System Specifications

Communication Media

Twisted Pair 1

3

2

2

Summary

This document defines the medium specific Physical Layer and Data Link Layer services for the Twisted Pair 1 (TP1) medium.

Data Link Layer interface and general definitions that are medium independent are specified in Chapter 3/3/2 “Data Link Layer General”.

Version 01.02.02 is a KNX Approved Standard.

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Document updates

Version	Date	Modifications
1.0	2001.04.13	Preparation of Approved Standard.
1.1	2008.12.12	Integration of Supplements and Application Notes.
1.2.00	2011.01.06	• **AN129 “TP1 Completions”** integrated.
01.02.01	2013.10.28	Editorial updates for the publication of KNX Specifications 2.1.
01.02.02	2013.12.10	Final editorial update in view of publication in the KNX Specifications v2.1.

References

[01] Chapter 3/3/2 “Data Link Layer – General Requirements”
[02] Chapter 3/4/1 “Application Interface Layer”
[03] Chapter 3/6/3 “External Message Interface”
[04] Part 4/4 “Specific Requirements for Application Products and Basic and System Components and devices”
[05] Part 8/2 “Medium Dependant Layer Tests”
[06] Chapter 8/2/2“TP1 Physical and Link Layer Tests”
[07] Part 9/1 “Cables and Connectors”
[08] Part 9/2 “Basic Components”

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Abbreviations

t_{pd}	pulse duration
t_{sd}	signal duration
t_{sp}	signal position
t_{cp}	character position
t_{cs}	character separation
t_{ts}	telegram separation
t_{as}	acknowledge separation
t_{pcs1}	polling character separation 1
t_{pcs2}	polling character separation 2

Contents

1 Physical Layer type Twisted Pair (PhL TP1-64 & TP1-256)

The Physical Layer described in this clause is called Physical Layer type Twisted Pair TP1-64 and Twisted Pair TP1-256. The main differences are shown in Figure 1. TP1-256 is backward compatible towards TP1-64. If common features of TP1-64 and TP1-256 are described, only the expression TP1 is used.

The Twisted Pair medium TP1 characteristics are

- data and power transmission with one wire pair, and
- asynchronous character-oriented data transfer, and
- half duplex bi-directional communication and
- a specific balanced baseband signal coding under SELV conditions.

All the characteristics given in the following subclauses, like maximum number of devices or possible cable length per physical Segment are only valid for the standardized bus cable and standard devices [1]. These characteristics may be different if other bus cables (e.g. with other core diameters) or not-standardized devices are used. For information on standardized cables, connectors, power supply and choke refer to [07] respectively [08]). Figure 1 gives an overview over the characteristics of the Physical Layer types.

Characteristics	Description TP1-64	Description TP1-256
Medium	shielded Twisted Pair	shielded Twisted Pair[2]
Topology	linear, star, tree or mixed	Linear, star, tree or mixed
Baud rate	9600 bps	9600 bps
device supplying	normal: bus powered devices optional: remote powered devices	normal: bus powered devices optional: remote powered devices
device power consumption	3 mA to-12 mA	3 mA to-12 mA
Power Supply Unit (PSU)	DC 30 V	DC 30 V
Number of PSU’s per physical Segment	max. 2	max. 2
Number of connectable devices per physical Segment	max. 64	max. 256
Number of addressable devices per physical Segment	max. 255 [3]	max. 255
Total cable length per physical Segment	max. 1000 m	max. 1000 m
distance between two devices	max. 700 m	max. 700 m
Total number of devices in a network	over 65 000 (with Bridges)	over 65 000
Protection against shock	SELV (Safety Extra Low Voltage)	SELV (Safety Extra Low Voltage)
Physical signal	balanced baseband signal encoding	balanced baseband signal encoding

Figure 1 - System parameters of Physical Layer Type TP1-64 and TP1-256

Figure 2 shows the logical structure of the Physical Layer type TP1 entity. Every device includes one; every Router and Bridge is equipped with two such Physical Layer type TP1 entities.

1) The fan-in model is specified in [04].

2) The shield is not mandatory, shielded cables with earth connection can improve noise immunity.

3) In TP1-64 a physical Segment can be extended with up to 3 extra physical Segments, each connected to it via a Bridge. Every physical Segment can contain 63 devices.

The Physical Layer type TP1 entity consists of four blocks:

1. Cable (Medium)
2. Connector: connects a device or a Bridge to the transmission medium.
3. Medium Attachment Unit (MAU) : converts information signals to analog signals and vice versa. Typically extracts DC power from the medium.
4. Logical Unit: converts the serial bit stream to octets and octets to the serial bit stream, which is a serial stream of characters.

Figure 3 shows the relationship between the bits of an octet and the UART character data bits.

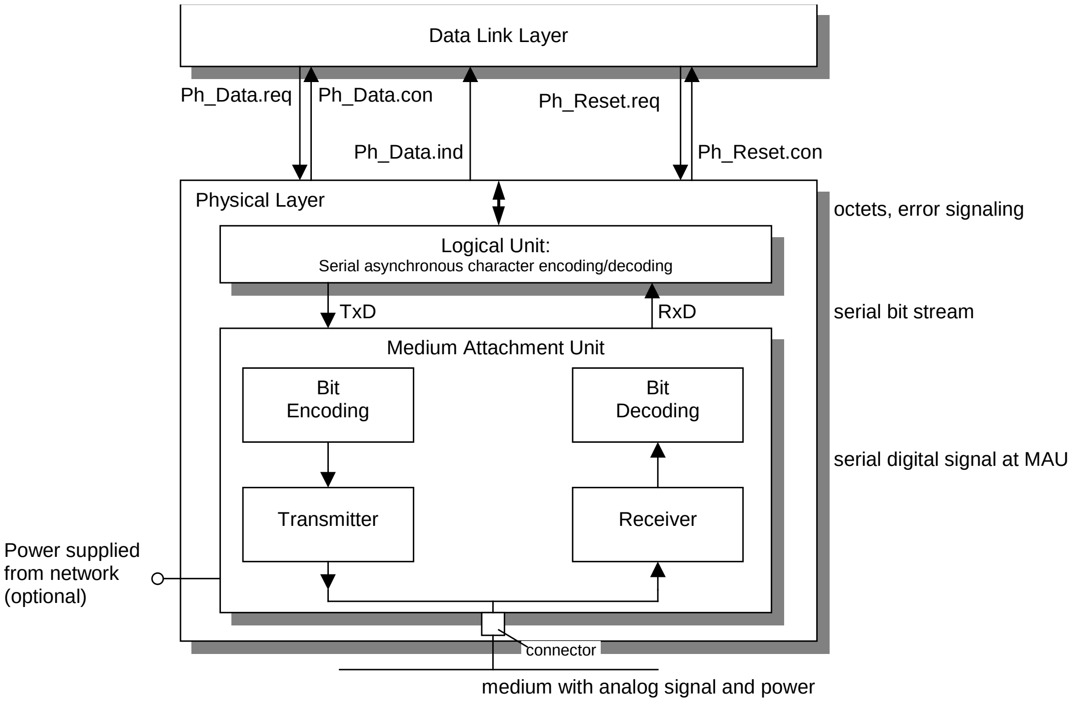


Figure 2 - Logical Structure of Physical Layer Type TP1

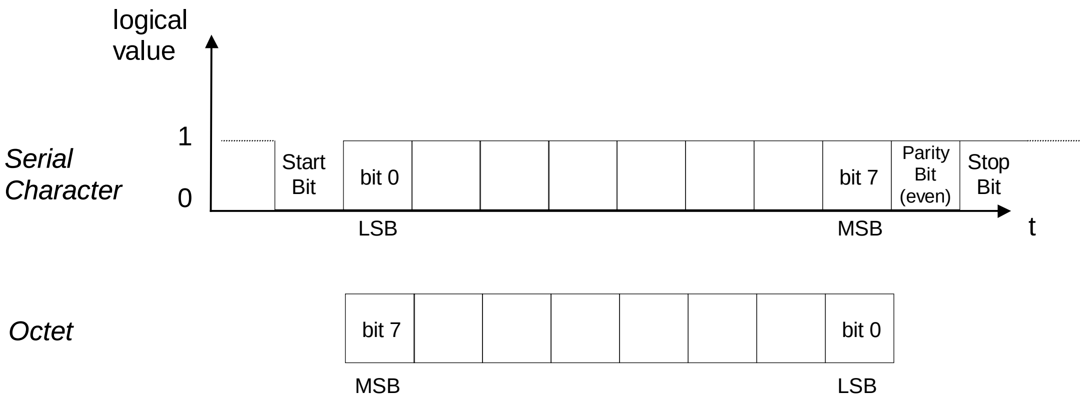


Figure 3 - Octet mapped to a Serial Character

1.1 General requirements for analog bus signals

In the underneath description, U_{REF} is an internal reference voltage for the DC part of the bus voltage, used by the transmitter/receiver for evaluating the sent/received signal levels and sampled before the start bit of a byte. These U_{REF} may vary with the values as indicated in clause 1.1.4 “Analog requirements within a byte”.

The underneath specifications classify a 0 and 1 signal on the bus : the requirements for signal generation and extraction for the transmitter respectively receiver as defined in 1.2.2.5 and 1.2.2.6.

1.1.1 Definition of logical ´1´

A logical ‘1’ can be regarded as the idle state of the bus, that means that the transmitter of a MAU is disabled during sending a ‘1’. The analogue signal at the bus consists normally only of the DC-Part. There is no difference between sending a ‘1’ and sending nothing. A decline of voltage during a ‘1’ can occur, if a ‘0 bit’ was preceding. The graph shall be within the gray shaded areas.

If the bus is in the state “Idle”, the maximum slope of the AC-part, as specified in Figure 4 and Figure 5, shall not be exceeded, in order to receive a logical ‘1’ correctly.

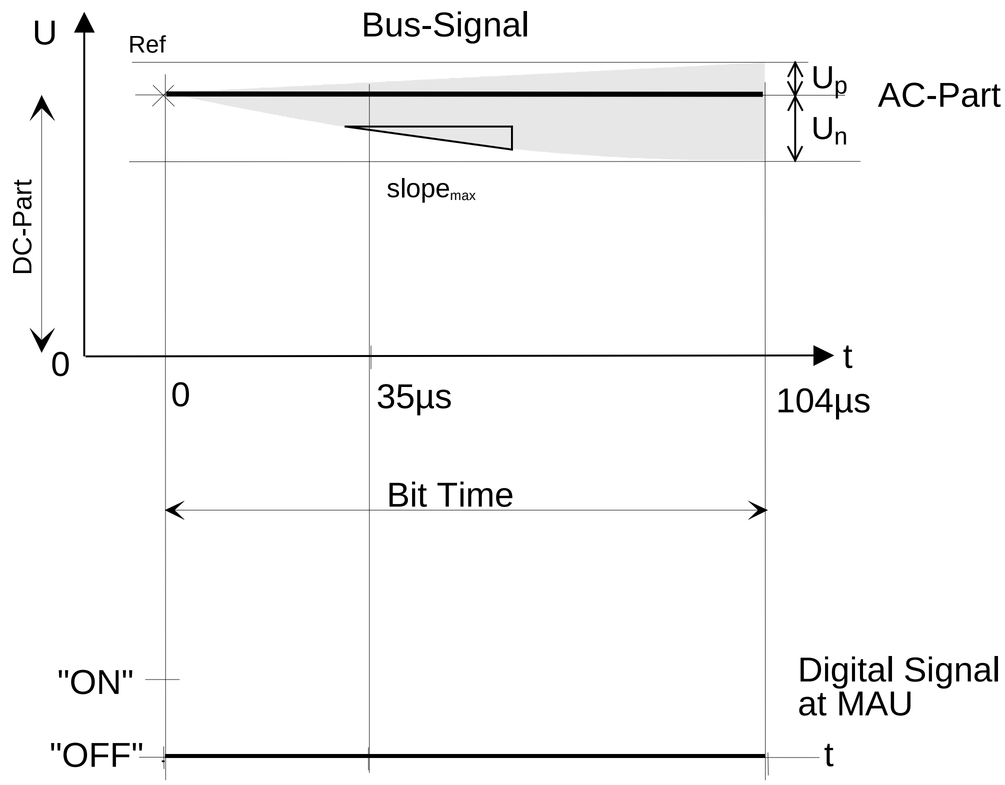


Figure 4 - “1”-Bit Frame

Parameter	Value
bit-time	1/9 600 s
voltage (DC-Part)	21 V_{DC} to 32 V_{DC}
voltage Up	max 0,3 V
voltage Un	max - 2 V
slopes (AC-Part)	max. 400 mV/ms

Figure 5 - Analog and Digital Signal of a Logical ´1´

1.1.2 Definition of logical ´0´ (single)

A logical ´0´ is a defined voltage drop (U_a) of the analog bus signal with a duration of t_{active} (see Figure 6). During the following equalization time the voltage can be higher than the DC-Part to enable recharging of energy consumed during the active part. The graph shall be within the grey shaded areas.

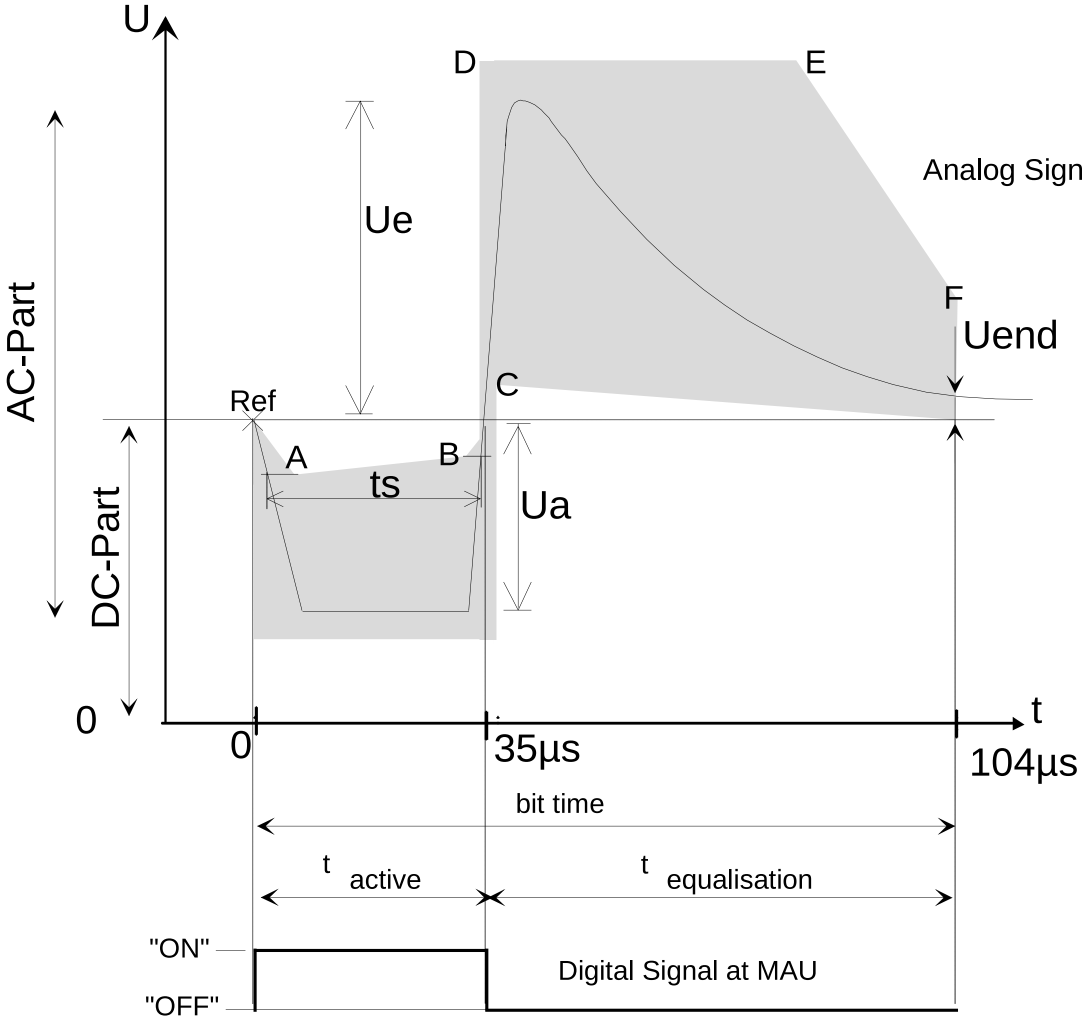


Figure 6 - “0”-Bit Frame

Parameter / Point	min	max
bit-time	1/9 600 s (typ)	
t_{active}	35 µs (typ)	
t_s (time between Ua > A and Ua > B)	25 µs	70 µs (see also 1.1.3)
time (Point D - E)	50 µs	
voltage (DC-Part)	21 V	32 V
voltage Ua (Point A) concerning Ref	-0,7 V	-10,5 V
voltage Ua (Point B) concerning Ref	-0,5 V	-10,5 V
voltage Ue (Point C - D) concerning Ref	0 V	+13 V
voltage Uend (Point F) concerning Ref	-0,35 V	+1,8 V

Figure 7 - Analog and Digital Signal of Logical ´0´

1.1.3 Definition of logical ´0´ (overlapping)

Overlapping means, that a logical ´0´ is transmitted at the same time from several devices (e.g. common ACK). Due to the propagation delay of the bus cable (PhL-Medium) a time shift of logical zeros can occur, if sending devices are far away located. The MAU and the MDS shall be able to handle these signals. Figure 8 shows an example of two mixed logical ´0´ that have a delay (td) of about 10 µs. Assuming that the point of measuring is at device A, the signal of device B appears after 10 µs with a lower signal amplitude than device A, because it is damped along the bus cable.

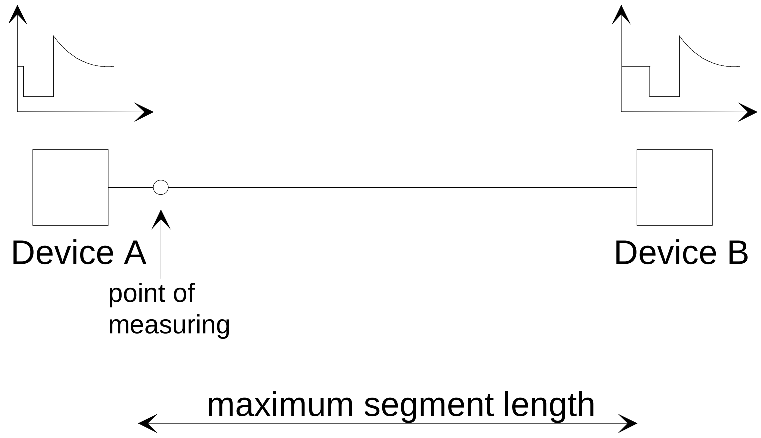


Figure 8 - Delayed Logical ‘0’

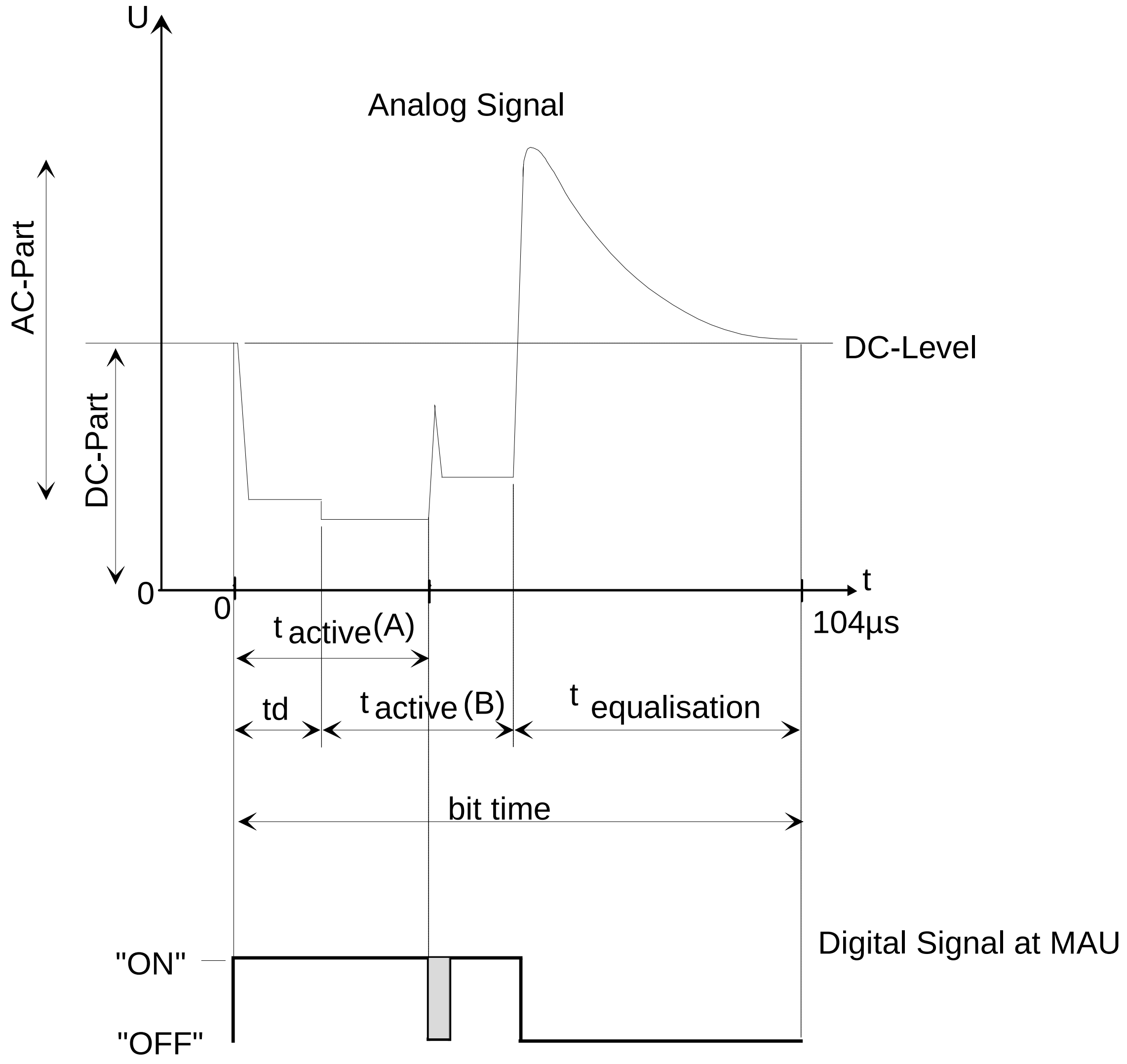


Figure 9 - Overlapping of Logical ´0´ (Example)

The receiver of MAU converts this mixed analog signal to a digital signal. This digital signal differs from that of a normal ‘0’, because the width of the receiver’s output pulse is the sum of t_{active} + td. However, it is possible, that the receiver’s output delivers a gap at the end of t_{active}. (See grey shaded area in Figure 9.) This behaviour requires dedicated decoding software that is able to decode such effects.

1.1.4 Analog requirements within a byte

Clauses 1.1.1 and 1.1.2 describe the voltage shape and timing within a logical bit. Within a byte, which consists of a series of bits, additional requirements have to be met. The values Ua* and Ue* are referred to Uref at the beginning of the active part of the first bit of the transmitted byte.

Parameter	Value
Ua*	max. –10,5 V
Ue*	max. 13 V
Uref (any bit)	max. –1 V / +3 V

Figure 10 - Limits within a Byte

1.1.5 Simultaneous sending / collision behavior

Although devices shall investigate the bus before they begin sending it can occur that two or more devices are sending simultaneously. Simultaneous sending of a byte is intended in case of transmitting acknowledgement frames (ACK, NACK or BUSY).

Sending of logical ‘0’ and logical ‘1’ at the same time result in a logical ‘0’.

Simultaneous sending of logical ‘0’ from several devices results in a signal that is nearly the same as that of a single transmitting device, because signal is coded in baseband.

This common signal has also to comply with Figure 7.

If a sending device detects that an own logical ‘1’ is overwritten by another logical ‘0’, transmission has to be disabled after this bit, however the receivers of both devices are still in progress.

This behaviour of Physical Layer allows a CSMA/CA medium access in Data Link Layer (see clause 2 "Data Link Layer type Twisted Pair (DL TP1)").

1.2 Medium Attachment Unit (MAU)

1.2.1 Goal

The MAU shall split the analog signal of the medium into the DC part and the serial bit stream. Vice versa the serial bit stream is converted to the analog bus signal.

The DC-Part is used internally to supply the device with power by using a DC/DC converter or voltage regulator. A wrongly connected MAU shall neither damage the device nor influence the bus communication.

1.2.2 General requirements within a physical Segment

Within a physical Segment the following principal requirements have to be met.

- In an installed system the DC voltage at every device shall be at least 21 V [4), 5)]
- The propagation delay of the serial bit stream at the MAU shall be short enough to allow bit-wise CSMA/CA arbitration during a bit time. The total delay (MAU - Cable - MAU) shall not exceed 12 µs. Refer also to clause 2 "Data Link Layer type Twisted Pair (DL TP1)" and clause 2.3 "Medium Access Control".
- The PSU(s) connected to a physical Segment shall provide the necessary effective current required by the devices connected to the physical Segment.
- SELV requirements have to be met.

1.2.2.1 Switch on behaviour

Bus devices have to meet certain criteria for powering up. Powering up means, that a single bus device is either connected to a ‘running’ bus segment or that a complete bus segment is switched to a Power Supply Unit (PSU). The difference is that the rising of bus voltage is different. "Switch On" procedure can be divided into two parts:

- *Start-up*: The internal capacitors are being charged with a current limitation.
- *Operation*: The capacitors are charged, voltages are constant.

4) Devices have to work with a DC voltage down to 20 V! 21 V are mandatory for the installer to get a reserve.

5) A voltage drop below 18 VDC in bus-powered devices with critical parameters/values in a volatile memory /RAM) may generate a call to a save routine that stores data in a non-volatile memory.

Switch on behaviour requires the following.

- Bus devices shall run up properly at any permitted topology if the associated segment is powered on by the PSU (slow ramp).
- A single bus device shall run up properly if connected to an operating bus segment. Other bus devices at this segment shall not suffer a ‘reset’ due to this connection (steep ramp).
- A possible signal disturbance, caused by the connection of a single bus device to an operating segment, takes not more than 20 ms to avoid telegram losses.

1.2.2.2 Switch off behaviour

The Switch-off behaviour occurs when the input to the power converter of the device breaks down. This input can either be the DC Part of the bus voltage or a remote power source (see 1.2.3).

The switching off behaviour can also be divided into three parts.

- *Operation:* The capacitors are charged, voltages are constant.
- *hold-up:* Capacitors are discharged.
- *Idle:* The power converter draws only a leakage current.

When switching from operation to hold-up, the Physical Layer may optionally generate signal U_{save}, to

- allow devices to back-up data before power breaks down
- disable further transmission of telegrams by the bus device

For bus powered devices, this U_{save} signal shall be generated when the bus voltage drops below 20 V max., thereby taking into account a hysteresis of at least 1 V.

The Physical Layer shall generate a Reset Signal when the correct functioning of the power converter can no longer be ensured, i.e. before the end of the hold-up time. This may be manufacturer specific. For a bus powered device the Ureset signal may not be generated for input voltages higher than for U_{save}.

1.2.2.3 DC behaviour

Bus devices may not draw more than the specified DC current from the bus to comply with the maximum number of connectable devices per segment which are defined in the system parameters (Figure 1). This current shall not be exceeded at worst case (20 V bus voltage and max. application consumption). The manufacturer has to specify the DC current in the product database.

Load changes within a device shall not disturb the signal voltage from the bus in any way. Fast current changes inside a device shall be transformed (smoothened) to slow slopes at bus side.

Parameter	TP1-64/TP1-256
Bus current (at 20V - 32V)	max. 12 mA
slope of input current	max. 0,5 mA/ms
slope of input current for manually operated devices (e.g. push buttons)	max. 2,5 mA/ms

Figure 11 - Unit currents for Standard Devices

1.2.2.4 Impedance behaviour

The impedance of a device is not only a property of the receiver. It is moreover valid for the complete device. Impedance behaviour means, which current is drawn from the bus by a device when the bus voltage has the shape of a square pulse (pulse duration of 35 µs and period of 1/9 600 s). The impedance value within a pulse (T = 1/9 600 s) is not constant. The value during active part (t < 35 µs) is different to this of equalization part. A special test method is provided to check the input impedance of devices (see [05]). Impedance matching is important to ensure that both signal damping is not too high and following bits are not disturbed by equalization event of preceding bits.

1.2.2.5 Transmission behaviour

If no Frame is transmitted, the voltage between Bus (+) and Bus (-) is about 21 V DC to 32 V DC, caused by the Power Supply Unit (PSU) and the voltage drop along the bus cable and the consumption of the devices. This state of the medium over a bit time of 1/9 600 s corresponds to a logical ´1´. The logical ´1´ also indicates the idle state when no Frame is being transmitted. The related output signal to the PhL MDS of the MAU is „OFF“ during the whole bit time.

In order to transmit a logical ´0´, the MAU shall draw an adapted current (I_{send}) to cause a defined voltage drop U_a of the analog signal with a duration of t_{active} (see also Figure 7).

During the following equalization time the energy consumed during the active time may be partly charged back to the bus cable and the connected devices. Thus bus-powered devices do not suffer a relevant power drop during transmission of a logical ´0´. The AC part of the analog signal is mainly generated by the transmitter of the MAU and the choke(s).

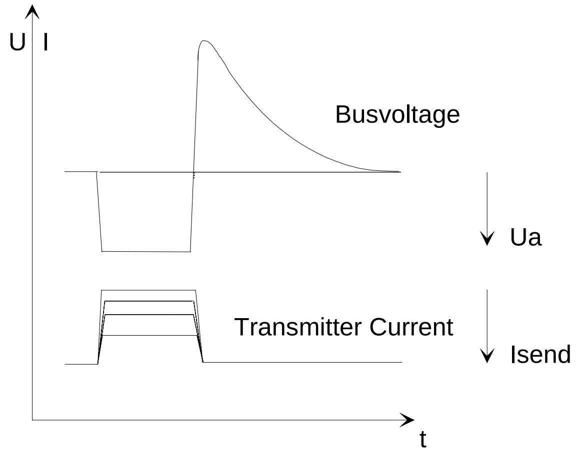


Figure 12 - Method of Transmitting

The value of send current of one device depends on:

- the number of connected bus devices,
- the number of bus devices that are sending simultaneously (e.g. in case of an acknowledgement frame),
- the busvoltage and
- the segment cable length.

Parameter	Value min.	Value max.
I_{send}	~ 0 mA [6)]	400 mA [7)]
U_A[8]	3 V	9 V

Figure 13 - Dynamic Requirements of a TP1-64 Transmitter

Parameter	Value min.	Value max.
I_{send}	~0 mA	400 mA
U_A	3 V	10 V

Figure 14 - Dynamic Requirements of a TP1-256 Transmitter

6) Valid for one device if the maximum number of devices are sending simultaneously.
7) Valid if only one device is sending and the segment is equipped with maximum number of devices.
8) Measured at the device.

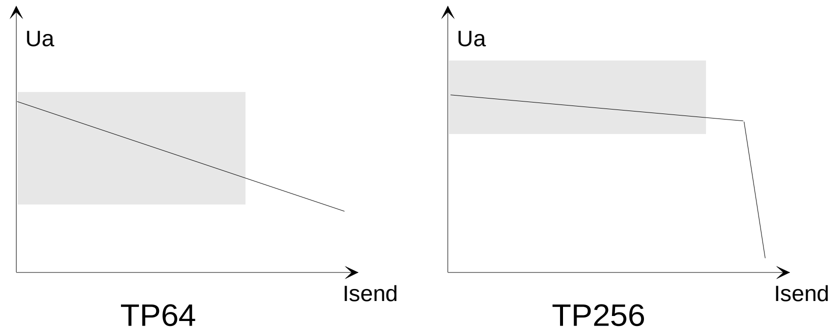


Figure 15 - Example of Transmitter Characteristics

Figure 16 shows an example of a principle diagram of a TP1-64 transmitter:

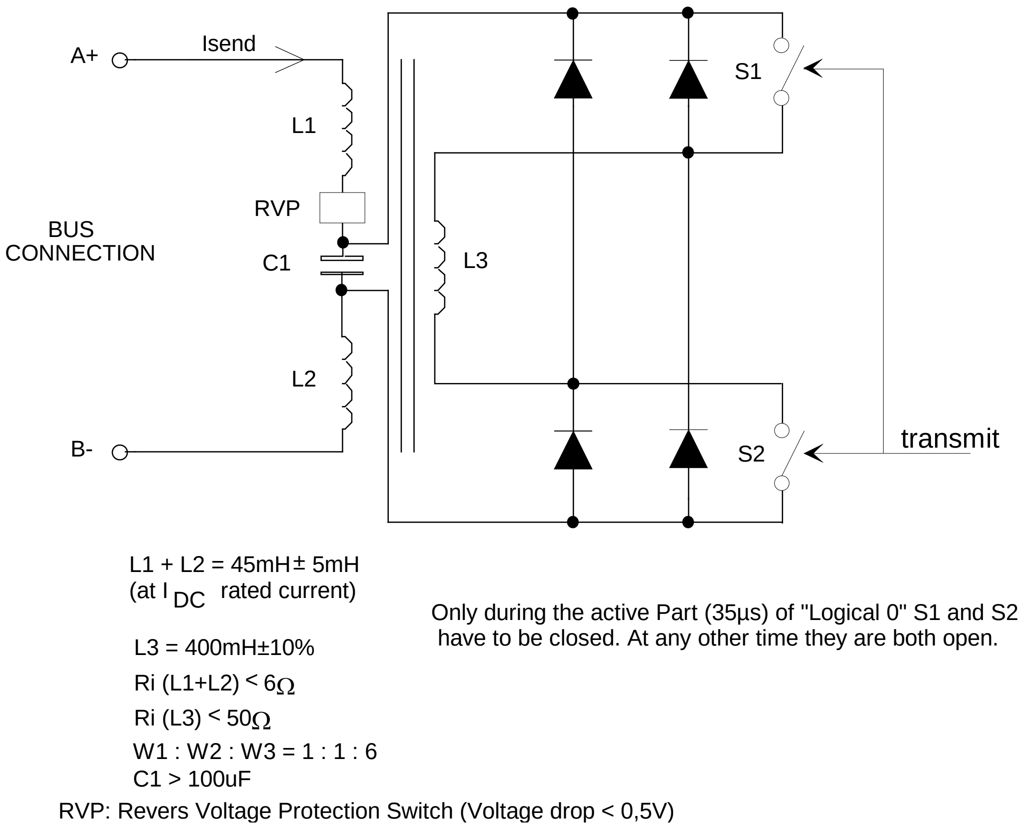


Figure 16 - Example of a diagram of a TP1-64 Transmitter

Figure 17 shows an example of a principal diagram of a TP1-256 transmitter:

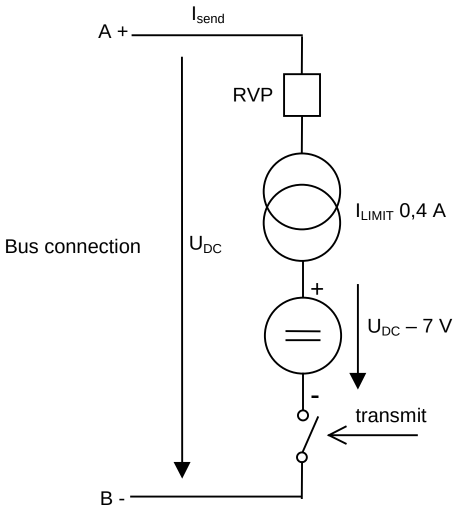


Figure 17 - Example of a diagram of a TP1-256 Transmitter (I_{limit} 0,4 A)

1.2.2.6 Receiving behavior

The MAU has to convert an analog signal to a digital signal by using a receiver function (see Figure 2). The required threshold voltages for the receiver are shown in Figure 18. The relation of ON/OFF and the bus voltage are explained in Figure 7. (See also test-specification in [05].)

State at MAU	Threshold Voltage TP1-64 (relative to DC part)			Threshold Voltage TP1-256 (relative to DC part)		
	min	typ	max	min	typ	max
ON	0,45 V	0,5 V	0,7 V	0,45 V	0,6 V	0,7 V
OFF	0,09 V	0,2 V	0,45 V	0,09 V	0,3 V	0,45 V
Hysteresis	0,05 V (min)					

Figure 18 - Requirements for the Receiver

1.2.2.7 Signal coding

The MDS of MAU has to convert framed data bits into an asynchronous timed serial signal. This signal is used to drive the transmitter of MAU. Figure 19 shows an example for a digital signal and the resulting serial bit stream.

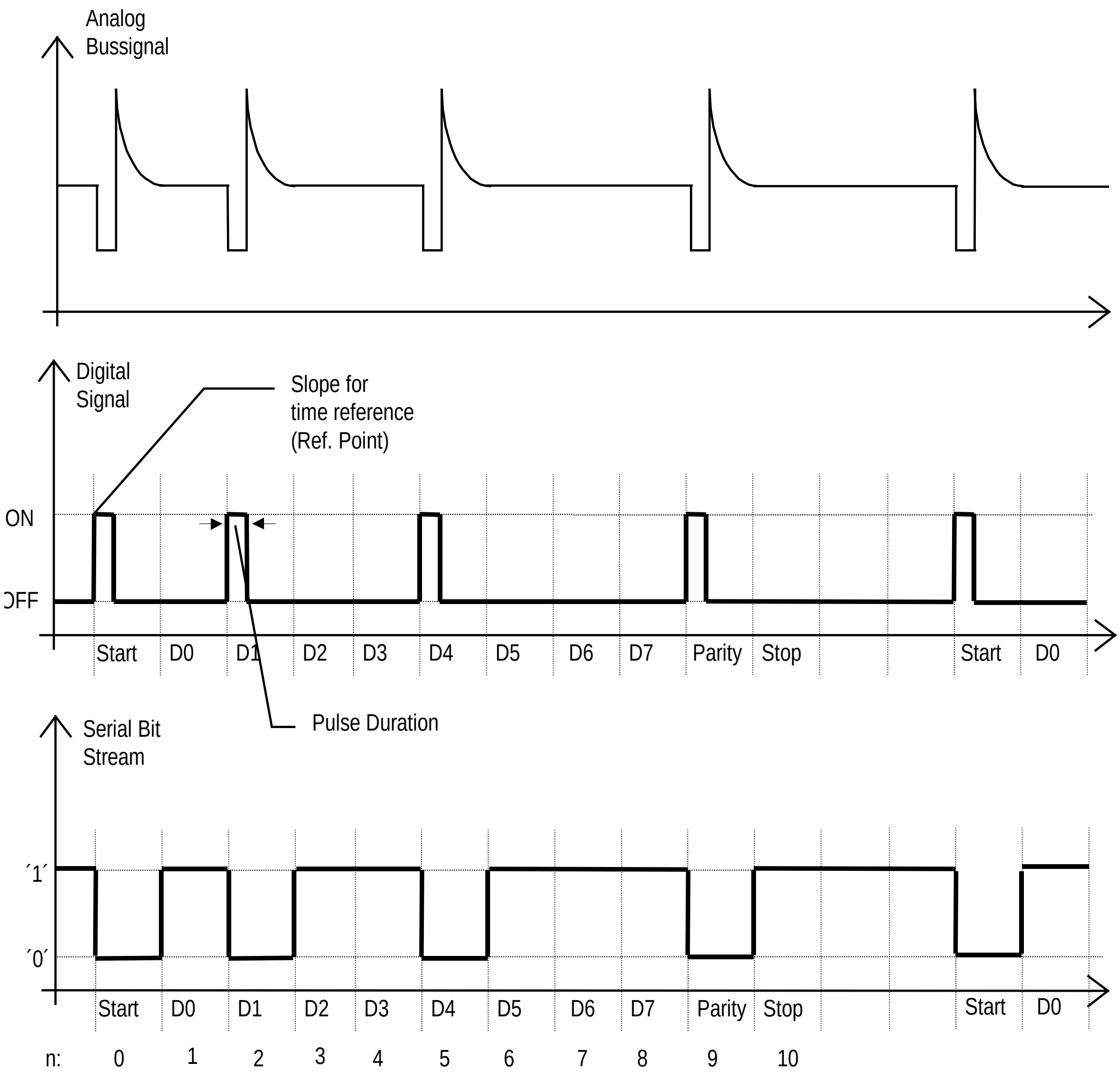


Figure 19 - Relation between Framed data and asynchronous signal

Parameter	min.	typ.	max.
Bit Time		1/9 600 s	
Pulse duration	34 µs	35 µs	36 µs
time from start-bit to following bits (within a byte)	(n bit times) – 2 µs	n bit times	(n bit times) + 2 µs

Figure 20 - Requirements for bit coding

Additional timing information concerning structure of telegrams is given in clause 1.4 "Services of the Physical Layer type TP1" and clause 2 "Data Link Layer type Twisted Pair (DL TP1)".

1.2.2.8 Signal decoding

The output signal of the receiver, regarded as a digital signal, shall be decoded to the serial bit stream by the bit decoding unit of the MAU (see also Figure 2). The following Figure 21 shows an example for a digital signal and the resulting serial bit stream.

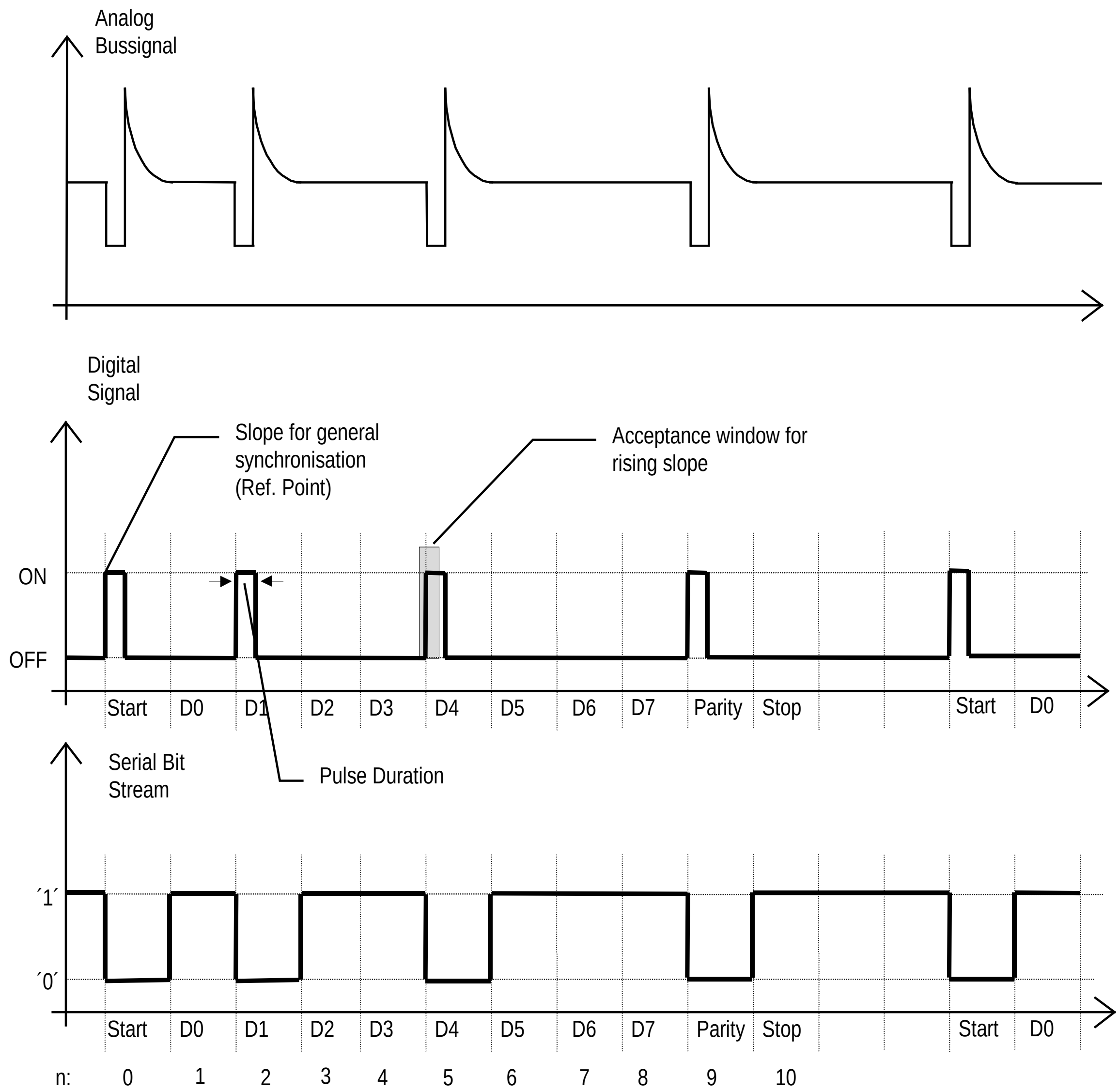


Figure 21 - Relation between digital signal and serial bit stream

The bit-decoding unit of the MAU uses an acceptance time window. The beginning of the acceptance time window is defined in relation to the start bit. In addition minimum and maximum pulse duration is required. The corresponding values are listed in the following table (Figure 22).

Parameter	minimum	typical	maximum
Bit Time		1/9 600 s	
Pulse Duration	25 µs	35 µs	70 µs [9)]
Acceptance window for the rising slope of a bit n, referred to rising edge of start bit (=Ref. point)	(n bit times) - 7 µs	n bit times	(n bit times) + 33 µs

Figure 22 - Requirements for the Bit Decoding Unit

The Physical Layer guarantees that the transmission of a logical ´0´ is dominant versus the simultaneous transmission of a logical ´1´. It is also guaranteed that during the simultaneous transmission of bits of equal value from a number of devices, the resulting physical signal corresponds to the same logical value of the bit being sent. This behaviour of the Physical Layer allows a CSMA/CA medium access in Data Link Layer (See clause 2 "Data Link Layer type Twisted Pair (DL TP1)" clause 2.3 “Medium Access Control”).

1.2.3 Remote Powered Devices

1.2.3.1 General

Remote powered bus devices (RPD) do not extract their energy for the application circuit and the bus controller from the bus but from another independent source of energy, e.g. mains. They only draw a minimal DC current from the bus line (segment). The AC load is similar to a standard device. Due to the reduced DC power consumption of RPD, a bus segment equipped with such devices requires less power from the installed Power Supply Unit(s).

The connection of bus-controller and application to the same electrical potential reduces the effort of galvanic separation in dedicated devices.

Galvanic separation can be implemented by using e.g. optocouplers or transformer. Only the transceiver is supplied from the bus segment.

Figure 23 shows an example of a remote powered device. Thus using remote powering it is possible to design a compact device for this dedicated application.

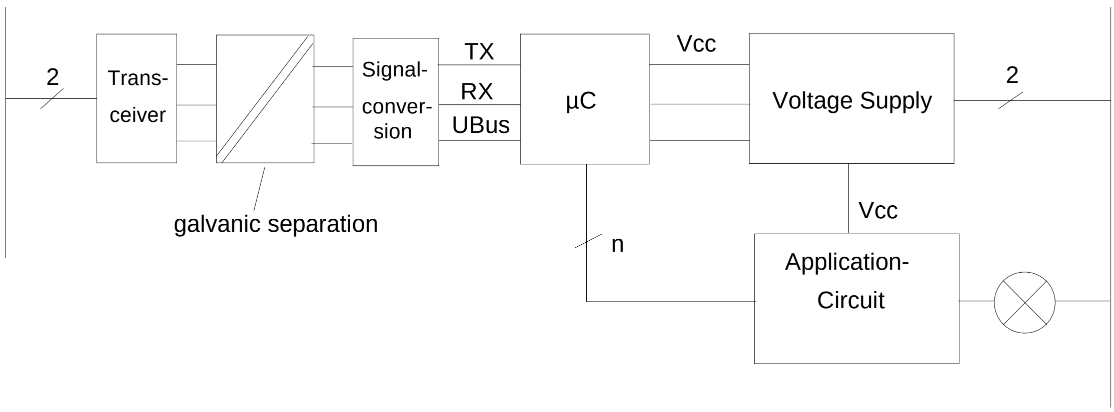


Figure 23 - Example of a light dimmer

9) See also Figure 10.

1.2.3.2 Reset and save behavior of RPD

RPD’s have access to two independent power sources, bus voltage and remote voltage.

The device supplying voltage is regarded as master voltage. That means, that ramp up or breaking down of this source causes reset, save and init. Save and init are the routines that can be defined in the user program. They are executed if the device detects either voltage ramps up or breaks down. The missing of master voltage shall not disturb the operating bus segment in any way.

Bus voltage is regarded as slave voltage. When the bus power breaks down, the RPD shall refrain from further transmission attempts. When the bus power is restored, the RPD shall continue normal operation [10)].

The behaviour of the device if either master or slave voltage is missing, shall be described in the manufacturers data sheet.

The manufacturer has to define how to reset a RPD. The device can also be forced to a reset from bus side, through sending a special reset service message.

1.3 Topology

1.3.1 Physical Segment [11)]

Devices are connected to a physical Segment. The topology of a physical Segment can be a linear, star or tree or mixed topology (see Figure 24). To make the figures easier to read, they always depict one bus topology as a representative for a physical Segment.

Up to 64 (TP1-64) or 256 (TP1-256) devices can be connected to a physical Segment if the recommended bus cable is used. This corresponds to the logical address space of a Subnetwork. The maximum distance between two devices in a physical Segment is 700 m. The maximum cable length in a tree or star topology may be longer than the maximum distance between two devices. Therefore the maximum cable length of a physical Segment is 1000 m for the recommended cables.

Loops within a physical Segment are allowed but not recommended.

No terminating resistors are required.

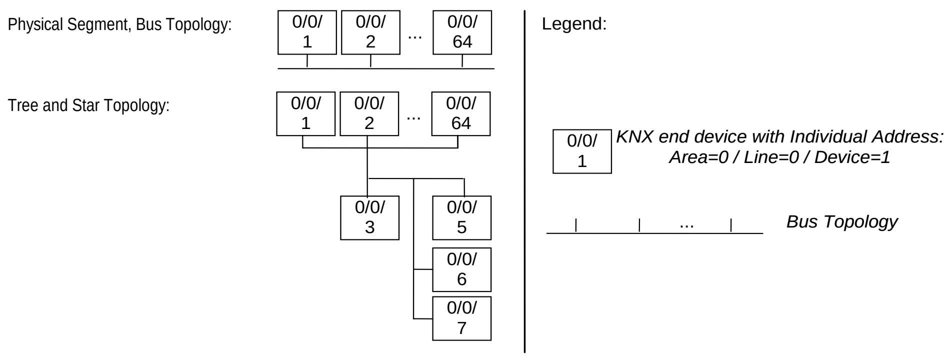


Figure 24 - Physical Segments

10) This is general requirement, also valid for purely bus-powered devices. This is part of the properly running up, as specified in clause 1.2.2.1 “Switch on behaviour”.

11) The calculations in the subsequent text are based on a maximum of 64 devices in a Segment, i.e. 3 x 64 = 192 devices per Segment. Of course in respect to the available logical address space 256 devices per Subnetwork are used for computations.
Instead, the figures show an example system, in which only two Segments (i.e. one Bridge) are used per Subnetwork. Therefore in the figures there are in the maximum 128 devices shown.

1.3.2 Bridge

Bridges are used to combine physical Segments to a Line in order to achieve longer distances and to allow up to 255 devices (Figure 25) on a Line with TP1-64 devices. The Bridge also guarantees a galvanic separation of the physical Segments connected to improve noise immunity. Bridges can be used to connect up to four physical Segments and achieve a total length of 3000 m. The maximum distance between two devices in a Line is therefore 700 m x 3 = 2 100 m for the standard cables. Bridges do not have an Individual Address, but they acknowledge the Frames they receive on Data Link Layer and transmit the received Frame on the other side of the Bridge.

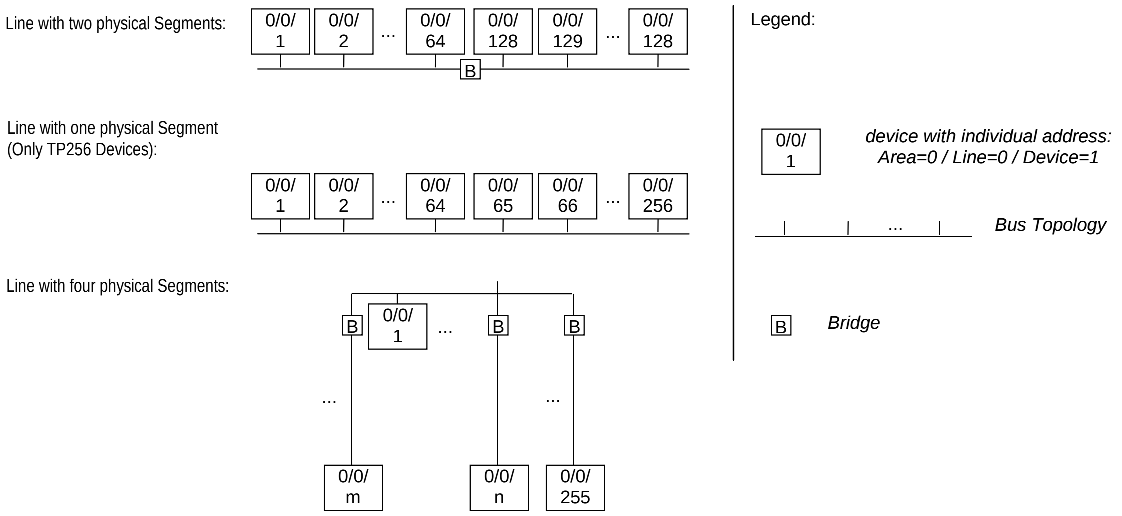


Figure 25 - Physical Segments combined to a Line

To simplify the following figures, a Line is always shown as two physical Segments having 128 devices.

1.3.3 Router, Line, Main Line and Area

A Router shall have an Individual Address and shall acknowledgement frames on Data Link Layer and transmit the received Frame on the other side of the Router, if the device associated with the Destination Address of the Frame is located on the other side. For larger networks, up to 16 Lines can be combined to an Area using 15 Routers (Figure 27). Not more than two Routers shall be in the path between any of two devices of an Area. The inner Line of an Area is also called Main Line; the outer Lines of an Area are called Lines.

The Router also guarantees the galvanic separation of the connected Lines.

Routers that combine Lines to an Area are called Line Couplers (LC).

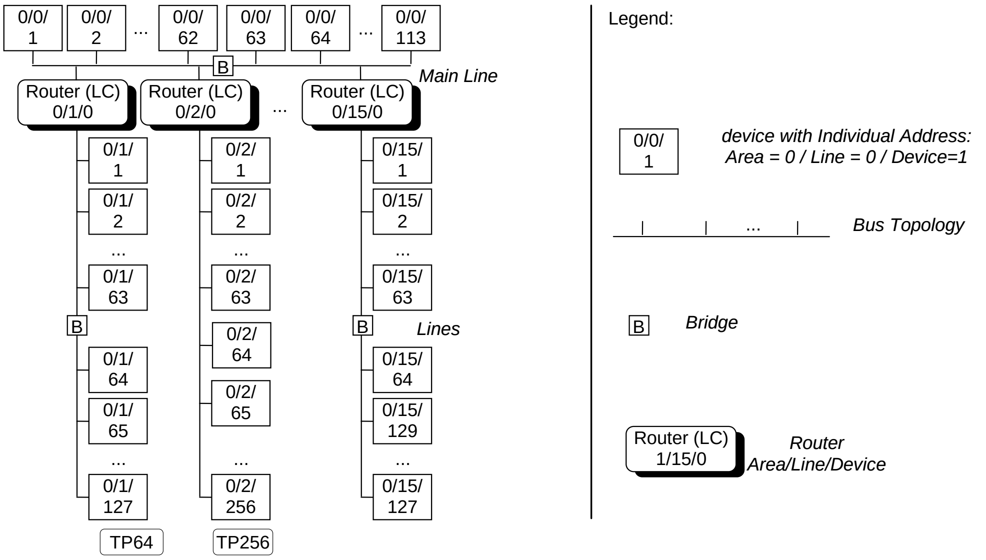


Figure 26 - Lines combined to an Area

Using the recommended cables and Bridges an Area may therefore have 256 x 16 = 4 096 devices and an extension of 4000 m x 16 = 64 km.

The maximum distance between two devices in an Area is then 700 m x 6 = 4,2 km [12)].

Routers can also be used to connect multiple Areas to a maximum size network (Figure 27). These Routers are called Backbone Couplers (BbC). Up to 16 Areas can be connected using 15 Backbone Couplers. Not more than two Backbone Couplers shall be in the path between any of two Areas. The Main Line of the inner Area is called Backbone Line.

A maximum size network may therefore have up to 4096 x 16 = 65 536 devices and a total network extension of 64 km x 16 = 1 024 km.

Not more than 6 Couplers (i.e. Bridges or Routers) shall be between any of two devices. The maximum distance between two devices in a maximum size Network using the recommended cables is then 700 m x 7 = 4,90 km.

1.3.4 Gateways to other networks

Gateways connect KNX systems to networks with communication layers different from the corresponding KNX layers. Gateways may be included at any Subnetwork. Gateway connections shall additionally be in conformance with the relevant national regulations.

NOTE 1 Areas may be linked together not only by using the Backbone Line but also by using higher level bus systems like ISDN or PROFIBUS, then requiring dedicated gateways.

1.3.5 Network topology configuration rules summary

Recommendation: A new installation normally should not contain a Bridge. The Bridges should be used for later extensions only.

A maximum of 6 Couplers is allowed in one transmission path; a Coupler is either a Bridge, a Line Coupler or a Backbone Coupler.

The connection of non-SELV lines to a TP1 network is not allowed.

There shall be no terminating resistors for matching purposes at the ends of the wires.

[12)] True on the supposition that in the maximum there is only one Bridge between any two devices.

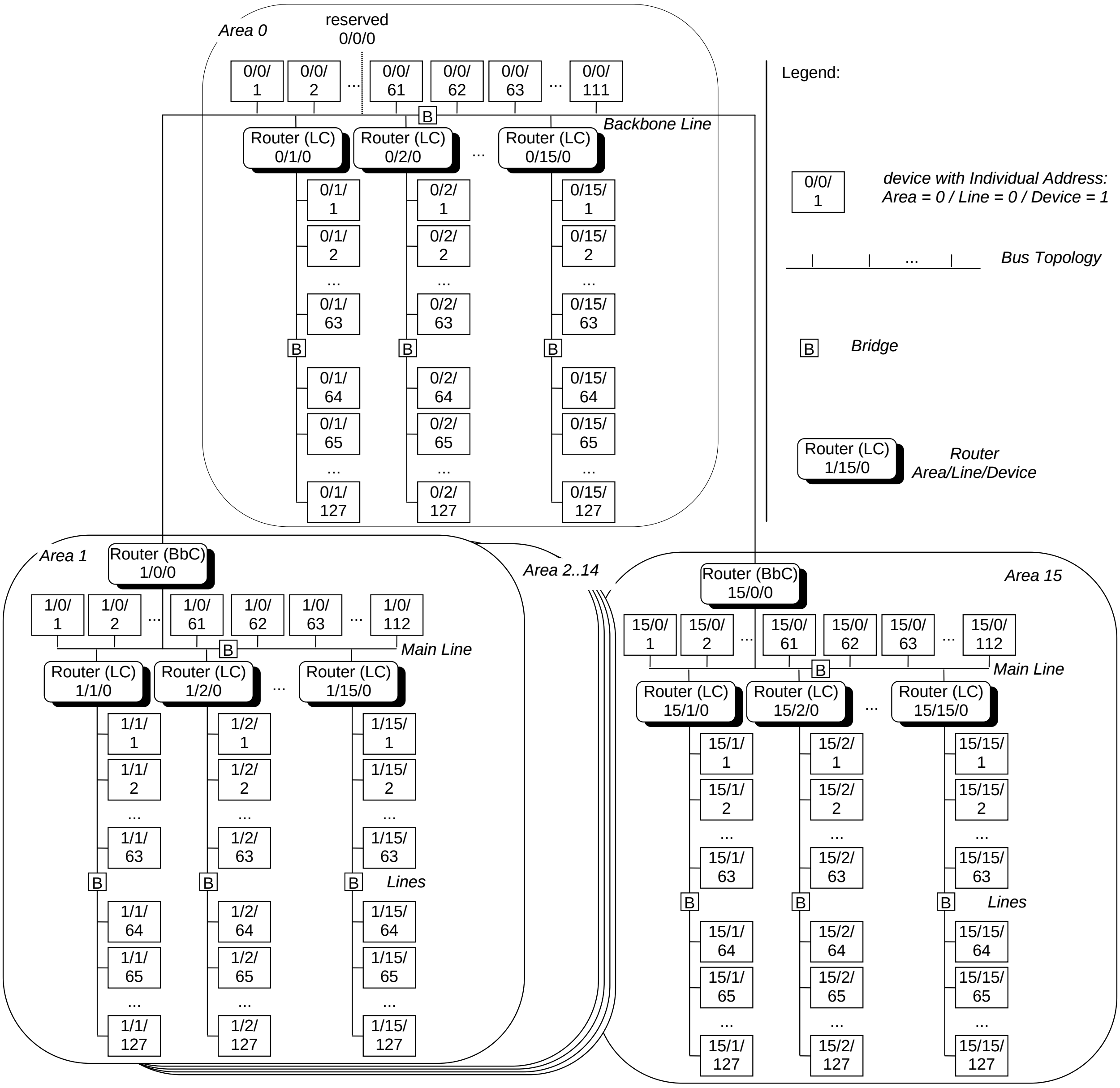


Figure 27 - Network Topology

1.4 Services of the Physical Layer type TP1

At the interface to the Physical Layer user the Physical Layer type TP1 offers the Ph_Data service and the Ph_Reset service.

1.4.1 Ph_Data Service

The Ph_Data service consists of three primitives Ph_Data.req, Ph_Data.ind and Ph_Data.con.

Ph_Data.req(p_class, p_data)

p_class:	start_of_Frame:	transmit first character of a Frame **with** bus free detection at the start bit. For bus free time and delay see clause 2.3 “Medium Access Control”.
	inner_Frame_char:	transmit character after two bit times **without** bus free detection at the start bit
	ack_char:	transmit character 15 bit times after the preceding character received **without** bus free detection at the start bit
	poll_data_char:	transmit character 5 bit times after the preceding character received **without** bus free detection at the start bit
	fill_char:	transmit character 6 bit times after previous character received **with** bus free detection at the start bit
	p_data: octet:	the octet to be converted to a UART character and to be transmitted.

The Ph_Data.req primitive is applied by the Physical Layer user to pass user data consisting of an octet via the p_data parameter to the Physical Layer type TP1. The p_class parameter describes the transmission task to be executed by the Physical Layer type TP1 entity.

See clause 1.5 for a more detailed description of Bus free detection at the start bit.

Ph_Data.con(p_status)

p_status:	OK:	character transmission succeeded
	bus_not_free:	no transmission, another device is transmitting
	collision_detected:	a collision was detected (logical ‘1’ transmitted, but logical ´0´ received)
	transceiver_fault:	transceiver fault detected

The Ph_Data.con primitive passes status information via the parameter p_status back to the Physical Layer user. The value of p_status indicates whether the transmission of the contents of the p_data parameter previously passed to the Physical Layer type TP1 entity via the Ph_Data.req primitive succeeded.

P_status shall be ‘collision_detected’ if a logical ‘1’ was transmitted as one of the UART character bits, but at the same time a logical ‘0’ was read at the Segment by the Physical Layer type TP1 entity. P_status shall be ‘transceiver_fault’ if a logical ‘0’ was transmitted as one of the UART character bits, but at the same time a logical ‘1’ was read at the Segment.

See clause 1.5 for a more detailed description of the conditions for p_status values ‘bus_not_free’, ‘collision_detected’ and ‘transceiver_fault’.

Ph_Data.ind(p_class, p_data)

p_class:	start_of_Frame:	first character of request Frame received. For timing see clause 2.3 "Medium Access Control".
	inner_Frame_char:	character received at 2 bit times after the preceding one
	ack_char:	character received 15 bit times after the preceding one
	poll_data_char:	character received at five or six bit times after the preceding one
	parity_error:	wrong parity bit detected in the character received
	framing_error:	wrong stop bit detected in the character received
	bit_error:	wrong data bit detected in the character. Data bit did not meet the bit decoding rules.
p_data:	octet:	the data octet extracted from the received character

The Ph_Data.ind primitive passes timing information via the parameter p_class and user data via the parameter p_data from the Physical Layer type TP1 entity to the Physical Layer user. See clause 1.5 for more details.

1.4.2 Ph_Reset Service

The Ph_Reset service shall be applied by the user of Physical Layer during start up, in order to synchronize to possibly existing network traffic.

Ph_Reset.req(); start synchronisation activity

Ph_Reset.con(p_status);

p_status:	OK:	a bus free time of 50 bit times was detected
	transceiver_fault:	undefined physical signal detected

The Ph_Reset.con primitive indicates either with value 'OK' of parameter p_status an idle time of 50 bit times or with 'transceiver_fault' a malfunctioning transceiver.

1.5 Behavior of the Physical Layer type TP1 entity

In addition to the rules listed in the description of each physical service (see 1.4) the following rules also apply for the Physical Layer type TP1 entity.

Bus free detection means that immediately before the transmission of the start bit of a character, the Physical Layer type TP1 entity shall check if another Physical Layer type TP1 entity is already transmitting at the same physical Segment.

According to clause 1.4.1 Bus free detection is on for the p_class values 'start_of_Frame', 'inner_Frame_char' and 'fill_char' of the Ph_Data.req primitive. In these cases the Ph_Data.req primitive may result in no transmission and in a Ph_Data.con primitive with p_status = bus_not_free.

On the other hand the p_class values 'ack_char' and 'poll_data_char' will result in the transmission of the start bit and subsequent data bit transmission with bus free detection off. In that case a Ph_Data.con primitive with p_status = bus_not_free cannot occur.

Collision avoidance shall be active during the transmission (i.e. during the execution of the Ph_Data.req primitive) of any character of p_class of value

- start_of_frame, or
- inner_frame_char, or
- poll_data_char, or
- fill_char

If a collision is detected, then the transmitter shall immediately stop its transmission. Collision detection shall be indicated by a Ph_Data.con primitive with p_status = 'collision_detected'. The following Ph_Data.ind primitive (p_class either of value 'start_of_frame' ,'inner_frame_char', 'poll_data_char' or 'fill_char') shall pass the p_data value with the complete octet received to the Physical Layer user.

It is recommended that collision avoidance is active during the transmission (i.e. during the execution of the Ph_Data.req primitive) of any character of p_class of value (see A.4)

- ack_char.

The overview of the above requirements is given in Table 1.

Table 1 – Overview of use of bus free detection and collision avoidance (informative)

p_class	BEFORE transmission bus free detection	DURING transmission collision avoidance
start_of_frame	on	enabled (see A.1)
inner_frame_char	off	enabled
ack_char	off	• (disabled) • enabled (recommended)
poll_data_char	off (see A.2)	enabled (see A.3)
fill_char	on	enabled

2 Data Link Layer type Twisted Pair (DL TP1)

2.1 Introduction

The Data Link Layer described in this clause is called Data Link Layer type Twisted Pair (TP1). Its medium access shall correspond to a CSMA/CA mechanism, Carrier Sense Multiple Access with Collision Avoidance.

2.2 Frame formats

2.2.1 Overview

The Data Link Layer shall have exactly the three Frame formats shown in the subsequent figures. Other Frame formats shall not be received. Each Frame shall be sent as a sequence of characters. The subsequent figures show octets instead of UART characters, i.e. the LPDU, to make it easier to read. The UART character that corresponds to octet 0 shall be sent firstly, the octet with the highest number shall be the last character being sent. The individual bits of an octet shall be sent in ascending order, i.e. the lowest significant bit (bit 1) shall be sent firstly. The different Frame formats shall be differentiated in the Control field.

The Data Link Layer Type Twisted Pair 1 shall support the 3 following Frame formats.

1. L_Data Frame Format
2. L_Poll_Data Frame Format
3. Acknowledgement frame Format

2.2.2 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. It shall include the Frame type flag, the Frame priority and a flag containing the information whether the LPDU is a repeated one, see Figure 28.

Control field

7	6	5	4	3	2	1	0	
Frame type		repeat flag		priority	priority			
FT	0	r	1	p1	p0	0	0	L_Data-Frame
1	1	1	1	0	0	0	0	L_Poll_Data-Frame
x	x	0	0	x	x	0	0	Acknowledgement Frame

FT = 0 : L_Data_Extended Frame
FT = 1 : L_Data_Standard Frame

r = 0 : repeated L_Data-Frame
r = 1 : not repeated L_Data-Frame

p1	p0	
0	0	system priority
1	0	urgent priority
0	1	normal priority
1	1	low priority

Figure 28 - Control field

The Control field shall indicate the type of the request Frame: L_Data_Standard Frame L_Data_Extended Frame, L_Poll_Data request 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 [01] 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, if two devices start transmission simultaneously.

Repeated L_Data Frames shall have the repeat_flag set to zero, non-repeated ones shall have it set to one.

NOTE 2 The Control field encoding '01r0$p_1p_0$00' shall not be used for future extensions of the Data Link Layer Twisted Pair 1 protocol.

2.2.3 L_Data Frame formats

Two L_Data Frame formats shall be available on the TP1 Medium. The usage of the different formats shall depend on the value of the Frame format parameter to the Data Link Layer (see [01]). 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.

2.2.4 L_Data_Standard Frame

2.2.4.1 Frame format

The structure of the variable length L_Data_Standard Frame shall comply with Figure 29 below.

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

Figure 29 - Frame fields with standard fieldname abbreviations

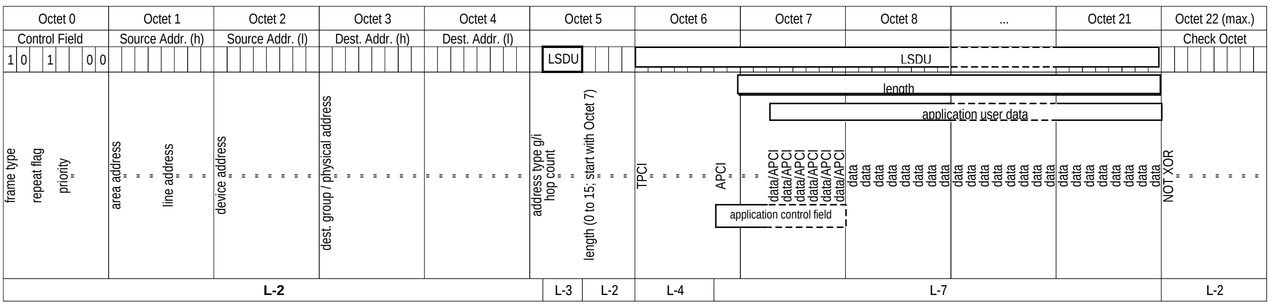


Figure 30 – Format 1s, L_Data_Standard Frame format

2.2.4.2 Control field (CTRL)

The common encoding of the Control field is specified in clause 2.2.2 “Control field” above.

2.2.4.3 Source Address (SA)

The octets one and two of the L_Data_Standard Frame shall be the high and lower octet of the Source Address. This shall be the Individual Address of the device that causes the transmission of the Frame.

2.2.4.4 Destination Address and Address Type (AT)

The Destination Address (octets three and four) shall define the devices that shall receive the Frame. For an L_Data_Standard Frame, the Destination Address can be either an Individual Address (AT = 0) or a Group Address (AT = 1), depending on the Destination Address Type (AT) in octet five.

2.2.4.5 Length

The L_Data_Standard Frame shall have a variable length. The length information shall indicate the number of characters (0…14) transported by the L_Data_Standard Frame starting with octet 7. This means that a L_Data_Standard request Frame with length 0 shall end after the sixth octet.

2.2.4.6 Check octet

The last octet of the L_Data_Standard Frame shall be the check octet (Figure 31) that shall make an odd parity over the set of corresponding bits belonging to the preceding octets of the Frame. This represents a logical NOT XOR function (F in Figure 31) over the individual bits of the preceding octets of the Frame.

Bit	7	6	5	4	3	2	1	0
Octet 0	$b_{0,7}$	$b_{0,6}$	$b_{0,5}$	$b_{0,4}$	$b_{0,3}$	$b_{0,2}$	$b_{0,1}$	$b_{0,0}$
Octet 1	$b_{1,7}$	$b_{1,6}$	$b_{1,5}$	$b_{1,4}$	$b_{1,3}$	$b_{1,2}$	$b_{1,1}$	$b_{1,0}$
Octet 2	$b_{2,7}$	$b_{2,6}$	$b_{2,5}$	$b_{2,4}$	$b_{2,3}$	$b_{2,2}$	$b_{2,1}$	$b_{2,0}$
…								
Octet N	$b_{N,7}$	$b_{N,6}$	$b_{N,5}$	$b_{N,4}$	$b_{N,3}$	$b_{N,2}$	$b_{N,1}$	$b_{N,0}$
F	1	1	1	1	1	1	1	1
Check octet	p_7	p_6	p_5	p_4	p_3	p_2	p_1	p_0

Figure 31 - Check octet

2.2.5 L_Data_Extended Frame

2.2.5.1 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-HEE 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 32 below.

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

Figure 32 - Frame fields with standard fieldname abbreviations

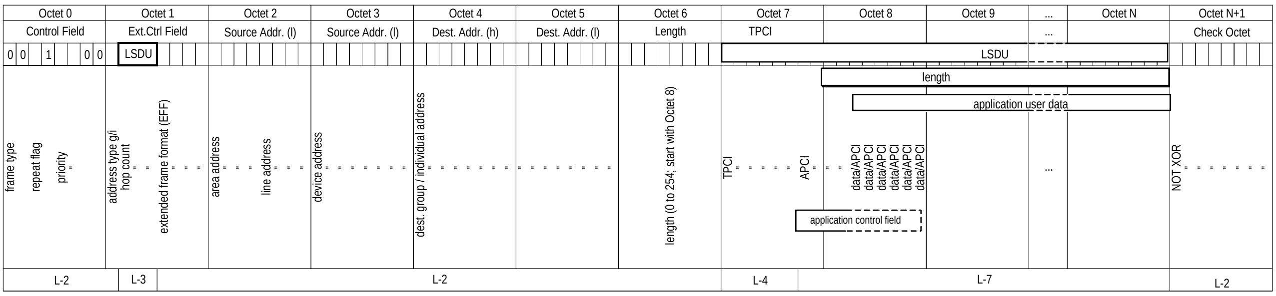


Figure 33 – Format 1e, L_Data_Extended Frame format

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

2.2.5.2 Control field (CTRL)

The common encoding of the Control field is specified in clause 2.2.2 “Control field” above.

2.2.5.3 Extended Control field (CTRLE)

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

The CTRLE 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.

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-HEE extended address type
								All other codes are reserved for future use

Figure 34 – Extended Control field

2.2.5.4 Source Address (SA)

The octets one and two of the 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 transmission of the Frame.

2.2.5.5 Destination Address (DA)

In L_Data_Extended Frame the type of the Destination Address shall, besides the Address Type (g/i flag), also depend 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 L_Data_Standard format. With EFF ≠ 0000b special address formats and tables shall be used.

2.2.5.6 Length (LG)

The L_Data_Extended Frame shall have a variable length. The length information shall indicate the number of characters (0 to 254, 255 = escape-code) that shall be transported by the L_Data_Extended Frame starting after the TPCI octet. 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-bit in the Control field and the length field, as specified in [01].

2.2.6 L_Poll_Data Frame

2.2.6.1 Frame format

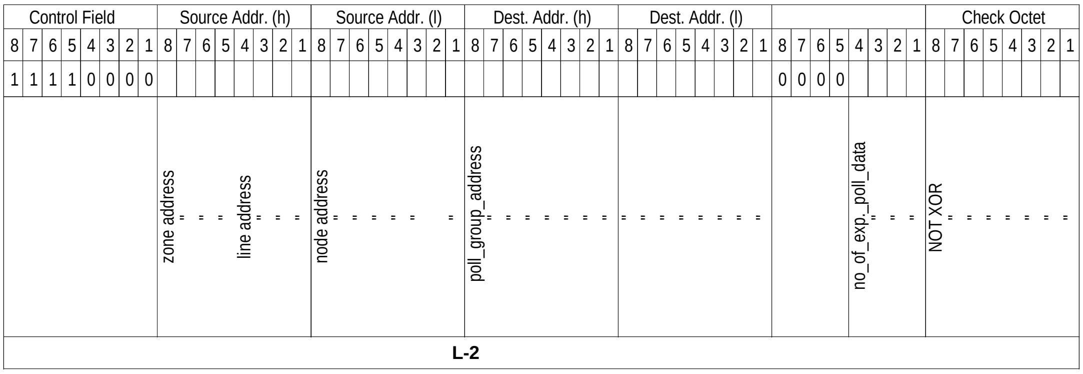


Figure 35 - Format 3, L_Poll_Data Request Frame Format

The Poll_Data request Frame is shown in Figure 31. The device that transmits the Poll_Data Frame is called Poll_Data master.

The Poll_Data response Frame is shown in Figure 36, consisting of a variable number of Poll_Data or FILL (FEh) characters. In Figure 36 each gray box symbolizes a character. There is five bit times idle time before a Poll_Data character is transmitted by a slave and 6 bit times idle time before a FILL character is transmitted by the master. A Poll_Data character transmitter is called Poll Data Slave. Each Poll Data Slave shall know his Poll Group and his response slot number.

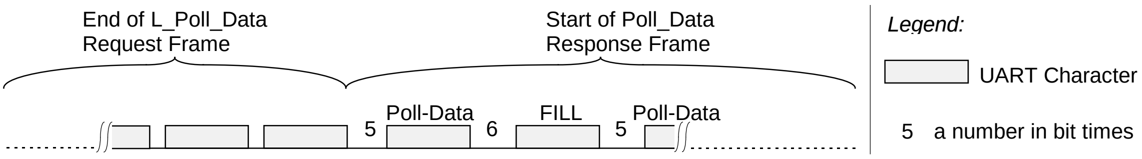


Figure 36 - Format 4, L_Poll_Data Response Frame Format

2.2.6.2 Source Address

The octets one and two of a request Frame are the high and lower octet of the Source Address. This shall be the Individual Address of the device that caused the transmission of the Frame.

2.2.6.3 Destination Address / Poll Group Address

The Destination Address (octets three and four) shall define the device(s) that shall receive the Frame. For L_Poll_Data request Frames the Destination Address shall always be a Poll Group Address. The Poll Group Address shall be unique in the physical Segment in which the Poll_Data request Frame is transmitted. The Poll Group Address addresses up to 15 Poll Data Slaves (slot 0 to slot 14) belonging to the same Poll Group.

2.2.6.4 Number of Expected Poll Data

The Number of Expected Poll Data shall be contained in the Poll_Data request Frame. It shall be a number from 1 to 15 and shall tell how many Poll Data characters are expected in the subsequent Poll_Data response Frame.

2.2.6.5 Check Octet

The last octet of the poll data request Frame shall be the check octet (Figure 31) that shall make an odd parity over the set of corresponding bits belonging to the preceding Poll_Data request Frame sent by the Poll_Data master. The Poll_Data or FILL character in the Poll_Data response Frame shall not be secured by the Check Octet. This represents a logical NOT XOR function (F in Figure 31) over the individual bits of the preceding octets of the Poll_Data request Frame.

2.2.6.6 Poll Data Slaves and Poll Data Octet

The poll data octet shall represent the information that shall be transmitted by the Poll Data Slave in its response slot (slot 0 to slot 14) in case its Poll Group is contained in a Poll_Data request Frame. The Data Link Layer user may choose any value of {00h to FFh} \ {FEh} for the poll data octet. FEh is reserved by the Data Link Layer protocol.

2.2.7 Acknowledge Frame

The short acknowledgment Frame format shall consist of 15 bit times idle time followed by a single character that shall be used to acknowledge an L_Data.req Frame (see also Figure 38). The following figure shows the corresponding codes of the short acknowledgment.

Octet 0								
Short acknwoledgement								
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
1	1	0	0	0	0	0	0	BUSY
0	0	0	0	0	0	0	0	NAK + BUSY [13)]

Figure 37 - Format 2, Short Acknowledgment Frame Format

2.3 Medium Access Control

2.3.1 Definition

The Twisted Pair 1 medium access control shall be CSMA/CA, Carrier Sense Multiple Access with Collision Avoidance. CSMA/CA means that collisions shall be resolved within a bit time. CSMA/CA relies on the bit-wise collision avoidance mechanism described in clause 1.4.1 “Ph_Data Service” above.

Figure 38 shows the character timings during the Data Link Layer message cycle. Each gray box symbolizes a UART character.

Before a device may start the transmission of a request Frame it has to wait for at least 50 bit times line idle since the last bit of the preceding Data Link Layer message cycle. A Data Link Layer message cycle shall always consist of a Data Link Layer request Frame and the subsequent Data Link Layer acknowledgment - or a subsequent Data Link Layer response Frame.

[13)] This coding is received, when BUSY an NAK are sent simultaneously without collision mechanism. This coding shall be handled as BUSY.

It may occur that devices start transmitting at the same time. Due to the CSMA/CA algorithm, which avoids Frames being disturbed by a collision, a transmitting device shall check for each individual bit, if the bit value that has been sent equals to the bit value that is received at the same time. If the Physical Layer indicates line busy or a collision, then the transmission of a Frame with higher priority sent by another device is in progress. To avoid further collisions, transmission shall be stopped immediately within that bit time. All Frame parts that have already been sent shall be interpreted as being part of the higher priority Frame of which the transmission is in progress.

The following diagram shows the typical timing.

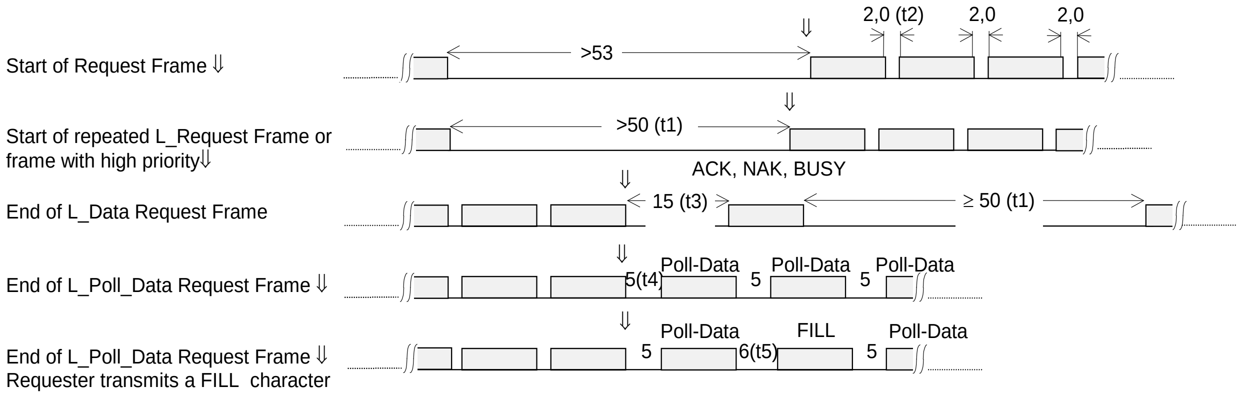


Figure 38 - Character timing

Parameter	time	minimum	typical	maximum
• p_class = start_of_frame: minimal time between the end of a possible preceding telegram and the start-bit of the telegram starting with the transmission of this character	t_{ts}			
• priority = low or normal, no repetition		(53 bit times) - 50 µs	53 bit times	- [14)]
• priority = urgent or system • repetition		(50 bit times) - 50 µs	50 bit times	-
• p_class = inner_frame_char: time from start-bit to start-bit of consecutive character	t_{cp}	(13 bit times) – 2 µs	13 bit times	(13 bit times) + 5 µs (see A.5)
• p_class = ack_char: time between the end of the last character of the preceding telegram and the start-bit of the acknowledge character	t_{as}	(15 bit times) – 5 µs	15 bit times	(15 bit times) + 20 µs
• p_class = poll_data_char: time from the end of the stop bit of the preceding character to the start bit of the polling character	t_{pcs1}	(5 bit times) – 30 µs	5 bit times	(5 bit times) + 30 µs
• p_class = fill_char: time from the end of the stop bit of the preceding character to the start bit of the polling fill character	t_{pcs2}	(6 bit times) – 30 µs	6 bit times	(6 bit times) + 30 µs

Figure 39 - Requirements for Character coding

[14)] There is no maximum time distance between telegrams.

Parameter	time	minimum	typical	maximum
• p_class = start_of_frame: minimal time between the end of a possible preceding telegram and the start-bit of the telegram starting with the transmission of this character	t_{ts}	(40 bit times)	50 bit times	-
• p_class = inner_frame_char: time from start-bit to start-bit of consecutive character	t_{cp}	(13 bit times) – 30 µs	13 bit times	(13 bit times) + 30 µs
• p_class = ack_char: time between the end of the last character of the prece-ding telegram and the start-bit of the acknowledge character	t_{as}	(15 bit times) – 5 µs (see A.6)	15 bit times	(15 bit times) + 30 µs (see A.7)
Time before polling character • p_class = poll_data_char: time from the end of the stop bit of the preceding character to the start bit of the polling character • _class = fill_char: time from the end of the stop bit of the preceding character to the start bit of the polling fill character	t_{pcs1} t_{pcs2}	(5 bit times) – 50 µs		(6 bit times) + 50 µs

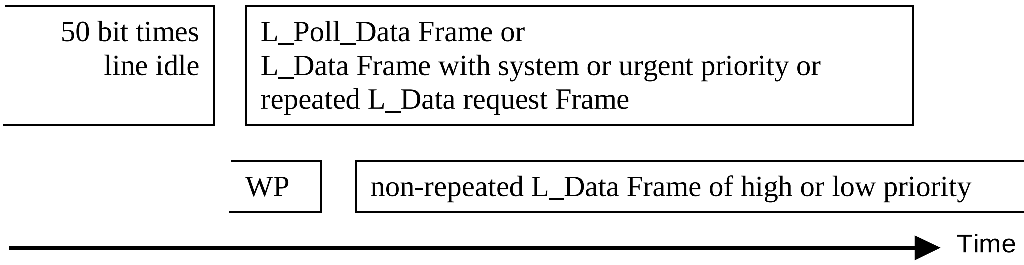
Figure 40 - Requirements for Character decoding

Due to the fact that a logical ´0´ value is dominant, Frames having more leading zeros obtain a higher priority versus Frames with less leading zeros, if their transmission starts at the same time. CSMA/CA means that a Frame with higher priority will not be disturbed by transmission attempts of lower priority.

After detection that the bus is not free and after a collision, the device shall wait until the end of the message cycle in progress and shall make another attempt to transmit the data link request PDU after 50 bit times or more line idle time.

2.3.2 Overview: priority operation algorithm of the Medium Access Control

Figure 28 shows the priority parameter and the repeat flag contained in the Control field of the L_Data request Frame. The priority parameter has an impact on the priority of a request Frame especially in Networks with a lot of traffic. System priority is reserved for the Data Link Layer. Urgent, normal and low priority may be chosen by the Data Link Layer user; see the Group Objects and the objects described in [02] for more details how to do that. Semantic definitions about the occasions when urgent, normal and low priorities should be used are left to a profile.



WP = 3 bit times (waiting period)

Figure 41 - Priority Operation

The repeat flag is reserved for the Data Link Layer.

Repeated and non-repeated L_Data request Frames having system or urgent priority and repeated L_Data request Frames with normal and low priority may be sent immediately after 50 bit times line idle time. Non-repeated L_Data request Frames of normal and low priority shall wait additionally for at least three further bit times.

L_Poll_Data request Frames exist only in a non-repeated version.

2.3.3 Priority sequence

If two Data Link Layer instances detect 50 bit-times line idle at exactly the same time then in case of colliding data link request Frames the following priority sequence holds true (in descending order of priority):

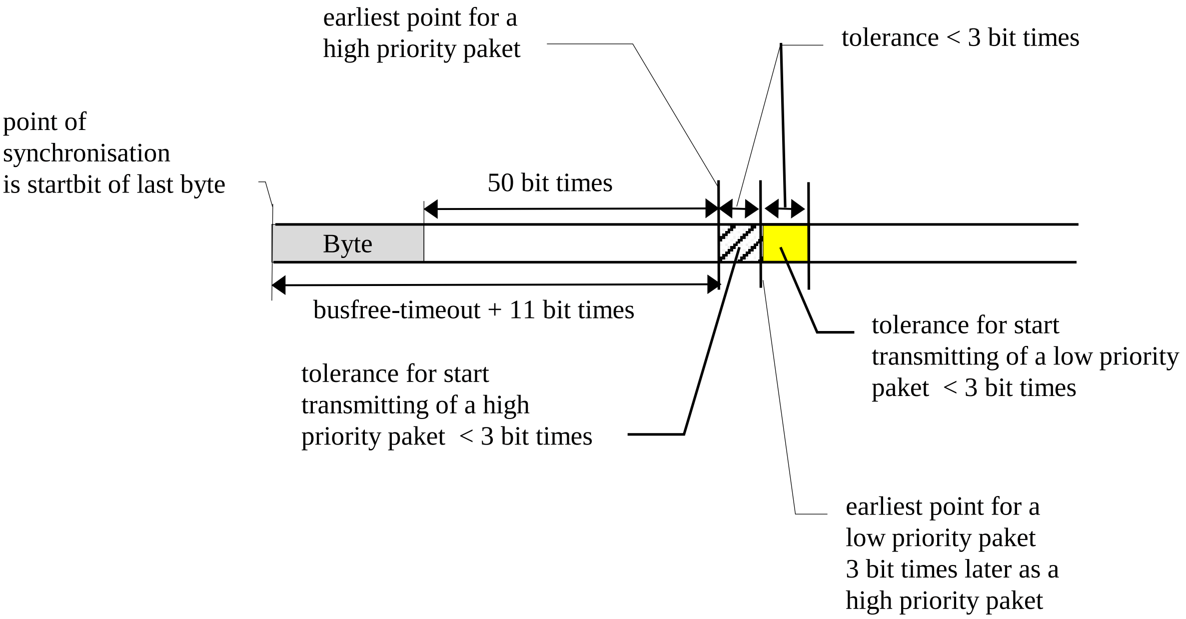
Control field	data link Frame type	priority	repeat flag	priority available to Data Link Layer user
1001 0000	L_DATA	system priority	repeated	no
1011 0000	L_DATA	system priority	not rep.	no
1111 0000	L_POLLDATA	system priority	not rep.	no
1001 1000	L_DATA	urgent priority	repeated	yes
1011 1000	L_DATA	urgent priority	not rep.	yes
1001 0100	L_DATA	normal priority	repeated	yes
1011 0100	L_DATA	normal priority	not rep.	yes
1001 1100	L_DATA	low priority	repeated	yes
1011 1100	L_DATA	low priority	not rep.	yes

Figure 42 - Priority Sequence, in Descending Order of Importance

2.3.4 Additional requirement: guarantee of access fairness

The Twisted Pair 1 medium access control algorithm is designed to reduce the number of Frame collisions sent by partner devices connected to the same line. Therefore the overall priority sequence behaviour described above shall be readjusted in that way that from system point of view no burst behaviour shall occur exactly after the end of the 50 bit times line idle time. Therefore in the implementation provisions shall be made to prevent from devices accessing the medium always exactly after 50 resp. 53 bit times. The main intention shall be laid upon fairness between all devices accessing the medium: an equal distribution of medium accesses shall be guaranteed.

NOTE 3 Provided that there is no configuration error in the Network (i.e. the Individual Addresses shall be unique), once the Source Address of a data link request Frame is transmitted all collisions shall be resolved.



2.4 Data Link Layer services

2.4.1 Data Link Layer operation modes and Data Link Layer acknowledge

The L_Data service shall be an acknowledged datagram service.

If the local user of Data Link Layer prepares an LSDU for the remote user it shall apply the L_Data.req primitive to pass the LSDU to the local Data Link Layer.

The local Data Link Layer shall accept the service request and shall try to send the LSDU to the remote Data Link Layer with Frame format 1. The Destination Address may be an Individual Address or a Group Address (multicast or broadcast).

Error and exception handling

- If the length of the LSDU requires an L_Data-Frame with value of the field Length ≥ 255 characters, then no L_Data-Frame shall be transmitted on the bus; the L_Data.req shall be confirmed by an L_Data.con with l_status = not_ok.

If the remote Data Link Layer instance receives an L_Data-Frame, it shall check the Frame correctness. An L_Data-Frame shall be considered correct if all of the following requirements are fulfilled.

1. The L_Data-Frame is correct according the general KNX TP1 Frame check conditions as specified in clause 2.5.3 Checking for correct request Frames.
2. The length of the Frame is between 8 and 23 characters for an L_Data_Standard-Frame or between 9 and 263 for an L_Data_Extended-Frame. (The character counting includes the Check octet.)

There shall at Data Link Layer level be no further checks concerning the Frame length.

EXAMPLE 1 For acknowledging the Frame, it shall not be checked whether the value of the field Length matches the real Frame length.

EXAMPLE 2 For acknowledging the Frame, it shall not be checked whether the Frame length exceeds the devices reception capabilities.

If the received Frame is not correct then it shall not be passed to the Data Link Layer user.

The remote Data Link Layer shall check whether it is addressed or not. The remote Data Link Layer is addressed in any of the following cases.

1. The Destination Address is an Individual Address
   1.1 that corresponds to the own Individual Address of the remote Data Link Layer, or
   1.2 that is topologically located on the other side of a Coupler, or
   1.3 that is one of the Tunnelling Individual Addresses of a KNXnet/IP Tunnelling Server
2. The Destination Address is
   - a Standard Mode Group Address or
   - an LTE-HEE Group Address,

   and the remote Data Link Layer supports the non-selective Data Link Layer acknowledge.
3. The Destination Address
   3.1 is a Standard Mode Group Address that is contained in the Group Address Table of the receiver or
   3.2 is an LTE-HEE Group Address addressing an Area that is assigned to the remote Data Link Layer.
4. The Destination Address is the broadcast address.

If the remote Data Link Layer is addressed then it shall confirm the Frame with an acknowledge-Frame.

- If the request Frame received is correct, the remote Data Link Layer shall send an ACK-Frame.
- If the request Frame received is correct but the remote Data Link Layer does not have resources to process it, the remote Data Link Layer shall react as follows:
  - If the Destination Address in the received Frame is a Group Address or the Broadcast Address or an Individual Address that is identical to the Individual Address of the device and if the device will again be able to process Frames that starts 100 ms after the reception of the original Frame [16)], the remote Data Link Layer may send a BUSY character.
  - If the Destination Address in the received Frame is a Group Address or the Broadcast Address or an Individual Address that is identical to the Individual Address of the device and if the device will not be able to process Frames that starts 100 ms after the reception of the original Frame, the remote Data Link Layer shall not send a BUSY character.
- If the received Frame is correct but exceeds that reception capabilities of the remote Data Link Layer (buffer size) then the Frame may be acknowledged by an ACK-Frame or may not be acknowledged (recommended); the Frame shall not be acknowledged by a NAK-Frame or a BUSY-Frame; the Frame shall not be passed to the Data Link Layer user.
- If the received Frame is not correct (see above) then the remote Data Link Layer shall send NAK-acknowledge.

[16)] This time has been chosen so that the device will be able to process the third repetition of the Frame.

If the remote Data Link Layer is not addressed then it shall ignore the received Frame (independently of whether the Frame is correct or not): it shall neither acknowledge (ACK, NACK or BUSY) the Frame nor pass it to the remote Data Link Layer user.

Furthermore, in case of a correctly received Frame, the remote Data Link Layer shall send an L_Data.ind primitive to the Data Link Layer user only if the Frame received is not a repetition of a directly preceding correctly received L_Data-Frame and if one of the following conditions applies:

- if the Destination Address is an Individual Address and if it corresponds to the own Individual Address of the receiver, or
- if the Destination Address is a Standard Mode Group Address and if the acceptance condition according to the respective Group Address Table Realisation Type is fulfilled, or is an LTE-HEE Group Address addressing an Area that is assigned to the device or
- if the Destination Address is the Broadcast Address.

In any other case, the received Frame shall be discarded.

If the remote Data Link Layer accepts the received Frame, it shall map the repeat flag of the Control field to the service parameter Repetition of the L_Data.ind.

The local Data Link Layer shall pass an L_Data.con primitive to the local user that shall indicate either a correct or erroneous data transfer.

Prior to passing the confirmation to the local user, the local Data Link Layer shall need an acknowledgment from the remote Data Link Layer (Frame format 2).

- If the acknowledgment is a positive acknowledgment (ACK), the local Data Link Layer shall pass an L_Data.con with l_status = OK to the local user.
- If the acknowledgment is BUSY, and if the L_Data.req service parameter repetition requires L2-repetition then the local Data Link Layer shall try to repeat after at least 150 bit times wait time (see A.8) for up to busy_retry times. If BUSY is received for more than busy_retry times, the local Data Link Layer shall pass an L_Data.con with l_status = not_ok to the local user.
- In all other cases, this is **if**
  - the acknowledgment is NAK or
  - the the acknowledgement is invalid or corrupted, or
  - after an acknowledgement time-out of 15 bit times + 30 µs (30 µs max. positive tolerance for p_class = ack_char, time t_{as}, see A.7) no Acknowledge is received,

  then local Data Link Layer shall repeat after 50 bit times up to nak_retry times. If for more than nak_retry times either a NAK or a corrupted acknowledgment is received or an acknowledge timeout occurs, the local Data Link Layer shall pass an L_Data.con with l_status = not_ok to the local user.

The parameters nak_retry and busy_retry shall be parameters of Data Link Layer. In the maximum, the same request LPDU is transmitted (nak_retry + busy_retry + 1) times, before the Data Link Layer shall stop retransmission.

L_Data.req(repetition, destination_address, AT, priority, lsdu)

repetition:	this shall specify whether the local Data Link Layer shall repeat the Frame on the medium in case of transmission errors (NAK, BUSY or acknowledge time-out)
destination_address:	either an Individual Address or a group address
AT:	destination address type indicates whether destination_address is an individual or a group address
priority:	system, urgent, normal or low priority
lsdu:	this is the user data to be transferred by Data Link Layer

L_Data.con(repetition, destination_address, AT, priority, lsdu, l_status)

repetition:		don’t care. This flag has the same value as in the L_Data.req
destination_address:		either an Individual Address or a group address
AT:		destination address type indicates whether destination_address is an individual or a group address
priority:		system, urgent, normal or low priority
lsdu:		this is the user data to be transferred by Data Link Layer
l_status:	ok:	request Frame sent successfully
	not_ok:	transmission of the request Frame didn’t succeed

L_Data.ind(repetition, source_address, destination_address, AT, priority, lsdu)

repetition:	This shall indicate that the Frame is a repeated Frame.
source_address:	Individual Address of the device that requested the L_Data service
destination_address:	the Individual Address of this device or a group address of this device
AT:	destination address type indicates whether destination_address is a physical or a group address
priority:	system, urgent, normal or low priority
lsdu:	this is the user data that has been transferred by Data Link Layer

NOTE 4 For the Transport Layer a negative L_DATA.con means either a connection-oriented or a connection-less message. In case of an untransmitted connectionless message it is left to the user application how to handle that. In case of an untransmitted communication-oriented message the Transport Layer attempts further three times to transmit the corresponding T_DATA request PDU. A fourth negative L_DATA.con leads to an abort of the Transport Layer connection.

2.4.2 L_Poll_Data service and protocol

The L_Poll_Data service is a confirmed multicast service. The local user of Data Link Layer is applying the L_Poll_Data.req primitive to request data from one or more remote users. The local Data Link Layer accepts the service request and tries to send the L_Poll_Data.req to the remote Data Link Layer with Frame format 3. The destination address is always a Poll Group Address. The Poll Group Address is a parameter of Data Link Layer.

L_Poll_Data request Frames that are not correctly received (see 2.5.3) shall be discarded.

After receiving a correct L_Poll_Data request Frame with a poll_group_address equal to its own Poll Group Address, the remote Data Link Layer responds with a single Poll_Data character, see 2.2, Frame format 4. The remote Data Link Layer gets the Poll_Data octet from its user with the L_Poll_Update.req primitive. The Poll_Data character shall be transmitted in the response slot associated with this device. The device’s response slot is a defined time slot in which the Poll Data Slave device shall transmit the Poll_Data character. The duration of a response slot is an idle time of 5 times followed by a single UART character. If e.g. a device has the third response slot then the device has to wait for two Poll_Data characters transmitted by other devices, until the device is transmitting its Poll_Data character in the third response slot (see also Figure 38). The response slot number is a parameter of Data Link Layer.

A device shall not respond if its response slot number is larger than the number of expected poll data (no_of_expected_poll_data) in the request Frame.

The local Data Link Layer expects a number of Poll_Data characters from the Poll Group. If an expected Poll_Data character has not started after five bit times the local Data Link Layer is sending a FILL (FEh) after six bit times. The remote Data Link Layer can therefore still count Poll_Data characters even if a member of the Poll Group doesn’t respond.

The local Data Link Layer passes a L_Poll_Data.con primitive to the local user that contains the received Poll_Data and FILL octets or an information that the service failed.

The L_Poll_Data Service can only be applied between devices on a single physical Segment. The number of expected Poll_Data characters is limited to 16.

L_Poll_Data.req(destination, no_of_expected_poll_data)

destination: a Poll Group Address

no_of_expected_poll_data: number of expected poll data cycles

L_Poll_Data.con(l_status, poll_data_sequence)

l_status: OK; valid poll_data_sequence

not_ok; invalid poll_data_sequence, i.e. collision occurred during transmission of a FILL, or at least one Poll_Data not correct

poll_data_sequence: sequence of Poll_Data octets and FILL octets

L_Poll_Update.req(Poll_Data)

Poll_Data: The value of the Poll_Data octet to be transmitted in the L_Poll_Data_Response Frame.

L_Poll_Update.con() Indicates that the L_Poll_Update.req has been accepted by the local Data Link Layer.

2.4.3 L_Busmon service

The L_Busmon service is a local data link service available only in data link bus monitor mode. It consists of the L_Busmon.ind primitive that transfers each received Frame from the local Data Link Layer to the local Data Link Layer user.

L_Busmon.ind(l_status, time_stamp, lpdu)

l_status: information whether a Frame error, bit error or a parity error was detected in the received Frame. Additional information about the number of already received Frames may also be contained.

time_stamp: timing information, when the start bit of the Frame was received

lpdu: all octets of the received Frame

2.4.4 L_Service_Information service

The L_Service_Information service is a local data link service available in data link normal mode. It consists of the L_Service_Information.ind primitive.

L_Service_Information.ind() a Frame was received which contained the Individual Address of the local Data Link Layer as Source Address.

2.5 Data Link Layer protocol

2.5.1 General

The Data Link Layer's task is to offer a reliable datagram service between devices at the same line. This means that corrupted Frames shall be retransmitted (i.e. repeated) for a sensible number of times, that only information of correctly received Frames is presented to the Data Link Layer user and that this information is not presented several times to the data link user (duplication prevention).

Clauses 2.2.7, 1.1.1, 2.4.2 and 2.6 contain certain aspects of the Data Link Layer protocol. The following subclauses explain additional protocol requirements to be fulfilled by each Data Link Layer protocol instance.

2.5.2 Assemble and 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 [01] 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 [01] and put into EFF field in CTRLE.
- The length information shall be calculated from the parameter octet_count and put into LG field on octet 6.
- The parameters priority and repeat flag shall be put into CTRL field.
- The parameters Destination Address and LSDU shall be inserted in the Frame.
- The Address Type AT shall be put into CTRLE field (group address flag g/i).
- The Network Layer information shall be put into CTRLE field.
- The Source Address and Check octet shall be inserted.

When receiving a PDU, the Data Link Layer shall do the reverse operation.

- It shall disassemble the Frame into parameters to be transmitted in an L_Data.ind Frame.
- It shall regenerate the Address Type from the value of the CTRLE.g/i flag.
- It shall generate the octet_count parameter from the value of CTRL and LG fields.

2.5.3 Checking for correct request Frames

As specified in clause 1.1.1 the Data Link Layer receiving a request Frame shall check whether the Frame is correct. A Frame is correct if:

– every UART character has a correct start/stop bit (otherwise: framing error) and parity bit (otherwise: parity error), and
– every bit of a UART character has a correct signal timing (otherwise: bit error), and
– the check octet has the correct value, and
– the Control field has a correct value.

2.5.4 Consequences of priority operation and fairness for duplication prevention

Figure 42 shows that a repeated low priority L_Data request Frame is less prior as e.g. a non-repeated urgent priority L_Data request, provided that Data Link Layer line idle detection occurs at the same time.

This implies that if an acknowledge to a non-repeated low or normal priority request Frame is corrupted and another device at the same physical segment at the same time has to transmit an urgent priority L_Data request to the acknowledging device, then the acknowledging device might lose the knowledge, that the subsequent repeated low or normal priority Frame is a duplicate.

Informal rules to remedy that:

- Reduce noise at the medium as much as necessary to avoid corrupted acknowledgements.
- Otherwise: Do not use many urgent priority Frames and
- Be aware during internal or external user application programming of the possibility that in rare cases a duplicated L_Data service may occur.

2.6 State machine of Data Link Layer

After power on, a device doesn't receive or transmit Frames. The Data Link Layer state machine (Figure 43) is using the Ph_Reset to synchronize with the start of request Frames of a possibly existing network. With the positive confirmation Ph_Reset.con(+) the Data Link Layer state machine is in the idle state where Data Link Layer shall work as described in the clauses above, i.e. receive Frames and transmit Frames. However if the Physical Layer indicates a transceiver error either with a Ph_Reset.con(-) or with a Ph_Data.con(-), the Data Link Layer shall perform the transition into the Off_Bus state, where no Frames shall be transmitted any more. Only a power on can make the Data Link Layer state machine leave the Off_Bus state. In Off_Bus state every data link request shall be negatively confirmed. Additionally the transmitter shall be switched off.

The Data Link Layer shall store in non-volatile memory when a transition to Off_Bus state did occur. The location for this information shall be the 'stuck flag', see Volume Three, Part One, Layer-8. The stuck flag may be reset by a configuration tool.

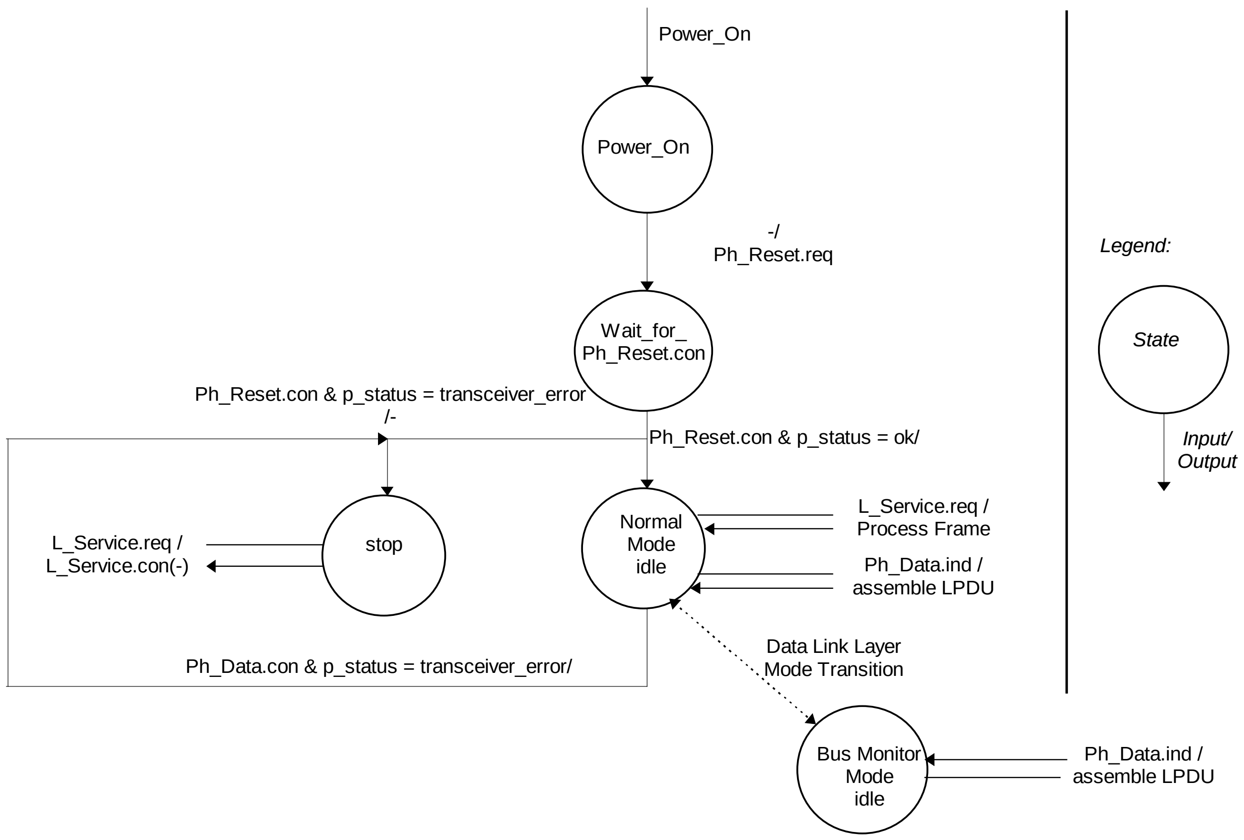


Figure 43 - State Machine of Data Link Layer

2.7 Parameters of Data Link Layer

The following parameters influence the behaviour of Data Link Layer and are required inside Data Link Layer in order to operate correctly:

Individual Address	unique Individual Address of this device
address table	address table with the group address(es) of this device
nak_retry	defines the number of retries in case of a NAK response or a acknowledgment timeout
busy_retry	defines the number of retries in case of a BUSY response
Poll Group Address	the Poll Group Address of this device
response slot number	the response slot number of this device
Data Link Layer mode	either the normal or the bus monitor mode of the Data Link Layer.

2.8 Reflections on the system behavior in case of L_Poll_Data configuration faults

The following L_Poll_Data misconfigurations potentially can be done:

- *Two L_Poll_Data masters belong to the same polling group:*

  Misconfiguration remains hidden unless someone at the bus monitor detects that the same polling group is used in two L_Poll_Data service requests with different Source Addresses.

- *Two Poll Data Slaves of the same polling group have the same Poll_Data response slot number:*

  In case both slaves transmit the same Poll_Data character value nothing irregular happens. If the values differ, the Poll_Data response with an earlier dominant bit will force collision avoidance at the other Poll Data Slave, so that the latter Poll Data Slave will not be able to transmit its response. Indirectly this kind of misconfiguration is detectable because at another slot an expected L_Poll_Data character will never appear.

- *Poll Data Slave illegally transmits a FILL character:*

  At the master side this will be interpreted as a missing Poll Data Slave and is therefore detectable easily.

2.9 The Data Link Layer of a Bridge

A bridge doesn’t need an Individual Address. An Individual Address of a bridge may be used to set manufacturer specific parameters in the bridge.

A bridge has a Data Link Layer that responds to all L_Data request Frames independent from the value of the destination address and transmits the L_Data request to the other side. All other Data Link Layer services are ignored.

2.10 The Data Link Layer of a Router

A router has a Data Link Layer that responds to a L_Data request Frame if the value of the destination address

- is listed in the routing_table
- or if the destination address is an Individual Address that indicates that the destination is on the other side of the router
- or is equal to the Individual Address of the router.

In these cases, the L_Data.ind is indicated to the Network Layer. All other Data Link Layer services are ignored.

A Router may send a Data Link Layer acknowledgement Frame to Standard Mode Group Address Frames and/or LTE-HEE Group Address Frames if the Router supports non-selective Data Link Layer acknowledge. In case the Router supports non-selective Data Link Layer acknowledge the Router sends a Data Link Layer acknowledge regardless of whether the Group Address is in the Filter Table or not.

2.11 Externally accessible Busmonitor and Data Link Layer interface

The Data Link Layer services can be made available to an external user application. See [03] clause "Bus Monitor EMI" for the L_Busmon external message format, clause "Data Link Layer EMI" for the normal mode Data Link Layer external message formats and clause "Layer Access Management" how to switch between bus monitor and Data Link Layer mode.

Annex A
TP1 Specification argumentation
(informative)

A.1

This is a consequence of the general requirement in clause 1.5 of the specifications: "During transmission (i.e. during Ph_Data.req primitive execution) collision detection shall never be disabled.

A.2

This is in the specification of poll_data_char in clause 1.4.1.

A.3

If two slaves were assigned the same time polling slot, then there will still be collision avoidance.

A.4

Implementations exist that do not have collision avoidance during the transmission of the ack_char class. It is recommended however to have collision avoidance active also for this p_class as well.

A.5

This allows with these tolerances that the collision avoidance still works within the first 4 characters (EFF-Frame) with max. distance of 700 m and current decoding tolerances: 30 µs / 4 (average spreading of tolerances) = 7,5 µs ➔ 5 µs with a reserve of 2 µs.

A.6

All senders stick to the most early transmission tolerance of -5 µs. There are no senders that send the acknowledge Frame more early. Also, any small transmission time will cause additional delays (signalling speed), so it is meaningful to have the decoding tolerance the same as the coding tolerance.

It is allowed to have a negative decoding tolerance larger than -5 µs, to also accept acknowledge Frames that start even more than 5 µs too early, but this is not required.

A.7

If a sender and a receiver are separated by 700 m and the acknowledge character sent by the receiver is sent with the maximal delay of 20 µs, it will at the sender (on its bus connection) be seen with a delay of 2 x 3,5 µs + 20 µs = 27 µs after it has completed its own initial transmission.
(3,5 µs = 700 m maximal distance between any two devices /2 x 10^8 ms^{-1} signalling speed on copper wire. This is shown in Figure 44:

1. The original telegram takes 3,5 µs from sender to receiver.
2. The receiver takes the full maximal allowed 20 µs to start emitting the acknowledge character.
3. Also this acknowledge character takes 3,5 µs from receiver back to the sender.

One should additionally note that if signals are used (Layer-2 code) or measured (testing) on the processor side of a transceiver, that the transceiver delay times should be taken into account as well.

With a reserve of 3 µs, this leads to a time-out for waiting for the Acknowledge of 15 bit times + 30 µs.

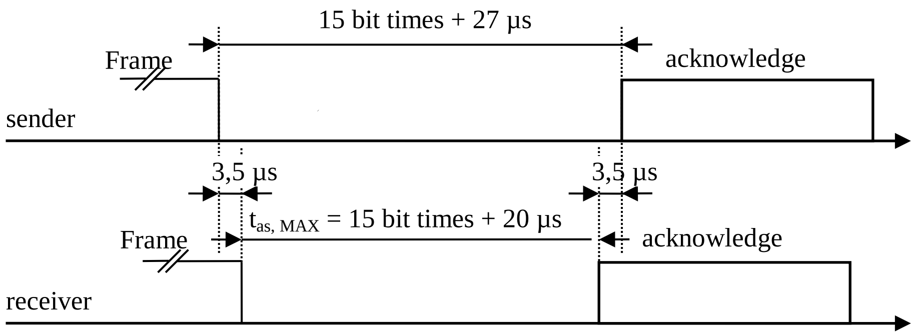


Figure 44 – Sender time-out waiting for the Acknowledge

A.8

The device shall wait for at least 150 bit times, regardless of whether the bus is free or not. After this wait time has elapsed, it may repeat the L_Data.req-Frame, with p_class = “repetition”, this is, there shall be a bus free period of at least 50 bit times. This also means that if the bus is free during the last 50 bit times of the wait time, that then the original sender may retransmit the L_Data.req-Frame immediately.

A.9

Here, it shall only be tested that the BDUT indeed transmits or starts transmitting its acknowledge Frame even if the line is discovered to be not free up to 35 µs before it would transmit itself. Side effects, e.g. caused by different contents of the Frame of the WG and the BDUT should be excluded. Therefore in the test specifications WG and BDUT send the same type of acknowledge Frame.

A.10

In the following, it is assumed that the timings 16 µs and 35 µs have to do with the fact that a device may not be able in due time after the reception of a Frame, to conclude that it is addressed by the Frame and should acknowledge the Frame and should thus inhibit its bus free detection. It is assumed that older implementations cannot inhibit bus free detection 16 µs before the own transmission; whereas newer implementations would be able to inhibit bus free detections already 35 µs on beforehand.
The ideal value would obviously be 50 µs (td3 = -50 µs in [06]).

Annex B
Summary of signals
(informative)

NOTE 5 The timings about "position" (where a signal starts) are counted from the **start** of the active phase of 0-signal to the start of the signal or character that is defined. The timings about "separation" (how far are signals separated in time) are counted from the **end** of the preceding 0-signal or 1-signal to the start of the signal or character that is defined.

Abbr.	Name	Typical duration	Definition
t_{pd}	pulse duration	35 µs	Duration of the active pulse of the 0-signal.
t_{sd}	signal duration	1 bit time	Total duration of the 0-signal or 1-signal.
t_{sp}	signal position	n bit times	Position of any bit n (1 ≤n ≤11) of a Character in relation to the start bit of that Character.
t_{cp}	character position	13 bit times	Position of the Character in relation to the start of the preceding Character.
t_{cs}	character separation	2 bit times	Time between a Character and the subsequent Character in the same telegram.
t_{ts}	telegram separation • priority low or normal and no repetition • priority urgent or system or repetition	 53 bit times 50 bit times	Time between a telegram and the subsequent Telegram.
t_{as}	acknowledge separation	15 bit times	Time between a Telegram and the Acknowledge Telegram for that Telegram.
t_{pcs1}	polling character separation 1	5 bit times	
t_{pcs2}	polling character separation 2	6 bit times	

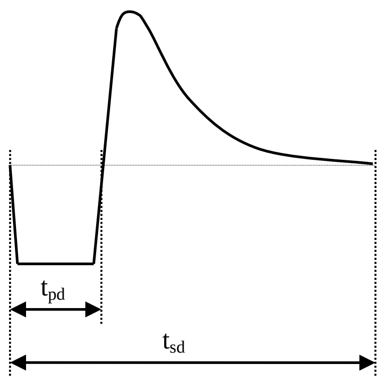


Figure 45 – Timings within the 0-signal

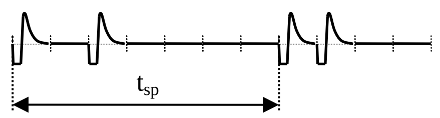


Figure 46 – Timing within the character

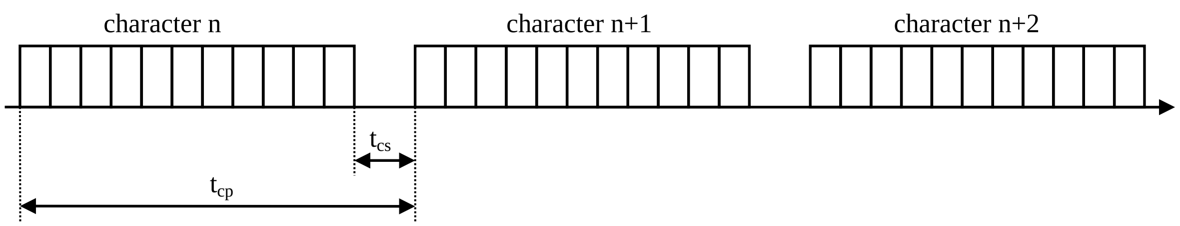


Figure 47 – Character timing

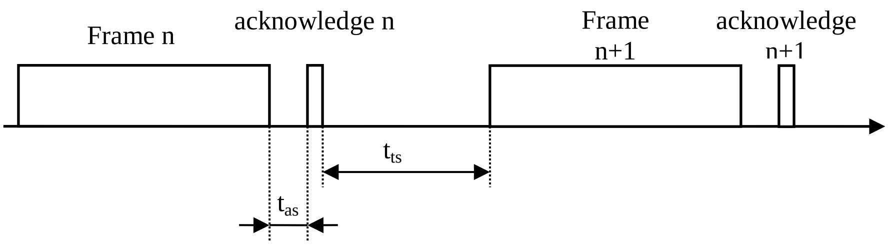


Figure 48 – Frame timing