If this repeated L_Data-request is received by another PL-BAU it shall check the consistency of the frame and whether it is addressed. After a time gap of 4 bits (-0/+5) after the last bit of the L_Data-request frame it shall start the transmission of an acknowledgement frame. The acknowledgement frame shall have a duration of 20 bit times. If the repeater does not receive the acknowledgement frame within 29 bit times it may repeat additional times depending on the repeater resend configuration. This is the normal resend timing as specified in clause 5.2.3.3.

If the repeater receives an acknowledgement frame within 29 bit times it shall repeat the acknowledgement frame 4 bit times (-0/+5) after the last bit of the received acknowledgement frame.

The initial transmitting PL-BAU shall detect the repeated frame and the repeated acknowledgement frame in order to decide whether the transmission is overall successful or not.

The repeater configures itself automatically because it gains access to the bus before a frame with system priority can start its transmission (see Figure 88 and Figure 90).

5.2.3.5 L_Data-request access Priorities

There shall be 9 different priority dependent time slots to start the transmission of L_Data-request frames. The first slot shall be reserved for repeater priority Repeated L_Data-requests only. The second slot shall be reserved for system priority L_Data-requests only. The slots 3 to 9 are reserved for operational priority L_Data-request frames. Each device with a pending operational priority L_Data-request shall choose one slot (3 ≤ selection ≤ 9) by random.

Slot number	Priority	Start[a]
0	repeated L_Data-request frame	33 (-0/+5)
1	repeater priority	49 (-0/+5)
2	system priority	65 (-0/+5)
3	operational priority Slot I	81 (-0/+5)
4	operational priority Slot II	97 (-0/+5)
5	operational priority Slot III	113 (-0/+5)
6	operational priority Slot IV	129 (-0/+5)
7	operational priority Slot V	145 (-0/+5)
8	operational priority Slot VI	161 (-0/+5)
9	operational priority Slot VII	177 (-0/+5)

[a] Bit times after the last bit of the last L_Data-request frame.

Figure 88 - L_Data-request priorities

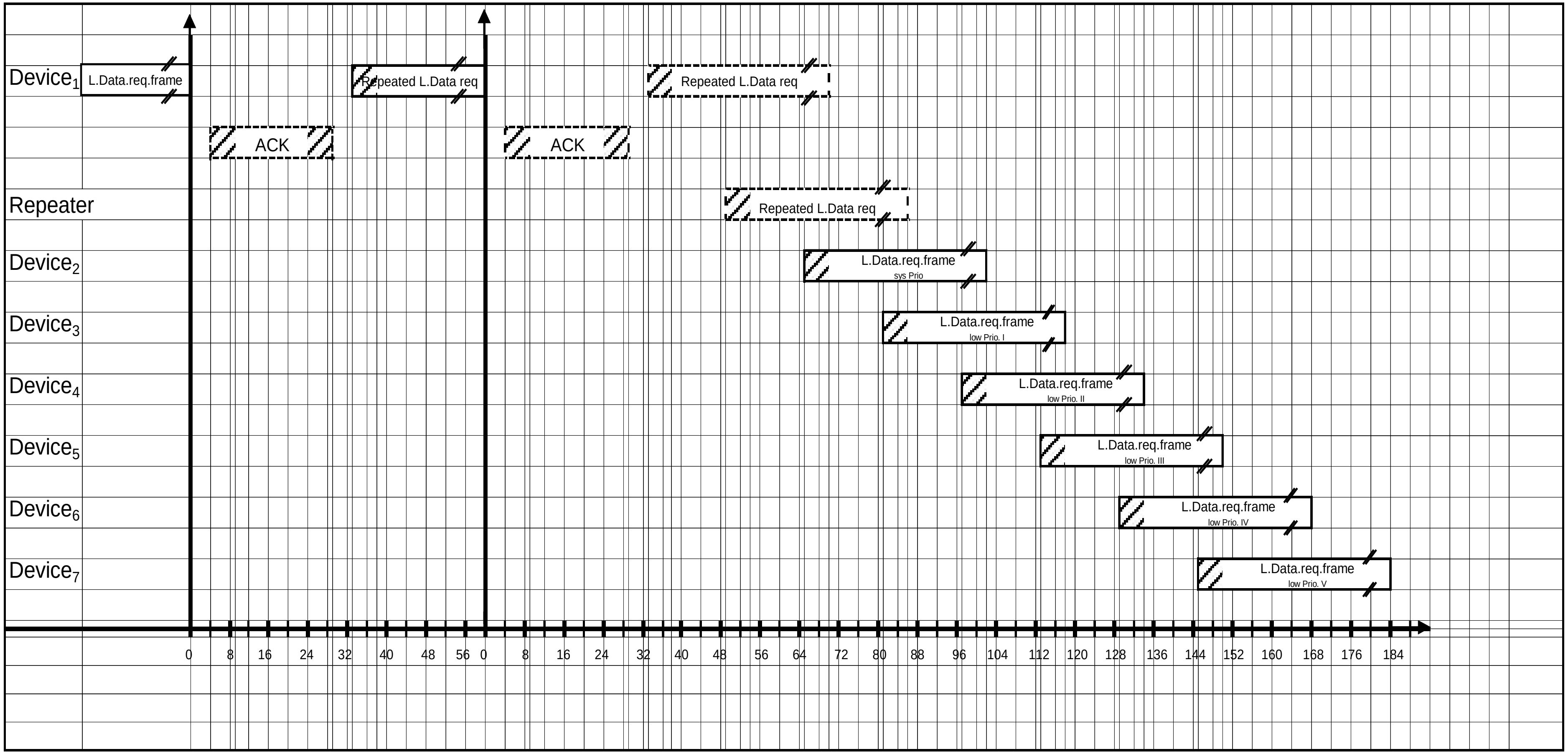


Figure 89 - Timing diagram of an L_Data-request frame without repeater

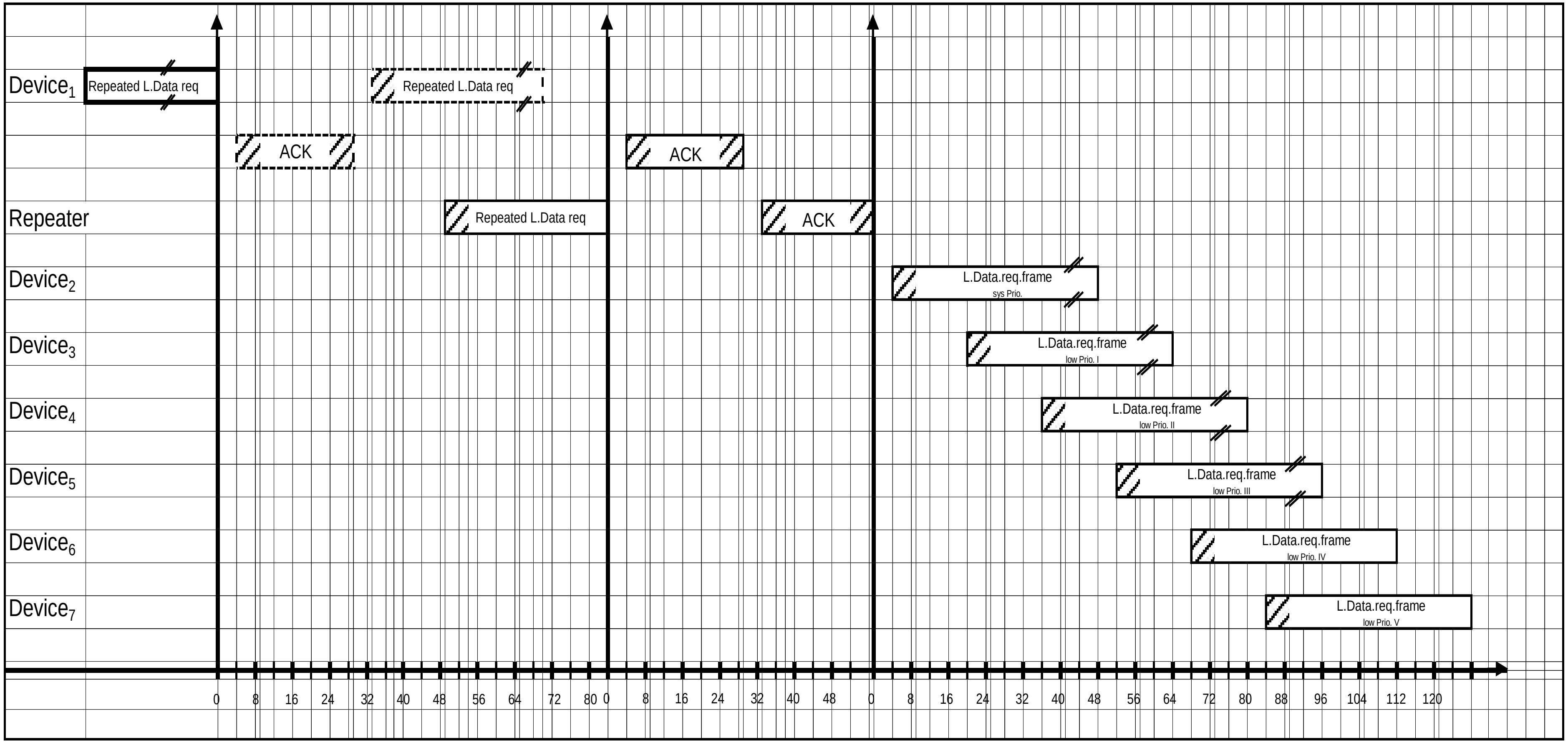


Figure 90 - Timing diagram of an L_Data-request frame with repeater

5.2.3.6 Checking for correct Request Frames

If the received Domain Address matches the own Domain Address and the Destination Address of a request frame corresponds to the Individual Address or one of the Group Addresses of a PL-BAU, the receiver of the frame shall check if the frame is correct. A frame shall be accepted as correct if:

- every Character is correct or at least correctable, and
- the Check Octet has the correct value, and
- the Control Field has the correct value, and
- an extended frame was detected, and
- the length of the data field is between 16 and 254 characters within the frame

The receiver of a frame shall acknowledge a repeated frame. The receiver shall discard it, if it has been received correctly before. A repeated frame shall have the same Source Address as the preceding frame (that applies to the repeater, too) with the repeat_flag set to 0.

5.2.4 Data Link Layer services

5.2.4.1 L_Data services

The L_Data service shall be a datagram service; in case of a single destination in the same physical segment it is even an acknowledged datagram service. The local user of Layer-2 shall prepare an LSDU for the remote user by filling in the local Individual Address as Source Address and the local Domain Address as source Domain Address. The local user of Layer-2 shall apply the L_Data.req primitive to pass the LSDU to the local Layer-2. The local Layer-2 shall accept the service request and try to send the LSDU to the remote Layer-2 with frame format 1. The Destination Address may be an Individual Address or a Group Address (multicast or broadcast). The local Layer-2 shall pass an L_Data.con primitive to the local user indicating either a correct or an erroneous data transfer.

Prior to passing the confirmation to the local user, the local Layer-2 shall wait for an acknowledgement from the remote Layer-2 (frame format 2). If the acknowledgement is a positive acknowledgement (ACK), the local Layer-2 shall pass an L_Data.con with l_status = ACK to the local user. If the acknowledge is missing the local Layer-2 shall pass an L_Data.con with l_status = not_ok to the local user. In all other cases, i.e. invalid or time-out after 29 bit times the local Layer-2 shall repeat once after 33 bit times. If it fails, the local Layer-2 shall pass an L_Data.con with l_status = not_ok to the local user.

If the request frame received is correct (see 5.2.3.6), the remote Layer-2 shall send an acknowledge and shall pass the LSDU with an L_Data.ind primitive to the remote user. If the request frame received is not correct, the remote Layer-2 shall not send an acknowledge.

L_Data.req(domain_address, destination_address, DAF, priority, lsdu)

domain_address:	Source and Destination Domain Address
destination_address:	either an Individual Address or a Group Address
DAF:	destination_address flag indicates whether destination_address is an Individual Address or Group Address
priority:	system, urgent, normal or low operational priority
lsdu:	this is the user data to be transferred by Layer-2

L_Data.con(l_status)

l_status:	ok,	requested frame sent successfully
	not_ok	transmission of the frame did not succeed.

L_Data.ind(domain_address, source_address, destination_address, DAF, priority, lsdu)

domain_address:	Source and Destination Domain Address
source_address:	Individual Address of the end device that requested the L_Data service
destination_address:	Individual Address of this device or a Group Address of this device
DAF:	destination_address flag indicates whether destination_address is an Individual (0) or Group Address (1)
priority:	system, urgent, normal or low operational priority
lsdu:	this is the user data that has been transferred by Layer-2

A Coupler (e.g.: a Media Coupler) shall connect one Subnetwork with another Subnetwork. It shall have a unique Individual Address. A Coupler shall acknowledge Layer-2 services and transmits the Layer-2 request frames to the other side, if the end device associated with the Destination Address of the frame is located on the other side. Thus receiving an acknowledge Frame does not guarantee that the destination (the end device) has received the L_Data-request, but it indicates that at least one destination or a Coupler did receive it.

5.2.4.2 L_Sys_Data service

The L_Sys_Data service shall be implemented as an unacknowledged datagram service. The local user of Layer-2 shall prepare a LSDU for the remote user by filling in the local Individual Address as Source Address and the system-broadcast Domain Address (0000h) as source Domain Address. The local user of Layer-2 shall apply the L_Sys_Data.req primitive to pass the LSDU to the local Layer-2. The local Layer-2 shall accept the service request and shall try to send the LSDU to the remote Layer-2 with frame format 1. The Destination Address shall be a broadcast Group Address. The local Layer-2 shall pass an L_Sys_Data.con primitive to the local user that shall indicate a correct data transfer. The local Layer-2 shall always repeat the L_Sys_Data.req once before passing a positive confirmation to the local user.

If the request frame received is correct (see 5.2.3.6), the remote Layer-2 shall pass the LSDU with an L_Sys_Data.ind primitive to the remote user. If the request frame received is not correct the remote Layer-2 shall not send an acknowledge.

L_Sys_Data.req(system_broadcast, source_address, destination_address, DAF, priority, lsdu)

domain_address:	system broadcast Domain Address 0000h
source_address:	Individual Address of the end device that requests the L_Data service
destination_address:	broadcast Group Address 0000h
DAF:	destination_address flag indicates always a Group Address (1)
priority:	system, urgent, normal or low operational priority
lsdu:	this is the user data to be transferred by Layer-2

L_Data.con(l_status)

l_status: ok:	requested frame sent successfully

L_Data.ind(system_broadcast, source_address, destination_address, DAF, priority, lsdu)

domain_address:	system broadcast domain_address 0000h
source_address:	Individual Address of the end device that requested the L_Data service
destination_address:	broadcast Group Address
DAF:	destination_address flag indicates a Group Address (1)
priority:	system, urgent, normal or low operational priority
lsdu:	this is the user data that has been transferred by Layer-2

5.2.5 Parameters of Layer-2

This part is identical to PL110. Please refer to clause 4.2.6.

5.2.6 The Layer-2 of a Repeater

There are three different modes in Data Link Layer:

1. Data Link Layer without Repeater detected
2. Data Link Layer with a Repeater detected
3. Data Link Layer of a Repeater

The Data Link Layer differs in the timing and in the structure of a Data Link Layer message cycle, depending on whether or not a repeater is detected in the network. A message cycle shall consist of at least an L_Data.request frame followed by an acknowledgement frame. If the acknowledgement frame fails to come within its timeslot the L_Data.request frame shall be repeated as often as configured.

The repeater listens for L_Data frames and acknowledgement frames. If no acknowledgement frame is detected after the L_Data frame the repeater shall itself repeat the L_Data frame in the repeater time slot and then listen for the acknowledgement frame. If the repeater receives the acknowledgement frame in the corresponding time slot it will repeat the acknowledgement frame again to signal the reception of L_Data frame to the original transmitter.

The original transmitter has to detect the repeated frame and shall wait for the end of reception / acknowledgement slots before a new frame can be transmitted.

If a repeater has to repeat a received L_Data.request frame the repeat flag in the control field (transmitted Octet 0) shall be set to zero.

The Source Address shall not be modified by the Repeater. I.e. the Source Address of the transmitting PL-BAU shall remain unchanged.

The Repeater is assigned to its Domain Address, i.e. it shall repeat only L_Data.request frames within its own Domain Address [5)].

5.2.7 The Layer-2 of a Media Coupler

This part is identical to PL110 specification. Please refer to clause 4.2.8.

5.2.8 State Machine of Layer-2

This part is identical to PL110 specification. Please refer to clause 4.2.9.

[5)] In addition the Repeater shall consider itself as member of the Domain Address 0000h. Though not recommended, several Repeaters of adjacent Domain Addresses may be installed within receiving range.

5.3 OFDM Properties

In order to optimize the OFDM performance in a given environment, the following set of settings shall be accessible via the property read/write mechanism (PID_OBJECT_TYPE = 50001).

Property	ID	Access	Range	Default	Description
PID_OFDM_BROADCAST_USED_ CARRIERS	0x10	r/w	0 to 7	0	0: 9 active carriers 1: 8 active carriers 2: 7 active carriers …
PID_OFDM_BROADCAST_FEC	0x11	r/w	0 to 1	1 (Conv.)	FEC for sent broadcast frames. 0: 8 to 12 coder 1: Convolutional coder
PID_OFDM_BROADCAST_-MODULATION	0x12	r/w	0 to 2	1 (DQPSK)	Carrier modulation for sent broadcast frames. 0: DBPSK, 1: DQPSK, 2: D8PSK
PID_OFDM_BROADCAST_-REPETITION_USED_ CARRIERS	0x18	r/w	-7 to 7	-3 (decrem.)	0: 9 active carriers 1: 8 active carriers 2: 7 active carriers … Or -1: decrement by 1, -2: decrement by 2, …
PID_OFDM_BROADCAST_-REPETITION_FEC	0x19	r/w	0 to 1	1 (Conv.)	FEC for repeated broadcast frames.
PID_OFDM_BROADCAST_-REPETITION_MODULATION	0x1A	r/w	-1 to 2	0 (DBPSK)	Carrier modulation for repeated broadcast frames. -1 means starting from the 1st modulation settings reduce modulation the next repetition, so e.g. D8PSK-DQPSK-DBPSK or DQPSK-DBPSK-DBPSK
PID_OFDM_BROADCAST_-REPETITION_COUNT	0x1B	r/w	0 to 7	1	Number of repetitions for broadcast frames

Property	ID	Access	Range	Default	Description
PID_OFDM_UNICAST_USED_ CARRIERS	0x20	r/w	0 to 7	0	0: 9 active carriers 1: 8 active carriers 2: 7 active carriers …
PID_OFDM_UNICAST_FEC	0x21	r/w	0 to 1	1 (Conv.)	FEC for sent unicast frames.
PID_OFDM_UNICAST_-MODULATION	0x22	r/w	0 to 2	2 (D8PSK)	Carrier modulation for sent broadcast frames.
PID_OFDM_UNICAST_-REPETITION_USED_CARRIERS	0x28	r/w	-7 to 7	-3 (decrem.)	0: 9 active carriers 1: 8 active carriers 2: 7 active carriers … Or -1: decrement by 1, -2: decrement by 2, …
PID_OFDM_UNICAST_-REPETITION_FEC	0x29	r/w	0 to 1	1 (Conv.)	FEC for repeated unicast frames.
PID_OFDM_UNICAST_-REPETITION_MODULATION	0x2A	r/w	-1 to 2	1 (DQPSK)	Carrier modulation for repeated unicast frames. -1 means starting from the 1st modulation settings reduce modulation the next repetition, so e.g. D8PSK-DQPSK-DBPSK or DQPSK-DBPSK-DBPSK
PID_OFDM_UNICAST_-REPETITION_COUNT	0x2B	r/w	0 to 7	2	Number of repetitions for unicast frames

Figure 91 - OFDM properties

Additionally an intelligent algorithm may use these Properties as transmission default values and may adapt these values dynamically using variable copies of these Properties.