EIBA Handbook Series

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Volume 3:
System Specifications

Part 2: Medium Dependent Layers

Chapter 2: EIB Implementation on Powerline

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1. Physical Layer Type Powerline PL110

In this clause the physical layer characteristics of the medium power line are described. According to the used frequency range this physical layer is called PL110. The main characteristics of the PL110 physical layer are:

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

The installation of the power line depends on its initial use as an electrical power distribution network. Physical properties of the medium power line 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. Power line communication is described in EN 50065-1 (general requirements, frequency allocation and electromagnetic disturbances).

The physical topology of the power line 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 Fig. 3/2/2-1:

Characteristic	**Description**
Medium	electrical power distribution network
Topology	installation dependant (e.g. linear, star, tree)
bit rate	1200 bps
mains frequency	50 Hz (acc. EN 50160)
number of Domain Addresses	255
number of Physical Addresses	32767
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	116 dBµV*
Input sensitivity	≤ 60 dBµV**
Device class	class 116*
Compliance to standards	EN 50065-1:1991

* measurement according EN 50065-1

** with artificial network according CISPR Publication 16-1, 2nd edition [(50µH+5Ω) / 50Ω]

Fig. 3/2/2-1: Features of Physical Layer Type PL110

The logical structure of the physical layer PL110 entity is shown in Fig. 3/2/2-2. Each PL110-device includes one.

The PL110 entity consist of three blocks:

- Connector
- Medium attachment unit (MAU)
- Error correction.

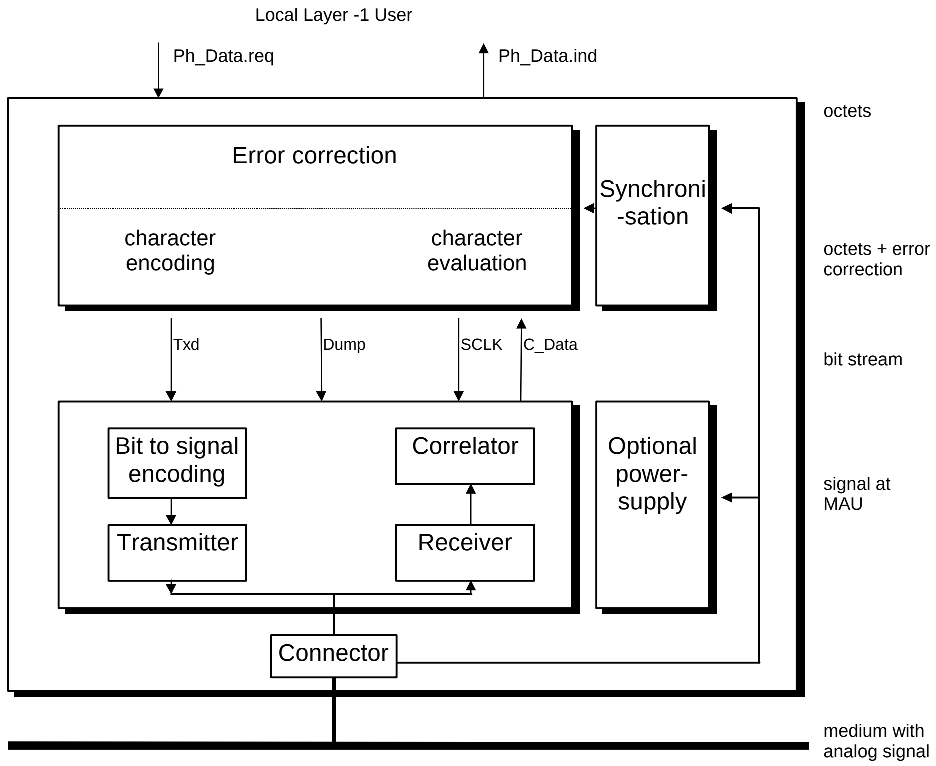


Fig. 3/2/2-2: Structure of the MAU (Example)

1.1 Transmission Medium

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).

1.1.2 Power Line Cables

The requirements for power line 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 Fig. 3/2/2-3. 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	25µΩ/m to 50 mΩ/m
Capacity	15 pF/m to 100 pF/m
Inductance	1.2 µH/m to 1.5µH/m

Fig. 3/2/2-3: Example of typical Cable Characteristics

<u>**Notice**</u>**: The use of shielded cables and cables with cross sections greater 35 mm^2 can influence power line signalling significantly!**

1.2 Medium Attachment Unit (MAU)

The medium attachment unit converts 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 are independent from each other. The requirements of the power supply are as follows:

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

TxD: 5V @ 30 mA / 24V @ 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.

1.2.1 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 Fig. 3/2/2-4 for illustration.

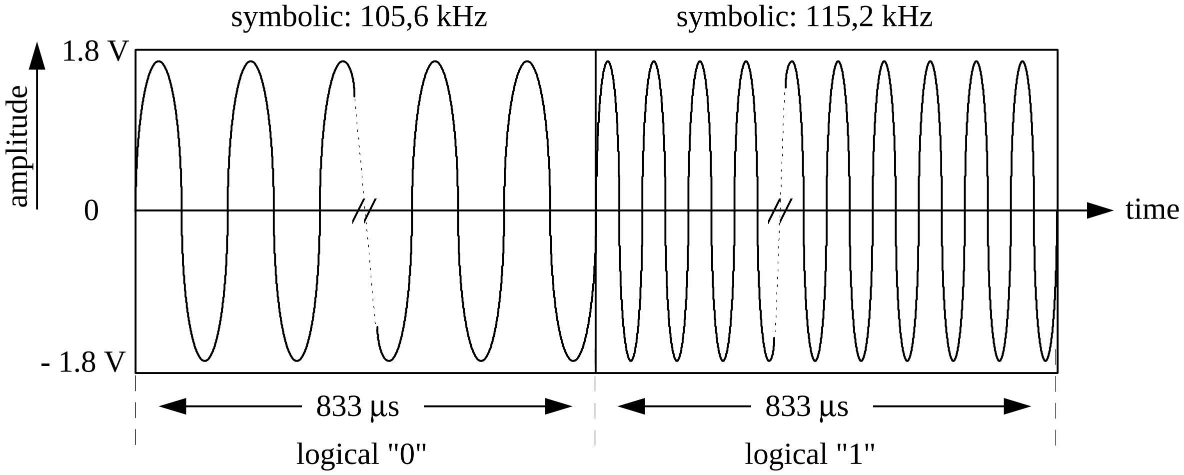


Fig. 3/2/2-4: Signal Encoding

These NRZ-signals are superimposed to the 230 V/50 Hz mains AC-voltage. The maximum amplitude of the signal must be limited to 116 dBµV, measured with CISPR 16-1 artificial mains network according EN 50065-1.

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

1.2.2 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 MAU's (e.g. common ACK), will result in fade-in / fade-out effects. Due to slight frequency deviations between several MAU's the signal will fade periodically with the difference of the MAU-frequencies. In PL110 power line communication this case is avoided by setting a unique group response flag to each assigned group address.

1.2.3 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.

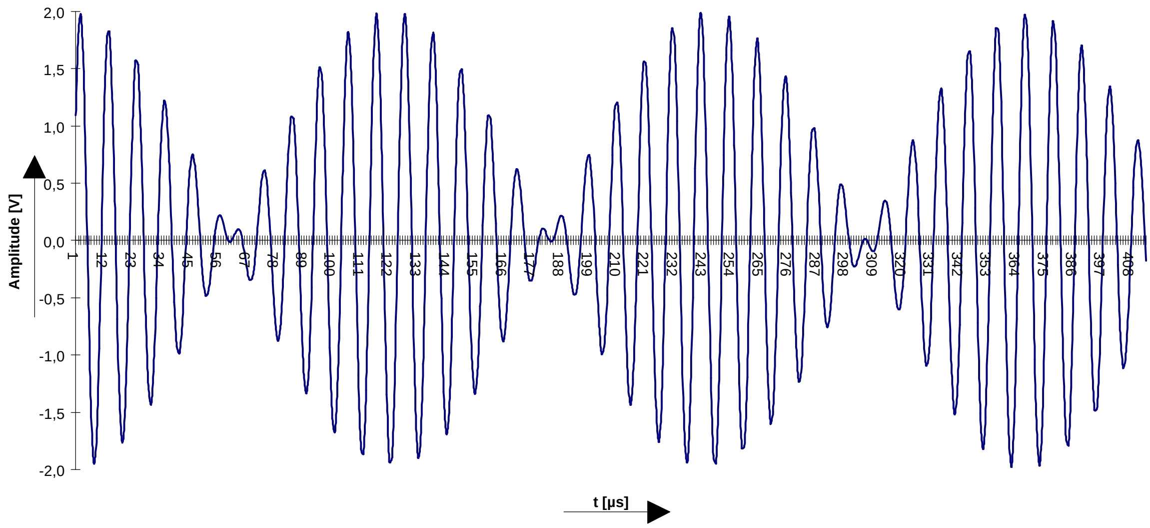


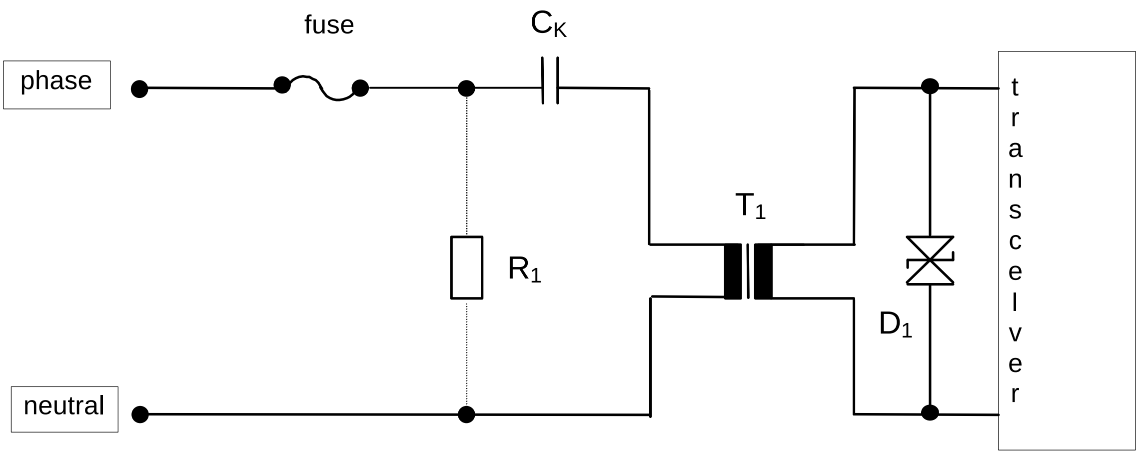
Fig. 3/2/2-5: Idealised overlapping of 105.4 kHz and 115.2 kHz

1.2.4 Impedance of the MAU

To limit the influence of connected MAU's on the characteristic of the power line 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:	$\lvert Z_{in} \rvert \geq 80\ \Omega$	@	100 kHz to 125 kHz
TxD:	$\lvert Z_{out} \rvert \leq 20\ \Omega$	@	100 kHz to 125 kHz

1.2.5 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)

Fig. 3/2/2-6: Example of a PL inductive Coupling Circuit

Electrical coupling of signals to the power line 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.

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.

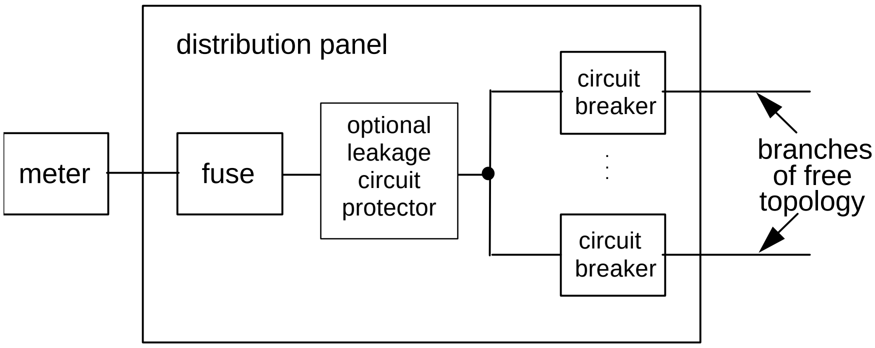


Fig. 3/2/2-7: Example of a typical PL Topology

1.4 Installation Requirements

The installation of the power line 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.

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.

1.6 PL Physical Layer Services and Protocol

1.6.1 Physical 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 can be called by the data link layer. Each Ph_Data.req() service primitive transfers a single octet to the physical layer. The class parameter contains 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 message cycle.
	start_of_of_prio_frame;	transmit Training Seq, Preamble I, Preamble II and character after at least $74 + (n-16) \mid 0 \leq n \leq 7$ 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.
	nack_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 can be called by the physical layer. Each Ph_Data.ind() service primitive transfers 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 was received
	inner_frame_char;	Character received immediately after the proceeding bit
	ack_char;	after detection of preamble I + preamble II a character was 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".

1.7 Features of Powerline PL110 Physical Layer

1.7.1 PL 110 Character Overview

Each PL 110 frame starts with a training sequence and a preamble. Training sequence and preamble are not coded. Each DL octet is coded to a 12 bit character (8 bits data + 4 bits error correction).

← transmission direction

7	6	5	4	3	2	1	0	E 3	E 2	E 1	E 0
Octet								Error Correction			

Fig. 3/2/2-8: Character

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

1.7.2 Frame Structure

The datagram consists of training sequence, preamble I / II, LPDU+CS and the Domain Address. Frame Check Sequence CS is only calculated with respect to TP LPDU, which is identical to the Twisted Pair LPDU. This leads to identical CS for physical layer Twisted Pair and Powerline.

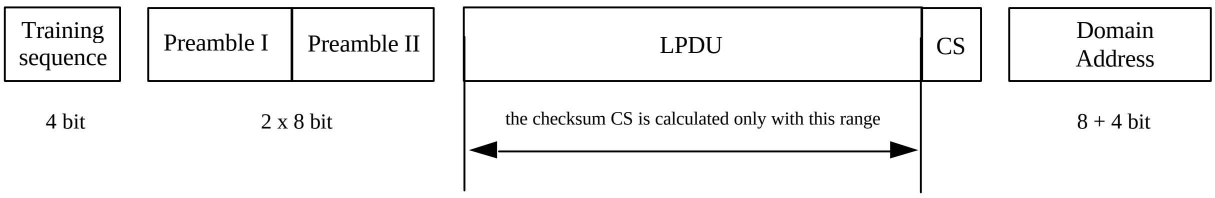


Fig. 3/2/2-9: Structure of a Datagram

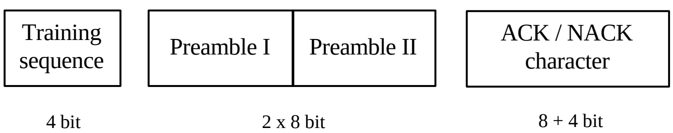


Fig. 3/2/2-10: Structure of an Acknowledge Frame

1.7.3 The Training Sequence

After switching into the status start_of_pdu the physical layer transmits a training sequence of 4 bit duration. The bit sequence is [0 1 0 1].

1.7.4 The Preamble Transmission Start

The next 16 bit are the preamble I and II. This preamble allows the receiver to start. The sequence of each preamble is 0xB0.

1.7.5 Faulty Transmission Detection

The error correction of the PL110 physical layer is done by powerline (12,8) block - coding. Generation is calculated with the following matrix:

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

Fig. 3/2/2-11: Generation Matrix of PL110

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

The code is 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 is subtracted by the received redundancy d_u. The result is 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

Fig. 3/2/2-12: Table of Syndromes related to Errors

For all calculations, GF2 arithmetic has 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	–

Fig. 3/2/2-13: 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

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

$$d = [d_o, d_u]^T = \begin{bmatrix}1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & | & 0 & 1 & 1 & 1\end{bmatrix}$$ 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 Fig. 3/2/2-12 a syndrome value of 6 corresponds to an error in column 3. Inverting bit number 3 leads to the corrected frame.

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:

↓ transmission ↓ error

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

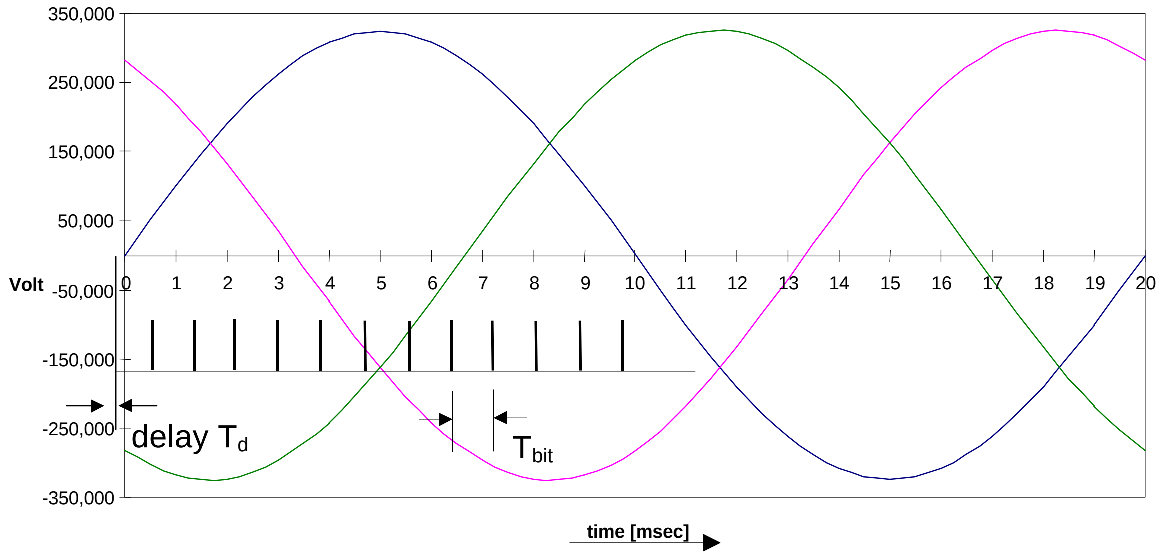


Fig. 3/2/2-14: Three Phase System

The start of a Transmission can not 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 MAU's detect the zero crossing of the mains voltage and measure the actual mains frequency. If the mains frequency (received by the described way) is placed within the permissible tolerance the bit width will 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 fixes its bit width to the nominal bit width of $833.\overline{3}$ µsec. Receiving the first preamble the receiver also fixes its bit width to the nominal bit width of $833.\overline{3}$ µsec and corrects the beginning of the following bit by:

12 * (actual bit width - nominal bit width)

2. Data Link Layer Type Powerline 110

The data link layer described in this clause is called data link layer type Powerline 110.

2.1 Domain Address/Physical Address/Group Address

Every PL-BAU shall have a Domain Address. PL-BAU's sharing the same Domain Address will belong to the same installation. The Domain Address is a two octet number. The most significant octet shall be set to zero, the lower significant octet contains the number of the Domain Address.

Every PL-BAU belongs to Domain Address zero, i.e. request frames with Domain Addresszero are system-broadcasts.

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							

Fig. 3/2/2-15: Domain Address

Every PL-BAU, i.e. a router or an end device shall have a unique Physical Address in a EIB network. The Physical Address is a two octet value that consists of an 8-bit sub-network address, and an 8-bit device address.

Physical Address															
Octet 0								Octet 1							
7[2]	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
Sub-network address								Device address							

Fig. 3/2/2-16: Physical Address

The device address shall be unique within a sub-network. Media couplers shall have the device address zero, i.e. end devices may have the device address 1-255.

The sub-network address shall be unique within an network.

[2] The most significant bit is the main-responder-flag. If the EEAddrTabLength is set to zero and the main-responder-flag is set all incoming group-messages are acknowledged but are passed to the next layer. If the main-responder-flag is not set all incoming group-messages remain unacknowledged but are passed to the next layer.

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

Fig. 3/2/2-17: Group Address

The group address is a 15 bit value that doesn't need to be unique. An end device may have more than one group address.

Every end device belongs to group zero, i.e. request frames with destination group address zero are broadcasts.

2.2 Frame Formats

There are two frame formats: the normal telegram frame and the acknowledge frame. Other frame formats shall not be received. Each frame is sent as a sequence of characters. The character that corresponds to octet 0 is sent first, the octet with the highest number is the last character being sent. The individual bits of an octet are sent in descending order, i.e. the most significant bit (bit 7) is sent first. The different frame formats differ in the control field.

2.2.1 Control Field

The first character of each frame is the control field. The control field contains the information about the layer-2 service, its class and a flag containing the information whether the LPDU is a repeated one, see Fig. 3/2/2-18

[3] 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.

Control Field								
7	6	5	4	3	2	1	0	
		repeat flag		class	class			
1	0	r	1	c1	co	0	0	L_DATA.req
x	x	0	0	x	x	0	0	Acknowledge frame

repeat flag = 0: repeated frame
repeat flag = 1: not repeated

c1	c0	
0	0	system priority
1	0	alarm priority
0	1	high priority
1	1	low priority

Fig. 3/2/2-18: Control Field

The control field indicates the type of the request frame, L_Data-request frame or Acknowledgement frame. The two class bits of the control field control the priority of the frame. Repeated format 1 frames have the repeat_flag set to zero, non-repeated ones have it set to one.

2.2.2 L_Data-Frame

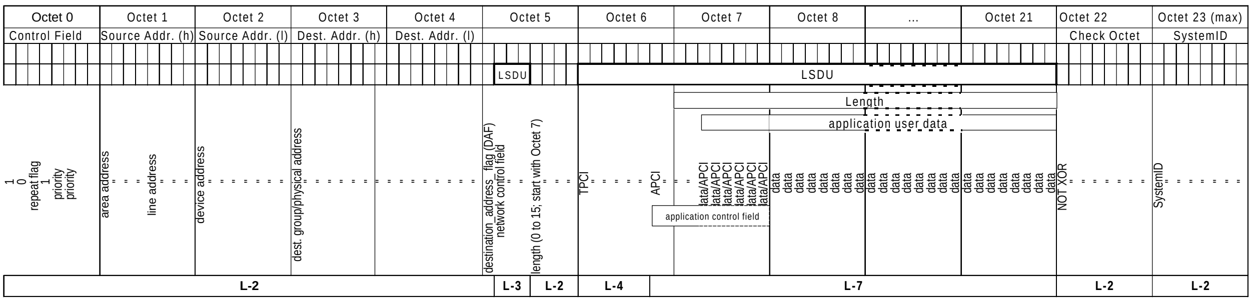


Fig. 3/2/2-19: Format 1, L_Data-Request Frame Format

2.2.2.1 Source Address

The octets one and two of a request frame are the high and low octet of the source address. This is the Physical Address of the end device that caused the transmission of the frame.

2.2.2.2 Destination Address and Destination Address Flag (DAF)

The destination address (octets three and four) defines the end device(s) that shall receive the frame. For L_Data-request frames, the destination address can either be a Physical Address (DAF=0) or a group address (DAF=1), depending on the destination address flag (DAF) of octet five.

2.2.2.3 Length

The L_Data-request frame format has a variable length; the maximum length is 24 characters. Octet 5 indicates the number of characters (0-15) of the L_Data-request frame starting with the seventh octet. That means that an L_Data-request frame with length 0 ends after the sixth octet.

2.2.2.4 Check Octet

The last but one octet of a request frame is the check octet which makes an odd parity over the set of corresponding bits belonging to the preceding octets of the frame. This represents a logical NOT XOR function over the individual bits of the preceding octets of the frame.

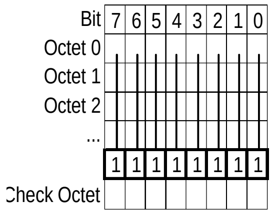


Fig. 3/2/2-20: Check Octet

2.2.2.5 Domain Address

The last octet of an L_Data-request frame represents the lower significant octet of the Domain Address. It determines the end devices that shall receive the frame.

2.2.3 Acknowledge-Frame

Octet 0								
Short Ack								
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	NACK

Fig. 3/2/2-21: Format 2, Short Acknowledgment Frame Format

The short acknowledgment frame format consists of a single character which is used to acknowledge an L_Data.req frame (see also Fig. 3/2/2-19). Any other than the shown figures are treated as NACK's. Fig. 3/2/2-21 shows the corresponding codes of the short acknowledgment.

2.3 Medium Access Control

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

Before a device may start a transmission it must wait for at least 58 bit times idle line since the last bit of the preceding data link message cycle . The structure of a data link 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 request frame and a subsequent data link acknowledgment or a subsequent data link 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 have the highest priority and will 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 notacknowledgment-frame, then a system- or alarm L_Data-request frame will gain access to the bus.
3. If the bus is not locked by a repetition, system- or alarm L_Data-request frames high/ low operational priority request frames will 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 repeats 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.

2.3.1 L_Data-request Message Cycle without Repeater

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

After a time gap of 4 bit after the last bit of the L_Data-request frame it starts the transmission of an acknowledgment frame. The acknowledgment frame has a duration of 32 bit times. By now the message cycle is 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 will start a retransmission with the next bit slot. If the addressed PL-BAU received the repeated L_Data-request frame properly it will 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 is 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.

2.3.2 L_Data-request Message Cycle with Repeater

After a specified idle time a PL-BAU initiates a message cycle transmitting an L_Data-request frame. If this L_Data-request is received by another PL-BAU it checks the consistency of the frame and whether it's addressed. After a time gap of 4 bit after the last bit of the L_Data-request frame it starts the transmission of an acknowledgment frame. The acknowledgment frame has 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 will not start a repetition of the L_Data-request frame. By now the message cycle is 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 will start a retransmission with the next bit slot. If the addressed PL-BAU received the repeated L_Data-request frame properly it will 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 will start the transmission of a not acknowledgment frame to inform the source device that the message cycle was not successful. Even if either the repeated L_Data-request frame or the acknowledgment frame has been destroyed the message cycle is 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.

2.3.3 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 ($2 \leq$ 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

Fig. 3/2/2-22: L_Data-request Priorities

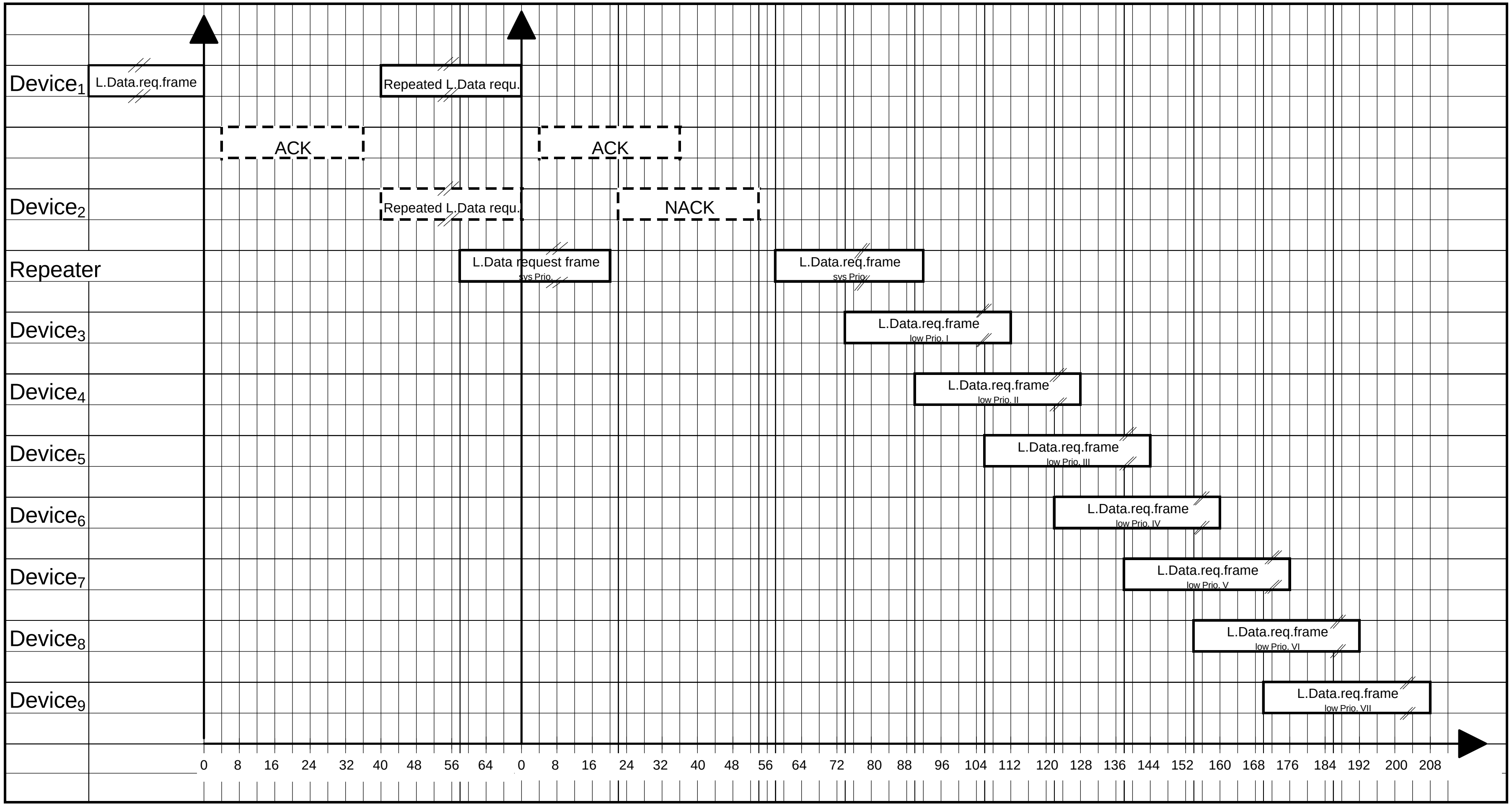


Fig. 3/2/2-23: Timing Diagram of an L_Data-request Frame

2.3.4 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 Physical Address or one of the group addresses of a PL-BAU, the receiver of the frame checks 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 has the same source address as the preceding frame (that applies to the repeater, too) with the repeat_flag set to 0.

2.4 Data Link Layer Services

2.4.1 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 prepares an LSDU for the remote user by filling in the local Physical Address as source address and the local Domain Address as source Domain Address. The local user of layer-2 applies the L_Data.req primitive to pass the LSDU to the local layer-2. The local layer-2 accepts the service request and tries to send the LSDU to the remote layer-2 with frame format 1. The destination address may be a Physical Address or a group address (multicast or broadcast). The local layer-2 passes an L_Data.con primitive to the local user that indicates either a correct or an erroneous data transfer.

Prior to passing the confirmation to the local user, the local layer-2 needs an acknowledgment from the remote layer-2 (frame format 2). If the acknowledgment is a positive acknowledgment (ACK), the local layer-2 passes an L_Data.con with l_status = ACK to the local user. If the acknowledge fails the local layer-2 passes 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 repeats once after 40 bit times. If it fails, the local layer-2 passes an L_Data.con with l_status = not_ok to the local user.

If the request frame received is correct (see 2.3.4 "Checking for correct Request Frames"), the remote layer-2 sends an acknowledge and passes 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, class, l_sdu)

domain_address:	source and destination domain_address
destination address:	either a physical address or a group address
DAF:	destination_address flag indicates whether destination_address is a physical address or group address
class:	system, alarm, high or low operational priority
l_sdu:	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, class, l_sdu)

domain_address:	source and destination domain_address
source_address:	Physical Address of the end device that requested the L_Data service
destination address:	Physical Address of this device or a group address of this device
DAF:	destination_address flag indicates whether destination_address is a physical (0) or group address (1)
class:	system, alarm, high or low operational priority
l_sdu:	this is the user data that has been transferred by layer-2

A router (e.g.: a media coupler) connects one sub-network with another sub-network. It has a unique Physical Address. A router acknowledges 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 router did receive it.

2.4.2 L_Sys_Data Service

The L_Sys_Data service is an unacknowledged datagram service. The local user of layer-2 prepares a LSDU for the remote user by filling in the local Physical Address as source address and the system-broadcast Domain Address (0x0000) as source Domain Address. The local user of layer-2 applies the L_Sys_Data.req primitive to pass the LSDU to the local layer-2. The local layer-2 accepts the service request and tries to send the LSDU to the remote layer-2 with frame format 1. The destination address must be a broadcast group address. The local layer-2 passes an L_Sys_Data.con primitive to the local user that indicates a correct data transfer. The local layer-2 always repeats the L_Sys_Data.req once before passing a positive confirmation to the local user.

If the request frame received is correct (see Checking for correct Request frames), the remote layer-2 passes 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, class, l_sdu)

domain_address:	system broadcast Domain Address 0x0000
source_address:	Physical Address of the end device that requested the L_Data service
destination address:	broadcast group address 0x0000
DAF:	destination_address flag indicates always a group address (1)
class:	system, alarm, high or low operational priority
l_sdu:	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, class, l_sdu)

domain address:	system broadcast domain_address 0x0000
source_address:	Physical 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)
class:	system, alarm, high or low operational priority
l_sdu:	this is the user data that has been transferred by layer-2

2.5 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
Physical Address:	unique Physical Address of this device
address table	address table with group address(es) of this end device

2.6 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 message cycle. A message cycle consists 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 is 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 transmits 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) is set to zero.

The source address is not modified by the repeater. I.e. the source address of the transmitting PL-BAU remains unchanged.

The repeater is assigned to its Domain Address, i.e. it repeats only L_Data.request frames within its own Domain Address[4].

2.7 The Layer-2 of a Media Coupler

To be defined.

2.8 State Machine of Layer-2

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

[4] In addition the repeater considers itself as member of the Domain Address 0x0000. Though not recommended, several repeaters of adjacent Domain Addresses may be installed within receiving range.