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Edition 4.0 2007-12

INTERNATIONAL STANDARD

Industrial communication networks – Fieldbus specifications – Part 2: Physical layer specification and service definition

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INDUSTRIAL COMMUNICATION NETWORKS – FIELDBUS SPECIFICATIONS –

Part 2: Physical layer specification and service definition

FOREWORD

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8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

NOTE Use of some of the associated protocol types is restricted by their intellectual-property-right holders. In all cases, the commitment to limited release of intellectual-property-rights made by the holders of those rights permits a particular data-link layer protocol type to be used with physical layer and application layer protocols in type combinations as specified explicitly in the IEC 61784 series. Use of the various protocol types in other combinations may require permission of their respective intellectual-property-right holders.

IEC draws attention to the fact that it is claimed that compliance with this standard may involve the use of patents as follows, where the [xx] notation indicates the holder of the patent right:

Type 2 (subclauses 5.3, 9.3, 10.3, Clauses 17 through 20, Annex F through Annex H):

5,396,197 [AB] Network Node TAP

IEC takes no position concerning the evidence, validity and scope of these patent rights.

The holders of these patent rights have assured IEC that they are willing to negotiate licences under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holders of these patent rights are registered with IEC. Information may be obtained from:

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Milwaukee, WI 53204
USA
Attention: Intellectual Property Dept.

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International Standard IEC 61158-2 has been prepared by subcommittee 65C: Industrial networks, of IEC technical committee 65: Industrial-process measurement, control and automation.

This fourth edition cancels and replaces IEC 61158-2:2003. This edition of this part constitutes a minor revision. This publication, together with its companion parts for Type 16, also partially replaces IEC 61491:2002 which is at present being revised. IEC 61491 will be issued as a technical report.

This edition includes the following significant technical changes with respect to the previous edition:

a) deletion of the former Type 6 fieldbus for lack of market relevance;
b) addition of new fieldbus types;
c) generalization of the seldom-used Type 1 radio to a more useful form.

The text of this standard is based on the following documents:

FDIS	Report on voting
65C/472/FDIS	65C/483/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with ISO/IEC Directives, Part 2.

NOTE Slight variances from the directives have been allowed by the IEC Central Office to provide continuity of subclause numbering with prior editions.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under http://webstore.iec.ch in the data related to the specific publication. At this date, the publication will be:

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

The list of all the parts of the IEC 61158 series, under the general title *Industrial communication networks — Fieldbus specifications,* can be found on the IEC website.

0 Introduction

0.1 General

This part of IEC 61158 is one of a series produced to facilitate the interconnection of automation system components. It is related to other standards in the set as defined by the “three-layer” fieldbus reference model described in IEC/TR 61158-1.

0.2 Physical layer overview

The primary aim of this standard is to provide a set of rules for communication expressed in terms of the procedures to be carried out by peer Ph-entities at the time of communication.

The physical layer receives data units from the data-link Layer, encodes them, if necessary by adding communications framing information, and transmits the resulting physical signals to the transmission medium at one node. Signals are then received at one or more other node(s), decoded, if necessary by removing the communications framing information, before the data units are passed to the data-link Layer of the receiving device.

0.3 Document overview

This standard comprises physical layer specifications corresponding to many of the different DL-Layer protocol Types specified in IEC 61158-4-1 to IEC 61158-4-18.

NOTE 1 The protocol Type numbers used are consistent throughout the IEC 61158 series.

NOTE 2 Specifications for Types 1, 2, 3, 4, 8 and 16 are included. Type 7 uses Type 1 specifications. The other Types do not use any of the specifications given in this standard.

NOTE 3 For ease of reference, Type numbers are given in clause names. This means that the specification given therein applies to this Type, but does not exclude its use for other Types.

NOTE 4 It is up to the user of this standard to select interoperating sets of provisions. Refer to the IEC 61784 series for standardized communication profiles based on the IEC 61158 series.

A general model of the physical layer is shown in Figure 1.

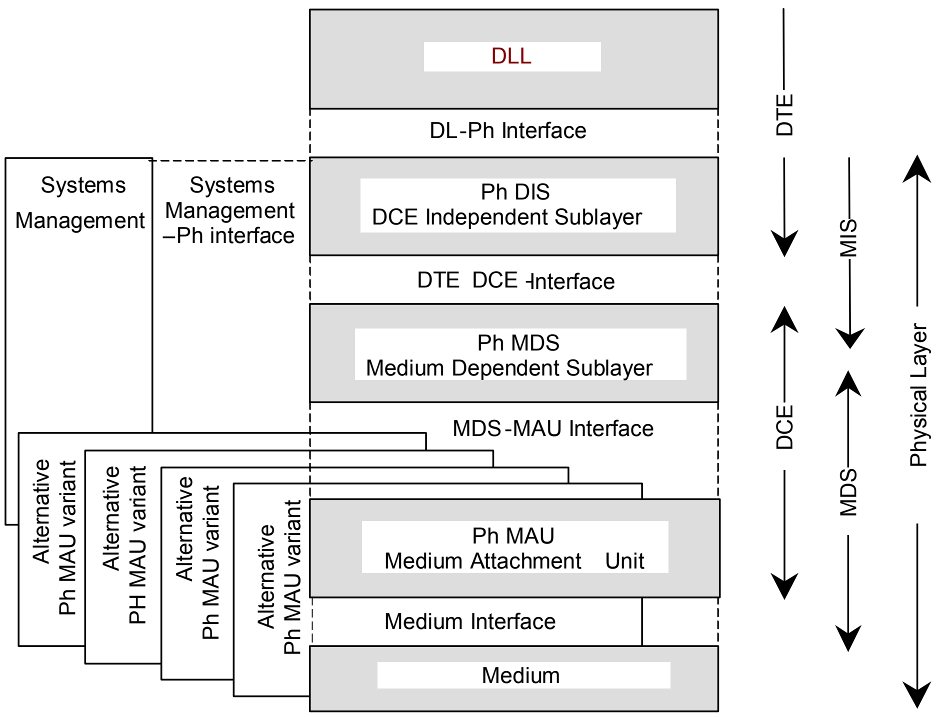

Figure 1 — General model of physical layer

NOTE 5 The protocol types use a subset of the structure elements.

NOTE 6 Since Type 8 uses a more complex DIS than the other types, it uses the term MIS to differentiate.

The common characteristics for all variants and types are as follows:

– digital data transmission;
– no separate clock transmission;
– either half-duplex communication (bi-directional but in only one direction at a time) or full-duplex communication.

0.4 Major physical layer variations specified in this standard

0.4.1 Type 1 media

0.4.1.1 Type 1: Wire media

For twisted-pair wire media, Type 1 specifies two modes of coupling and different signaling speeds as follows:

a) voltage mode (parallel coupling), 150 Ω, data rates from 31,25 kbit/s to 25 Mbit/s;
b) voltage mode (parallel coupling), 100 Ω, 31,25 kbit/s;
c) current mode (serial coupling), 1,0 Mbit/s including two current options.

The voltage mode variations may be implemented with inductive coupling using transformers. This is not mandatory if the isolation requirements of this standard are met by other means.

The Type 1 twisted-pair (or untwisted-pair) wire medium physical layer provides the options:

– no power via the bus conductors; not intrinsically safe;
– power via the bus conductors; not intrinsically safe;
– no power via the bus conductors; intrinsically safe;
– power via the bus conductors; intrinsically safe.

0.4.1.2 Type 1: Optical media

The major variations of the Type 1 optic fiber media are as follows:

– dual fiber mode, data rates from 31,25 kbit/s to 25 Mbit/s;
– single fiber mode, 31,25 kbit/s.

0.4.1.3 Type 1: Radio media

The Type 1 radio medium specification provides a generalized FSK/PSK radio capability at arbitrary bit rates.

0.4.2 Type 2: Coaxial wire and optical media

Type 2 specifies the following variants:

– coaxial copper wire medium, 5 Mbit/s;
– optical fiber medium, 5 Mbit/s;
– network access port (NAP), a point-to-point temporary attachment mechanism that can be used for programming, configuration, diagnostics or other purposes;
– repeater machine sublayers (RM, RRM) and redundant physical layers.

0.4.3 Type 3: Twisted-pair wire and optical media

Type 3 specifies the following synchronous transmission:

a) twisted-pair wire medium, 31,25 kbit/s, voltage mode (parallel coupling) with the options:
   – power via the bus conductors: not intrinsically safe;
   – power via the bus conductors: intrinsically safe;

and the following asynchronous transmission variants:

b) twisted-pair wire medium, up to 12 Mbit/s, ANSI TIA/EIA-485-A;
c) optical fiber medium, up to 12 Mbit/s.

0.4.4 Type 4: Wire medium

Type 4 specifies wire media with the following characteristics:

– RS-485 wire medium up to 76,8 kbit/s;
– RS-232 wire medium up to 230,4 kbit/s.

0.4.5 Type 8: Twisted-pair wire and optical media

The physical layer also allows transmitting data units that have been received through a medium access by the transmission medium directly through another medium access and its transmission protocol to another device.

Type 8 specifies the following variants:

– twisted-pair wire medium, up to 16 Mbit/s;
– optical fiber medium, up to 16 Mbit/s.

The general characteristics of these transmission media are as follows:

– full-duplex transmission;
– non-return-to-zero (NRZ) coding.

The wire media type provides the following options:

– no power supply via the bus cable, not intrinsically safe;
– power supply via the bus cable and on additional conductors, not intrinsically safe.

0.4.6 Type 12: Wire medium

Type 12 specifies wire media with the following characteristics:

– LVDS wire medium up 100 Mbit/s.

0.4.7 Type 16: optical media

Type 16 specifies a synchronous transmission using optical fiber medium, at 2 Mbit/s, 4 Mbit/s, 8 Mbit/s and 16 Mbit/s.

0.4.8 Type 18: Media

0.4.8.1 Type 18: Basic media

The Type 18-PhL-B specifies a balanced transmission signal over a shielded 3-core twisted cable. Communication data rates as high as 10 Mbit/s and transmission distances as great as 1,2 km are specified.

0.4.8.2 Type 18: Powered media

The Type 18-PhL-P specifies a balanced transmission signal over a 4-core unshielded cable in both flat and round configurations with conductors specified for communications signal and network-embedded power distribution. Communication data rates as high as 2,5 Mbit/s and transmission distances as great as 500 m are specified.

INDUSTRIAL COMMUNICATION NETWORKS – FIELDBUS SPECIFICATIONS –

Part 2: Physical layer specification and service definition

1 Scope

This part of IEC 61158 specifies the requirements for fieldbus component parts. It also specifies the media and network configuration requirements necessary to ensure agreed levels of

a) data integrity before data-link Layer error checking;

b) interoperability between devices at the physical layer.

The fieldbus physical layer conforms to layer 1 of the OSI 7-layer model as defined by ISO 7498 with the exception that, for some types, frame delimiters are in the physical layer while for other types they are in the data-link Layer.

2 Normative references

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

IEC 60050-731, *International Electrotechnical Vocabulary – Chapter 731: Optical fibre communication*

IEC 60079-11, *Explosive atmospheres – Part 11: Equipment protection by intrinsic safety "i"*

IEC 60079-14, *Electrical apparatus for explosive gas atmospheres – Part 14: Electrical installations in hazardous areas (other than mines)*

IEC 60079-25, *Electrical apparatus for explosive gas atmospheres – Part 25: Intrinsically safe systems*

IEC 60096-1, *Radio-frequency cables – Part 1: General requirements and measuring methods*

IEC 60169-8, *Radio-frequency connectors – Part 8: RF coaxial connectors with inner diameter of outer conductor 6,5 mm (0,256 in) with bayonet lock – Characteristic impedance 50 ohms (Type BNC)*

IEC 60169-17, *Radio-frequency connectors – Part 17: RF coaxial connectors with inner diameter of outer conductor 6,5 mm (0,256 in) with screw coupling – Characteristic impedance 50 ohms (Type TNC)*

IEC 60189-1:1986, *Low-frequency cables and wires with PVC insulation and PVC sheath – Part 1: General test and measuring methods*[1]

IEC 60255-22-1:1988, *Electrical relays – Part 22-1: Electrical disturbance tests for measuring relays and protection equipment – 1 MHz burst disturbance tests*[2]

———————

[1] There exists a new edition of this publication (2007).

[2] There exists a new edition of this publication (2007).

IEC 60364-4-41, *Low-voltage electrical installations of buildings – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-5-54, *Electrical installations of buildings – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements, protective conductors and protective bonding conductors*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60603-7, *Connectors for frequencies below 3 MHz for use with printed boards – Part 7: Detail specification for connectors, 8-way, including fixed and free connectors with common mating features, with assessed quality*

IEC 60760, *Flat, quick-connect terminations*

IEC 60793 (all parts), *Optical fibres*

IEC 60794-1-2, *Optical fibre cables – Part 1-2: Generic specification – Basic optical cable test procedures*

IEC 60807-3, *Rectangular connectors for frequencies below 3 MHz – Part 3: Detail specification for a range of connectors with trapezoidal shaped metal shells and round contacts – Removable crimp contact types with closed crimp barrels, rear insertion/rear extraction*

IEC 60874-10-1, *Connectors for optical fibres and cables — Part 10-1: Detail specification for fiber optic connector type BFOC/2,5 terminated to multimode fibre type A1*

IEC 61000-4-2, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques — Electrostatic discharge immunity test* (Basic EMC Publication)

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques — Radiated, radio-frequency, electromagnetic field immunity test* (Basic EMC Publication)

IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 44: Testing and measurement techniques — Electrical fast transient/burst immunity test* (Basic EMC Publication)

IEC 61131-2, *Programmable controllers – Part 2: Equipment requirements and tests*

IEC 61156-1, *Multicore and symmetrical pair/quad cables for digital communications – Part 1: Generic specification*

IEC 61158-4-2, *Industrial communication network – Fieldbus specifications — Part 4-2: Data-link protocol specification — Type 2 elements*

IEC 61158-4-3, *Industrial communication network – Fieldbus specifications — Part 4-3: Data-link protocol specification — Type 3 elements*

IEC 61754-2, *Fibre optic connector interfaces – Part 2: Type BFOC/2,5 connector family*

IEC 61754-13, *Fibre optic connector interfaces – Part 13: Type FC-PC connector*

IEC 61754-22, *Fibre optic connector interfaces – Part 22: Type F-SMA connector family*

ISO/IEC 7498 (all parts), *Information technology – Open Systems Interconnection – Basic Reference Model: The Basic Model*

ISO/IEC 8482, *Information technology – Telecommunications and information exchange between systems – Twisted pair multipoint interconnections*

ISO/IEC 8802-3, *Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*

ISO/IEC 9314-1, *Information processing systems – Fibre distributed data interface (FDDI) Part 1: Token ring physical layer protocol (PHY)*

ISO/IEC 10731, *Information technology – Open Systems Interconnection – Basic reference model – Conventions for the definition of OSI services*

ANSI TIA/EIA-232-F, *Interface Between Data Terminal Equipment and Data Circuit – Terminating Equipment Employing Serial Binary Data Interchange*

ANSI TIA/EIA-422-B, *Electrical Characteristics of Balanced Voltage Digital Interface Circuits*

ANSI TIA/EIA-485-A, *Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems*

ANSI TIA/EIA-644-A, *Electrical Characteristics of Low Voltage Differential Signaling (LVDS) Interface Circuits*

3 Terms and definitions

For the purposes of this document, the terms and definitions of ISO/IEC 7498, and the following definitions apply.

3.1 Common terms and definitions

NOTE Many definitions are common to more than one protocol type; they are not necessarily used by all protocol types.

3.1.1
activity
presence of a signal or noise at the input terminals of a fieldbus device that is of a level that is above the receiver signal level threshold of that device

3.1.2
barrier
physical entity that limits current and voltage into a hazardous area in order to satisfy intrinsic safety requirements

3.1.3
bit
unit of data consisting of a 1 or a 0

NOTE A bit is the smallest data unit that can be transmitted.

3.1.4
bus
trunk and all devices connected to it

3.1.5
cable plant interface connector
CPIC
point at which test and conformance measurements are made and that the interface between the network device and the cable plant

3.1.6
communication element
part of a fieldbus device that communicates with other elements via the bus

3.1.7
connector
coupling device employed to connect the medium of one circuit or communication element with that of another circuit or communication element
[IEEE Std 100-1996, modified]

3.1.8
coupler
physical interface between trunk and spur or trunk and device

3.1.9
Data Communications Equipment
DCE
embodiment of the media, modulation and coding-dependent portion of a fieldbus-connected device, comprising the lower portions of the physical layer within the device

3.1.10
Data Terminal Equipment
DTE
embodiment of the media, modulation and coding-independent portion of a fieldbus-connected device, comprising the uppermost portion of the physical layer and all higher layers within the device

3.1.11
decibel(milliwatt)
dB(mW)
logarithmic unit of power, referenced to 1 mW. (Also written **dBm**.)

$$P_{dBm} = 10 \log \left(P_{mW}\right)$$

NOTE If P_{mW} is the measured power in mW, then P_{dBm} is the power expressed logarithmically in dB(mW), or equivalently, dBm.

3.1.12
delimiter
flag that separates and organizes items of data

3.1.13
device
physical entity connected to the fieldbus composed of at least one communication element (the network element) and which may have a control element and/or a final element (transducer, actuator, etc.)

NOTE A device may contain more than one node.

3.1.14
effective launch power
effective power coupled into the core of a fiber optic waveguide by the transmitter. This power is measured with a standard test fiber connected to the CPIC

3.1.15
effective power
the difference, expressed in dBm, between the absolute optical power measured in milliwatt at the midpoint in time of the Hi level to the absolute optical power measured in milliwatt at the midpoint of the Lo level

NOTE Effective power is believed to give a more accurate measurement of the conditions that affect the receivers than traditional measurements, such as peak and average power. methods for measuring effective power are for further study.

3.1.16
error
discrepancy between a computed, observed or measured value or condition and the specified or theoretically correct value or condition

3.1.17
extinction ratio
ratio of the absolute optical power measured in milliwatt at the midpoint in time of the Hi level to the absolute optical power measured in milliwatt at the midpoint in time of the Lo level.

NOTE The following gives an example of the computation of effective power and extinction ratio. If the midpoint of Hi level is measured as 105 µW, and if the midpoint of Lo level is measured as 5 µW, then the difference is 100 µW. Therefore, the effective power is 10 log ((100 µW) / 1 mW)), which equals –10,0 dBm. The extinction ratio is (105/5), which equals 21:1.

3.1.18
fiber optic cable
cable containing one or more fiber optic waveguides with jacketing material provided to facilitate handling and to protect the fiber

3.1.19
fiber optic receiver
combined optics and electronics in the communicating device that accept the optical signal received by the communicating device through the CPIC

3.1.20
fiber optic receiver operating range
range of optical power that must be present at the CPIC to ensure that the bit error rate specifications are met

3.1.21
fiber optic transmitter

device that emits optical signals for propagation into a fiber optic waveguide through the CPIC

3.1.22
fiber optic waveguide
flexible, optically transparent strand that is used to transport optical signals from one geographic point to another geographic point

3.1.23
frame
set of consecutive digit time slots in which the position of each digit time slot can be identified by reference to a framing signal
[IEEE Std 100-1996]

3.1.24
intrinsic safety
design methodology for a circuit or an assembly of circuits in which any spark or thermal effect produced under normal operating and specified fault conditions is not capable under prescribed test conditions of causing ignition of a given explosive atmosphere
[IEC 60079-11]

3.1.25
isolation
physical and electrical arrangement of the parts of a signal transmission system to prevent electrical interference currents within or between the parts
[IEEE Std 100-1996]

3.1.26
jabber
continuous transmission on the medium due to a faulty device

3.1.27
jitter
offset of the 50 % transition points of pulse edges from their ideal position as the result of all causes

3.1.28
Manchester encoding
means by which separate data and clock signals can be combined into a single, self-synchronizing data stream, suitable for transmission on a serial channel

3.1.29
medium
cable, optical fiber, or other means by which communication signals are transmitted between two or more points

NOTE In this standard "media" is used only as the plural of medium.

3.1.30
network
all of the media, connectors, repeaters, routers, gateways and associated node communication elements by which a given set of communicating devices are interconnected

3.1.31
node
end-point of a branch in a network or a point at which one or more branches meet
[IEV 131-02-04]

3.1.32
optical active star
active device in which a signal from an input fiber is received, amplified and retransmitted to a larger number of output optical fibers. Retiming of the received signal is optional.

3.1.33
optical fall time
time it takes for a pulse to go from 90 % effective power to 10 % effective power, specified as a per cent of the nominal bit time

3.1.34
optical passive star
passive device in which signals from input fibers are combined and then distributed among output optical fibers

3.1.35
optical rise time
time it takes for a pulse to go from 10 % effective power to 90 % effective power, specified as a per cent of the nominal bit time

3.1.36
peak emission wavelength
λp
wavelength at which radiant intensity is maximized

3.1.37
receiver
receive circuitry of a communication element

3.1.38
repeater
Two–port active physical layer device that receives and retransmits all signals to increase the distance and number of devices for which signals can be correctly transferred for a given medium

3.1.39
segment
trunk–cable section of a fieldbus that is terminated in its characteristic impedance

NOTE Segments are linked by repeaters within a logical link and by bridges to form a fieldbus network

3.1.40
separately powered device
device that does not receive its operating power via the fieldbus signal conductors

3.1.41
shield
surrounding earthed metallic layer to confine the electric field within the cable and to protect the cable from external electrical influence

NOTE Metallic sheaths, armours and earthed concentric conductors may also serve as a shield.

3.1.42
spur
branch-line (i.e. a link connected to a larger one at a point on its route) that is a final circuit

NOTE The alternative term ‘drop cable’ is used in this standard.

3.1.43
terminator
resistor connecting conductor pairs at both ends of a wire medium segment to prevent reflections from occurring at the ends of cables

NOTE For Type 2 the terminator is mounted in a BNC or TNC plug.

3.1.44
transceiver
combination of receiving and transmitting equipment in a common housing employing common circuit components for both transmitting and receiving
[IEEE Std 100-1996 modified for non-radio use]

NOTE A medium attachment unit can be the transceiver or can contain the transceiver, depending on Type and implementation.

3.1.45
transmitter
transmit circuitry of a communication element

3.1.46
trunk
main communication highway acting as a source of main supply to a number of other lines (spurs)

3.1.47
typical half-intensity wavelength
$\Delta\lambda$
range of wavelength of spectral distribution in which the radiant intensity is no less than one-half of the maximum intensity

3.2 Type 1: Terms and definitions

3.2.1
activity
[see 3.1.1]

3.2.2
barrier
[see 3.1.2]

3.2.3
bus
[see 3.1.4]

3.2.4
cable plant interface connector
CPIC
[see 3.1.5]

3.2.5
communication element
[see 3.1.6]

3.2.6
connector
[see 3.1.7]

3.2.7
coupler
[see 3.1.8]

3.2.8
Data Communications Equipment
DCE
[see 3.1.9]

3.2.9
Data Terminal Equipment
DTE
[see 3.1.10]

3.2.10
dBm
[see 3.1.11]

3.2.11
delimiter
[see 3.1.12]

3.2.12
device
[see 3.1.13]

3.2.13
effective launch power
[see 3.1.14]

3.2.14
effective power
[see 3.1.15]

3.2.15
fiber optic cable
[see 3.1.17]

3.2.16
fiber optic receiver
[see 3.1.19]

3.2.17
fiber optic receiver operating range
[see 3.1.20]

3.2.18
fiber optic transmitter
[see 3.1.21]

3.2.19
fiber optic waveguide
[see 3.1.22]

3.2.20
frame
[see 3.1.23]

3.2.21
Gaussian minimum shift keying
form of frequency modulation where a 1 is represented by a frequency of $F\mathrm{c} + f$ and a 0 is represented by $F\mathrm{c} - f$ where f is equal to the bit rate divided by 4 and where the modulating frequency is first passed through a Gaussian filter before being imposed on the carrier

3.2.22
intrinsic safety
[see 3.1.24]

3.2.23
isolation
[see 3.1.25]

3.2.24
jabber
[see 3.1.26]

3.2.25
Manchester encoding
[see 3.1.27]

3.2.26
medium
[see 3.1.29]

3.2.27
network
[see 3.1.30]

3.2.28
node
[see 3.1.31]

3.2.29
optical fall time
[see 3.1.32]

3.2.30
optical rise time
[see 3.1.34]

3.2.31
peak emission wavelength
λp
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3.2.34
separately powered device
[see 3.1.40]

3.2.35
shield
[see 3.1.41]

3.2.36
spur
[see 3.1.42]

3.2.37
terminator
[see 3.1.43]

3.2.38
transceiver
[see 3.1.43]

3.2.39
transmitter
[see 3.1.45]

3.2.40
trunk
[see 3.1.46]

3.3 Type 2: Terms and definitions

3.3.1
activity
[see 3.1.1]

3.3.2
bit
[see 3.1.3]

3.3.3
blanking or blanking time
length of time required after transmitting before a node is allowed to receive

3.3.4
bus
[see 3.1.4]

3.3.5
communication element
[see 3.1.6]

3.3.6
connector
[see 3.1.7]

3.3.7
Data Communications Equipment (DCE)
[see 3.1.9]

3.3.8
dBm
[see 3.1.11]

3.3.9
delimiter
[see 3.1.12]

3.3.10
device
[see 3.1.13]

3.3.11
end delimiter
unique sequence of symbols that identifies the end of a frame

3.3.12
end node
producing or consuming node

3.3.13
error
[see 3.1.16]

3.3.14
frame
[see 3.1.23]

3.3.15
isolation
[see 3.1.25]

3.3.16
jabber
[see 3.1.26]

3.3.17
Manchester encoding
[see 3.1.27]

3.3.18
medium
[see 3.1.29]

3.3.19
M_symbol
representation of the MAC data bits to be encoded and transmitted by the physical layer

3.3.20
MAC frame
collection of M_symbols transmitted on the medium that contains a preamble, start delimiter, data, CRC and end delimiter

3.3.21
network
[see 3.1.30]

3.3.22
network access port
physical layer variant that allows a temporary node to be connected to the link by connection to the NAP of a permanent node

3.3.23
node
[see 3.1.31]

NOTE A node is additionally a connection to a link that requires a single M_ID

3.3.24
non-data symbol
physical layer Manchester coded signal, used for delimiters, carrying no data

3.3.25
optical isolators, optos
components located within the physical layer transceiver of a node that converts current into light, and then back to an electrical signal

3.3.26
permanent node
node whose connection to the network does not utilize the network access port (NAP) physical layer variant

NOTE This node may optionally support a NAP physical layer variant to allow temporary nodes to connect to the network.

3.3.27
redundant media
more than one medium to minimize communication failures

3.3.28
repeater
[see 3.1.38]

3.3.29
segment
[see 3.1.39]

3.3.30
shield
[see 3.1.41]

3.3.31
slot time
maximum time required for detecting an expected transmission
NOTE Each node waits a slot time for each missing node during the implied token pass.

3.3.32
spur
[see 3.1.42]

NOTE This is an integral part of network taps.

3.3.33
start delimiter
unique sequence of symbols that identifies the beginning of a frame

3.3.34
tap
point of attachment from a node or spur to the trunk cable

NOTE A tap provides easy removal of a node without disrupting the link.

3.3.35
terminator
[see 3.1.43]

3.3.36
tool
executable software program that interacts with the user to perform some function

3.3.37
transceiver
[see 3.1.43]

3.3.38
transient node
node that is only intended to be connected to the network on a temporary basis using the NAP physical layer medium connected to the NAP of a permanent node

3.3.39
transmitter
[see 3.1.45]

3.3.40
trunk
[see 3.1.46]

3.3.41
trunk cable
bus or central part of a cable system

3.3.42
trunk–cable section
length of trunk cable between any two taps

3.4 Type 3: Terms and definitions

3.4.1
activity
[see 3.1.1]

3.4.2
barrier
[see 3.1.2]

3.4.3
bit time
time to transmit one bit

3.4.4
bus
[see 3.1.4]

3.4.5
communication element
[see 3.1.6]

3.4.6
confirmation (primitive)
[ISO/IEC 10731]

3.4.7
connector
[see 3.1.7]

3.4.8
coupler
[see 3.1.8]

3.4.9
Data Communications Equipment (DCE)
[see 3.1.9]

3.4.10
Data Terminal Equipment (DTE)
[see 3.1.10]

3.4.11
dBm
[see 3.1.11]

3.4.12
device
[see 3.1.13]

3.4.13
DL-entity
[ISO/IEC 7498-1]

3.4.14
fiber optic cable (FOC)
[see 3.1.17]

3.4.15
frame
[see 3.1.23]

3.4.16
indication (primitive)
[ISO/IEC 10731]

3.4.17
intrinsic safety
[see 3.1.24]

3.4.18
isolation
[see 3.1.25]

3.4.19
jabber
[see 3.1.26]

3.4.20
medium
[see 3.1.29]

3.4.21
(N)-entity
[ISO/IEC 7498-1]

3.4.22
(N)-service
[ISO/IEC 7498-1]

3.4.23
network
[see 3.1.30]

3.4.24
node
[see 3.1.31]

3.4.25
Ph-entity
[ISO/IEC 7498-1]

3.4.26
Ph-service
[ISO/IEC 7498-1]

3.4.27
repeater
[see 3.1.38]

3.4.28
request (primitive)
[ISO/IEC 10731]

3.4.29
reset
[ISO/IEC 7498-1]

3.4.30
segment
[see 3.1.39]

3.4.31
separately powered device
[see 3.1.40]

3.4.32
shield
[see 3.1.41]

3.4.33
spur
[see 3.1.42]

3.4.34
station
node

3.4.35
terminator
[see 3.1.43]

3.4.36
transceiver
[see 3.1.43]

3.4.37
transmitter
[see 3.1.45]

3.4.38
trunk
[see 3.1.46]

3.5 Type 4: Terms and definitions

3.5.1
activity
[see 3.1.1]

3.5.2
bus
[see 3.1.4]

3.5.3
connector
[see 3.1.7]

3.5.4
Data Communications Equipment (DCE)
[see 3.1.9]

3.5.5
Data Terminal Equipment (DTE)
[see 3.1.10]

3.5.6
device
[see 3.1.13]

3.5.7
idle counter
counter to measure the number of bit periods for which the signal level on the physical link has been high for normal class and simple class devices in half duplex mode

3.5.8
isolation
[see 3.1.25]

3.5.9
medium
[see 3.1.29]

3.5.10
network
[see 3.1.30]

3.5.11
normal class device
a device that initiates transmission and replies to requests and that can act as a server (responder) and as a client (requestor) - this is also called a peer

3.5.12
shield
[see 3.1.41]

3.5.13
simple class device
a device that replies to requests from Normal Class Devices and acts as a server or responder only

3.5.14
transmitter
[see 3.1.45]

3.6 Type 6: *This subclause has been removed*

NOTE This subclause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the subclause numbering of the prior edition.

3.7 Type 8: Terms and definitions

3.7.1
activity
[see 3.1.1]

3.7.2
bus coupler
a device that divides the ring into segments by opening the ring and integrating another ring at this point

3.7.3
cable plant interface connector (CPIC)
[see 3.1.5]

3.7.4
communication element
[see 3.1.6]

3.7.5
connector
[see 3.1.7]

3.7.6
dBm
[see 3.1.11]

3.7.7
effective launch power
[see 3.1.14]

3.7.8
effective power
[see 3.1.15]

3.7.9
fiber optic cable
[see 3.1.17]

3.7.10
fiber optic receiver
[see 3.1.19]

3.7.11
fiber optic receiver operating range
[see 3.1.20]

3.7.12
fiber optic transmitter
[see 3.1.21]

3.7.13
fiber optic waveguide
[see 3.1.22]

3.7.14
frame
[see 3.1.23]

3.7.15
incoming interface
interface to receive data from the previous device and to send data, which are received via an outgoing interface, to the previous device

3.7.16
isolation
[see 3.1.25]

3.7.17
local bus
a ring segment of a network with alternate media specifications, which is coupled to a remote bus via the bus coupler

3.7.18
local bus device
a device that operates as a slave on a local bus

3.7.19
master
a device that controls the data transfer on the network and initiates the media access of the slaves by sending messages and that constitutes the interface to the control system

3.7.20
medium
[see 3.1.29]

3.7.21
minimum optical receiver sensitivity
minimum optical power at the optical receiver input required to achieve a bit error rate of less than 10^{-9} for the optical transmission system

3.7.22
network
[see 3.1.30]

3.7.23
optical fall time
[see 3.1.32]

3.7.24
optical rise time
[see 3.1.34]

3.7.25
outgoing interface
interface to send data to the next slave in a way, that data that is received through this interface is sent via another outgoing interface to the next slave or via an incoming interface to the previous slave and back to the master

3.7.26
peak emission wavelength (λp)
[see 3.1.36]

3.7.27
polymer optical fiber
POF
plastic fiber optic waveguide whose nominal characteristics are compatible with IEC 60793 [fiber type: A4a (980/1000)]

3.7.28
plastic clad silica fiber
PCS
fiber optic waveguide consisting of a glass core and a plastic cladding and whose nominal characteristics are compatible with IEC 60793 [fiber type: A3c (200/230 μm)]

3.7.29
remote bus
a ring segment of a network

3.7.30
remote bus device
device operating as a slave on a remote bus

3.7.31
remote bus link
connection of two remote bus devices

3.7.32
ring segment
one section of a network

NOTE The master constitutes the first ring segment, further ring segments may be linked by bus couplers

3.7.33
shield
[see 3.1.41]

3.7.34
slave
a device that accesses the medium only after it has been initiated by the preceding slave or master

3.7.35
spectral full width half maximum (Δλ)
range of wavelength of spectral distribution in which the radiant intensity is no less than one-half of the maximum intensity

3.7.36
terminator
[see 3.1.43]

3.8 Type 12: Terms and definitions

3.8.1
activity
[see 3.1.1]

3.8.2
bit
[see 3.1.3]

3.8.3
connector
[see 3.1.7]

3.8.4
coupler
[see 3.1.8]

3.8.5
Data Communications Equipment (DCE)
[see 3.1.9]

3.8.6
Data Terminal Equipment (DTE)
[see 3.1.10]

3.8.7
delimiter
[see 3.1.12]

3.8.8
device
[see 3.1.13]

3.8.9
error
[see 3.1.16]

3.8.10
frame
[see 3.1.23]

3.8.11
idle
symbol at the media between EOF and SOF

3.8.12
isolation
[see 3.1.25]

3.8.13
jitter
[see 3.1.27]

3.8.14
Manchester encoding
[see 3.1.28]

3.8.15
medium
[see 3.1.29]

3.8.16
network
[see 3.1.30]

3.8.17
receiver
[see 3.1.37]

3.8.18
shield
[see 3.1.41]

3.8.19
terminator
[see 3.1.43]

3.9 Type 16: Terms and definitions

3.9.1
attenuation
fact that the optical power at the receiver is less than at the transmitter

3.9.2
barrier
[see 3.1.2]

3.9.3
bit
[see 3.1.3]

3.9.4
bit stuffing
procedure, by which after five logical 1's, the transmitter automatically inserts a zero which is then removed again by the receiver. This zero causes a change in signal edges which makes it possible for the receiver to retrieve a receiving clock

3.9.5
connector
[see 3.1.7]

3.9.6
Data Communications Equipment (DCE)
[see 3.1.9]

3.9.7
Data Terminal Equipment (DTE)
[see 3.1.10]

3.9.8
dBm
[see 3.1.11]

3.9.9
delimiter
[see 3.1.12]

3.9.10
device
[see 3.1.13]

3.9.11
error
[see 3.1.16]

3.9.12
fiber optic cable
[see 3.1.18]

3.9.13
frame
[see 3.1.23]

3.9.14
F-SMA connector
connector meeting the F-SMA standard in accordance with IEC 61754-22

3.9.15
fill signals
sequence of seven 1's followed by a 0

3.9.16
jitter
[see 3.1.27]

3.9.17
medium
[see 3.1.29]

3.9.18
network
[see 3.1.30]

3.9.19
node
[see 3.1.31]

3.9.20
non-return-to-zero-inverted
NRZI
signal exchanges taking place only at regular, fixed points in time in synchronization with the transmitting clock pulse of the bit rate; a signal edge change is assigned to a logical 0 only

3.9.21
optical fall time
[see 3.1.33]

3.9.22
optical rise time
[see 3.1.35]

3.9.23
pad
a sequence of octets added to assure that the telegram is long enough for proper operation

3.9.24
peak emission wavelength (λp)
[see 3.1.36]

3.9.25
receiver
[see 3.1.37]

3.9.26
repeater
[see 3.1.38]

3.9.27
repeater function
feature, by which a telegram that has been received by a node is passed on and reclocked to the next node on the network, while being logically

3.9.28
transmitter
[see 3.1.45]

3.9.29
typical half-intensity wavelength ($\Delta\lambda$)
[see 3.1.47]

3.9.30
zero bit stream
sequence of logical zeros which, in NRZI coding, results in a regular signal edge change on the transmission line (only used in test mode)

3.10 Type 18: Terms and definitions

3.10.1
activity
[see 3.1.1]

3.10.2
bit
[see 3.1.3]

3.10.3
bus
[see 3.1.4]

3.10.4
communication element
[see 3.1.6]

3.10.5
connector
[see 3.1.7]

3.10.6
Data Communications Equipment (DCE)
[see 3.1.9]

3.10.7
Data Terminal Equipment (DTE)
[see 3.1.10]

3.10.8
device
[see 3.1.13]

3.10.9
error
[see 3.1.16]

3.10.10
isolation
[see 3.1.25]

3.10.11
medium
[see 3.1.29]

3.10.12
network
[see 3.1.30]

3.10.13
node
[see 3.1.31]

3.10.14
receiver
[see 3.1.37]

3.10.15
segment
[see 3.1.39]

3.10.16
shield
[see 3.1.41]

3.10.17
spur
[see 3.1.42]

3.10.18
station
network device embodying one node

3.10.19
terminator
[see 3.1.43]

3.10.20
transceiver
[see 3.1.44]

3.10.21
transmitter
[see 3.1.45]

3.10.22
trunk
[see 3.1.46]

4 Symbols and abbreviations

4.1 Symbols

4.1.1 Type 1: Symbols

Symbol	Definition	Unit
A_{max}	Maximum inter-device attenuation	dB
AD_{max}	Maximum inter-device attenuation distortion	dB
BR	Nominal bit rate	Mbit/s
ΔBR	Maximum deviation from BR	–
CS_{max}	Maximum coupler spacing to form a cluster	m
Din_{min}	Minimum device input impedance	kΩ
dBm	Logarithmic unit of power referenced to 1 mW	dB(mW)
F_c	Center carrier frequency used in frequency shift keying	kHz
F_{c+f}	Frequency that corresponds to logical 1 in frequency shift keying	kHz
F_{c-f}	Frequency that corresponds to logical 0 in frequency shift keying	kHz
f_r	Frequency corresponding to the nominal bit rate	MHz
f_{min}	Nominal minimum frequency for the nominal bit rate	MHz
f_{max}	Nominal maximum frequency for the nominal bit rate	MHz
f_{QTOmax}	Maximum frequency for QTO_{max} measurement	MHz
L_{max}	Maximum inter-device distance	m
MD_{max}	Maximum inter-device mismatching distortion	dB
N+	Non-data symbol – positive; Manchester coded signal with a high level for one bit time, used for delimiters, carrying no data	–
N–	Non-data symbol – negative; Manchester coded signal with a low level for one bit time, used for delimiters, carrying no data	–
N_{max}	Maximum number of devices	–
P	Nominal period of octet transmission	s
PICS	Protocol Implementation Conformance Statement	–
QTO_{max}	Maximum quiescent transmitter output	mV
T_{bit}	Nominal bit duration	µs
ΔT_{bit}	Maximum deviation from T_{bit}	–
T_{rf}	Maximum signal rise or fall time	ns
V_{DD}	The most positive (or least negative) supply level	V
V_{IH}	Minimum high-level input voltage	V
V_{IL}	Maximum low-level input voltage	V
V_{OH}	Minimum high-level output voltage	V
V_{OL}	Maximum low-level output voltage	V
Z	Impedance; vector sum of resistance and reactance (inductive or capacitive)	Ω
Z_{f_r}	Characteristic impedance ; impedance of a cable, and of its terminators, at frequency f_r	Ω
Z_O	Characteristic impedance ; impedance of a cable, and of its terminators, over the defined frequency range	Ω

4.1.2 Type 2: Symbols

Symbol	Definition	Unit
dBm	Logarithmic unit of power referenced to 1 mW	dB (mW)
f_r	Frequency corresponding to the bit rate	Hz
GND	Ground supply level	V
H	Physical symbol – high level	–
L	Physical symbol – low level	–
M_0	Medium Access Control – data symbol – “zero”; Symbol at the DL-Ph interface, representing the transmitted and received Manchester coded signal with a high level for half a bit time, and a low level for half a bit time, carrying data “zero”	–
M_1	Medium Access Control – data symbol – “one”; Symbol at the DL-Ph interface, representing the transmitted and received Manchester coded signal with a low level for half a bit time, and a high level for half a bit time, carrying data “one”	–
M_ND+	Medium Access Control – non-data symbol – positive; Symbol at the DL-Ph interface, representing the transmitted and received Manchester coded signal with a high level for one complete bit time, used for delimiters, carrying no data	–
M_ND–	Medium Access Control – non-data symbol – negative; Symbol at the DL-Ph interface, representing the transmitted and received Manchester coded signal with a low level for one complete bit time, used for delimiters, carrying no data	–
Rx_H	Receive – high level (NAP interface)	V
Rx_L	Receive – low level (NAP interface)	V
Tx_H	Transmit – high level (NAP interface)	V
Tx_L	Transmit – low level (NAP interface)	V
V_{in}	Voltage on the coaxial cable center conductor (V_{in}+ or V_{in}–) as referenced to the coaxial shield	V
V_{sense}+	Positive data sensitivity limit	V
V_{sense}–	Negative data sensitivity limit	V
V_{sense}H	High carrier sensitivity limit	V
V_{sense}L	Low carrier sensitivity limit	V

4.1.3 Type 3: Symbols

Symbol	Definition	Unit
dBm	Logarithmic unit of power referenced to 1 mW	dB (mW)
f_r	Frequency corresponding to the bit rate	Hz, kHz, MHz
N–	Non-data symbol – negative; Manchester coded signal with a low level for one bit time, used for delimiters, carrying no data	–
N+	Non-data symbol – positive; Manchester coded signal with a high level for one bit time, used for delimiters, carrying no data	–
P	Nominal period of octet transmission	s
R_d	Pull-down resistor	Ω
R_t	Bus terminator	Ω
R_u	Pull-up resistor	Ω
SYN	Synchronizing bits of a frame (period of idle)	s
t_{BIT}	The bit time t_{BIT} is the time, which elapses during the transmission of one bit.	s
T_{SBIT}	Extended tolerance (only for stop bit)	s
T_{SYN}	Synchronization time	s
T_{SYNI}	Synchronization interval time	s
V_{DD}	The most positive (or least negative) supply level	V
V_{IH}	Minimum high-level input voltage	V
V_{IL}	Maximum low-level input voltage	V
V_{OH}	Minimum high-level output voltage	V
V_{OL}	Maximum low-level output voltage	V
VP	Voltage-Plus	V
Z	Impedance; vector sum of resistance and reactance (inductive or capacitive)	Ω
Z_O	Characteristic impedance ; impedance of a cable, and of its terminators, over the defined frequency range	Ω

4.1.4 Type 4: Symbols

Symbol	Definition	Unit
Vcc	The most positive (or least negative) supply level	V
GND	Ground supply level	V

4.1.5 Type 6: *This subclause has been removed*

NOTE This subclause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the subclause numbering of the prior edition.

4.1.6 Type 8: Symbols

Symbol	Definition	Unit
dBm	Logarithmic unit of power referenced to 1 mW	dB (mW)
f_r	Frequency corresponding to the bit rate	Hz
Vdd	The most positive (or least negative) supply level	V
GND	Ground supply level	V

4.1.7 Type 12: Symbols

Symbol	Definition	Unit
fr	Frequency corresponding to the nominal bit rate	MHz
N+	Non-data symbol – positive; Manchester coded signal with a high level for one bit time, used for delimiters, carrying no data	–
N–	Non-data symbol – negative; Manchester coded signal with a low level for one bit time, used for delimiters, carrying no data	–
T_{bit}	Nominal bit duration	µs
Z	Impedance; vector sum of resistance and reactance (inductive or capacitive)	Ω
Z_O	Characteristic impedance ; impedance of a cable, and of its terminators, over the defined frequency range	Ω

4.1.8 Type 16: Symbols

Symbol	Definition	Unit
j	Jitter	µs
J_{noise}	Jitter of the optical signal	µs
J_{t2}	Jitter in t_2	µs
J_{tscyc}	Jitter in t_{Scyc}	µs
P	Power	dBm or µW
P_{RmaxH}	Maximum received power at optical high level	dBm or µW
P_{RmaxL}	Maximum received power at optical low level	dBm or µW
P_{RminH}	Minimum received power at optical high level	dBm or µW
P_{TmaxH}	Maximum transmission power at optical high level	dBm or µW
P_{TmaxL}	Maximum transmission power at optical low level	dBm or µW
PTminH	Minimum transmission power at optical high level	dBm or µW
P_x	Power threshold	dBm or µW
t_{cable}	Time, by which the transmitted signal is delayed by the cable, for each unit of length (approx., 5 ns/m)	ns
t_{fri}	Time for the optical low level at the input of a slave	ns
t_{fro}	Time for the optical low level at the output of a slave	ns
t_{rep}	Time, by which the received signal is delayed by a forwarding slave (input-output)	ns
t_{ring}	Time, which a master telegram needs, until it has passed through the network and reached the master again	µs
t_{RPAT}	Maximum transition time in a slave to switch from the repeater function to the transmitter function for the AT	µs
$t_{RPAT.2}$	Maximum transition time in slave 2 to switch from the repeater function to the transmitter function for the AT	µs

4.1.9 Type 18: Symbols

Symbol	Definition	Unit
V_{DD}	Voltage potential supplied to power digital logic components	V
V_{OL}	Output voltage, low level	V
V_{OH}	Output voltage, high level	V
V_{IL}	Input voltage, low level	V
V_{IH}	Input voltage, high level	V

4.2 Abbreviations

4.2.1 Type 1: Abbreviations

CTS	Clear-to-send signal (from DCE)	
DCE	Data communication equipment	
DIS	DCE independent sublayer	
DL	Data-link (as a prefix)	[ISO/IEC 7498-1]
DLE	Data-link entity	
DLL	Data-link layer	[ISO/IEC 7498-1]
DTE	Data terminal equipment	
EMI	Electro-magnetic interference	
IDU	Interface data unit	[ISO/IEC 7498-1]
IS	Intrinsic safety	
LbE	Loopback-enable signal (to MAU)	
MAU	Medium attachment unit (for wire media, MAU = transceiver)	
MDS	Medium dependent sublayer	
min o/p	Minimum output voltage peak-to-peak	
MIS	Media independent sublayer	
NRZ	Non-return-to-zero code	

NOTE High level = logic 1, Low level = logic 0

Ph	Physical (as a prefix)	[ISO/IEC 7498-1]
PhE	Physical layer entity	[ISO/IEC 7498-1]
PhL	Physical layer [ISO/IEC 7498-1]	
PhICI	Physical layer interface control information	[ISO/IEC 7498-1]
PhID	Physical layer interface data	[ISO/IEC 7498-1]
PhIDU	Physical layer interface data unit	[ISO/IEC 7498-1]
PhPCI	Physical layer protocol control information	[ISO/IEC 7498-1]
PhPDU	Physical layer protocol data unit	[ISO/IEC 7498-1]
PhS	Physical layer service [ISO/IEC 7498-1]	
PhSAP	Physical layer service access point	[ISO/IEC 7498-1]
PhSDU	Physical layer service data unit	[ISO/IEC 7498-1]
pk	Peak	
pk-pk	Peak-to-peak	
RDF	Receive-data-and-framing signal (from DCE)	
RFI	Radio frequency interference	
RTS	Request-to-send signal (to DCE)	
RxA	Receive-activity signal (from DCE)	
RxC	Receive-clock signal (from DCE)	
RxS	Receive signal (from MAU)	
SDU	Service data unit [ISO/IEC 7498-1]	
TxC	Transmit-clock signal (from DCE)	

TxD	Transmit -data signal (to DCE)
TxE	Transmit -enable signal (to MAU)
TxS	Transmit signal (to MAU)

4.2.2 Type 2: Abbreviations

BNC	Bayonet Neill Concelman (connector for coaxial cable having a bayonet-type shell with two small knobs on the female connector, which lock into spiral slots in the male connector when it is twisted)	[IEC 60169–8]
DCE	Data communication equipment	
DL	Data-link (as a prefix)	[ISO/IEC 7498-1]
DLL	Data-link layer	[ISO/IEC 7498-1]
MAC	Medium access control (lower section of the data-link layer, interfacing with the physical layer)	
MAC ID	Medium access control identification - address of a node	
MAU	Medium attachment unit (for wire media, MAU = transceiver)	
MDS	Medium dependent sublayer	
MIS	Media independent sublayer	
NAP	Network access port (local access to a device, i.e. not via the bus)	
NetEnable	Transmit-enable signal	
NUT	Network update time	[IEC 61158-4-2]
Ph	Physical (as a prefix)	[ISO/IEC 7498-1]
PhL	Physical layer	[ISO/IEC 7498-1]
pk	Peak	
Rcv	Receive	
Rx	Receive	
RxCarrier	Receive-carrier signal	
RxData	Receive-data signal	
RxPTC	Receive-data signal (NAP interface)	
RM	Repeater machine (mechanism for extending bus length, providing multiple medium interfaces, and allowing medium redundancy)	
RRM	Ring repeater machine (mechanism for providing a ring topology on optical medium)	
SMAX	Scheduled maximum address	[IEC 61158-4-2]
TNC	Threaded Neill Concelman (threaded version of the BNC connector)	[IEC 60169–17]
Tx	Transmit	
TxDataBar	Transmit-data signal (inverted)	
TxDataOut	Transmit-data signal	
TxPTC	Transmit-data signal (NAP interface)	
Xmit	Transmit	

4.2.3 Type 3: Abbreviations

ASC	Active star coupler	
BER	Bit error rate	
CO	Converter	
CTS	Clear-to-send signal (from DCE)	
DCE	Data communication equipment	
DGND	Data ground	
DIS	DCE independent sublayer	
DL	Data-link (as a prefix)	
DLE	Data-link entity	
DLL	Data-link layer	[ISO/IEC 7498-1]
DLPDU	Data-link protocol data unit	[ISO/IEC 7498-1]
DTE	Data terminal equipment	
DUT	Device under test	
EMC	Electro-magnetic-compatibility	
EMI	Electro-magnetic interference	
FEC	Forward error correction	
FISCO	Fieldbus intrinsically safe concept [7]	
FO	Fiber optic	
FOC	Fiber optic cable	
IS	Intrinsic safety	
LbE	Loopback enable signal (to MAU)	
LSS	Line selector switch	
M/S	Master / slave station	
MAU	Medium attachment unit (for wire media, MAU = transceiver)	
MDS	Medium dependent sublayer	
MIS	Media independent sublayer	
n	Number of a station	
NRZ	Non-return-to-zero code	

NOTE High level = logic 1, Low level = logic 0

OST	Overshot of transition	
PC	Physical contact	
Ph	Physical (as a prefix)	
Ph-ASYN-DATA	Physical data service for asynchronous transmission	
PhE	Physical layer entity	[ISO/IEC 7498-1]
PhICI	Physical layer interface control information	[ISO/IEC 7498-1]
PhID	Physical layer interface data	[ISO/IEC 7498-1]
PhIDU	Physical layer interface data unit	[ISO/IEC 7498-1]
PhL	Physical layer	[ISO/IEC 7498-1]
PhM	Ph-management	

PhMS	Ph-management service	
PhPCI	Physical layer protocol control information	[ISO/IEC 7498-1]
PhPDU	Physical layer protocol data unit	[ISO/IEC 7498-1]
PhS	Physical layer service	[ISO/IEC 7498-1]
PhSAP	Physical layer service access point	[ISO/IEC 7498-1]
PhSDU	Physical layer service data unit	[ISO/IEC 7498-1]
pk-pk	Peak-to-peak	
RDF	Receive-data-and-framing signal (from DCE)	
REP	Repeater	
RFI	Radio frequency interference	
RTS	Request-to-send signal (to DCE)	
RxA	Receive-activity signal (from DCE)	
RxC	Receive-clock signal (from DCE)	
RxS	Receive Signal (from MAU)	
Stn	Stations (master or slave)	
TPC	Twisted-pair cable	
TxC	Transmit-clock signal (from DCE)	
TxD	Transmit-data signal (to DCE)	
TxE	Transmit-enable signal (to MAU)	
TxS	Transmit Signal (to MAU)	
UART	Universal asynchronous receiver/transmitter	

4.2.4 Type 4: Abbreviations

CTS	Clear-to-send signal (from DCE)	
DCE	Data communication Equipment	
DL	Data-link (as a prefix)	[ISO/IEC 7498-1]
DLE	Data-link entity	
DLL	Data-link layer	[ISO/IEC 7498-1]
DTE	Data terminal equipment	
MAU	Medium attachment unit (for wire media, MAU = transceiver)	
MDS	Medium dependent sublayer	
MIS	Media independent sublayer	
NRZ	Non-return-to-zero code	

NOTE High level = logic 1, Low level = logic 0

Ph	Physical (as a prefix)	[ISO/IEC 7498-1]
PhE	Physical layer entity	[ISO/IEC 7498-1]
PhL	Physical layer	[ISO/IEC 7498-1]
PhID	Physical layer interface data	[ISO/IEC 7498-1]
PhPDU	Physical layer protocol data unit	[ISO/IEC 7498-1]
RTS	Request-to-send signal (to DCE)	

RxS	Receive Signal (from MAU)	
TxE	Transmit-enable signal (to MAU)	
TxS	Transmit Signal (to MAU)	

4.2.5 Type 6: *This subclause has been removed*

NOTE This subclause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the subclause numbering of the prior edition.

4.2.6 Type 8: Abbreviations

BC	Bus connector	
BLL	Basic link layer	
BSY	Busy	
CPIC	Cable plant interface connector	
CRC	Cyclic redundancy check	
CTS	Clear-to-send	
DL	Data-link (as a prefix)	[ISO/IEC 7498-1]
DLL	Data-link layer	[ISO/IEC 7498-1]
DI	Data In	
DLPDU	Data-link process data unit	
DO	Data out	
DS	Data select	
GND	Ground	
ICI	Interface control information	
ID	Identifier	
LbE	Loopback enable	
LSB	Least significant byte (octet)	
MA	Medium activity	
MAC	Medium access control	
MAU	Medium attachment unit	
MDS	Medium dependent sublayer	
MIS	Media independent sublayer	
MSB	Most significant bit	
NRZ	Non-return-to-zero	
PCS	Plastic-clad silica fiber	
Ph	Physical (as a prefix)	[ISO/IEC 7498-1]
PhE	Physical layer entity	[ISO/IEC 7498-1]
PhICI	Physical interface control information	
PhIDU	Physical interface data unit	
PhL	Physical layer	[ISO/IEC 7498-1]
PhPDU	Physical protocol data unit	
PhSDU	Physical service data unit	
PNM1	Peripherals network management of layer 1	

POF	Polymer optical fiber
RI	Reset-in
RO	Reset-out
RqDly1	Request delay 1
RqDly2	Request delay 2
RTS	Request-to-send
RxA	Receive-activity
RxC	Receive-clock
RxCR	Receive control line
RxD	Receive data
RxS	Receive sequence
RxSL	Receive select line
SL	Select line
T_{Rst}	Coding and decoding (of the Reset PhPDU)
TxC	Transmit clock
TxCR	Transmit control line
TxD	Transmit data
TxS	Transmit sequence
TxSL	Transmit select line

4.2.7 Type 12: Abbreviations

EBUS	A Type 12 physical layer as described in this international standard
EOF	End of Frame
LVDS	Low Voltage Differential Signaling
PCB	Printed Circuit Board
RxS	Receive Signal
SOF	Start of Frame
TxS	Transmit Signal

4.2.8 Type 16: Abbreviations

DPLL	digital phase locked loop
HCS	hard clad silica (glass fiber)
IC	Integrated circuit
LED	light emitting diode
LSB	least significant bit
MSB	most significant bit
NRZI	non-return-to-zero-inverted
POF	polymer optical fiber (plastic fiber)
RxCLK	receiving clock
RxD	received data

TxCLK	transmitting clock
TxD	transmitted data

4.2.9 Type 18: Abbreviations

CMOS	Complimentary Metal Oxide Silicon – a class of digital logic interface specifications
DA / DB	Data A and Data B – the communications signal pair
DG	Data Ground – zero potential communications signal reference
FG	Field Ground – the zero potential device reference
NRZI	Non-Return to Zero Inverted
PhL-B	Physical layer – Basic type
PhL-P	Physical layer – Powered type
RxS	Receive Signal
SLD	Shield – linear Faraday cage
TTL	Transistor-Transistor Logic – a class of digital logic interface specifications
TxE	Transmit Enable
TxS	Transmit Signal
UL	Unit Load

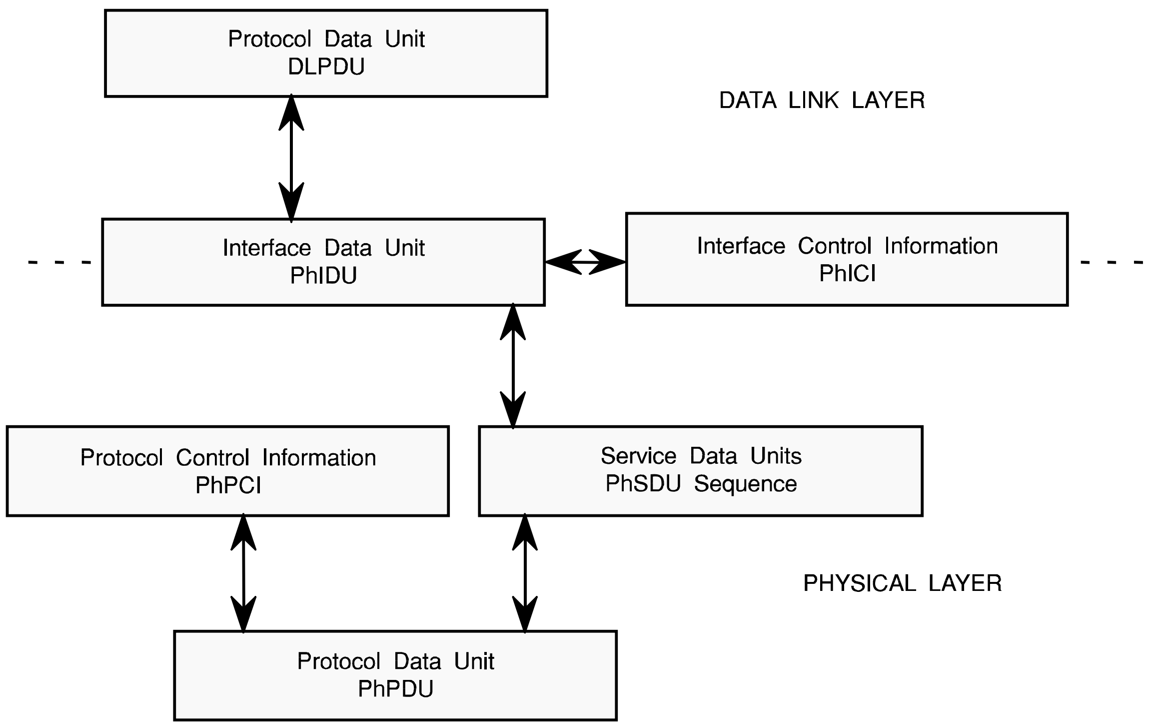
5 DLL – PhL interface

5.1 General

This clause defines the required physical service (PhS) primitives and constraints on their use.

NOTE 1 The data-link – Physical interface is a virtual service interface between virtual machines; there are no requirements for physical signal lines as the standard does not require this interface to be exposed.

PhIDUs shall be transferred between the DLL and the PhL in accordance with the requirements of ISO/IEC 7498 as shown in Figure 2.



NOTE PhPCI and PhICI support are type specific.

Figure 2 — Mapping between data units across the DLL – PhL interface

NOTE 2 These services provide for the interchange of PhIDUs between a DLL entity and its associated PhL entity. Such a transfer is part of a transaction between cooperating DLL entities. The services listed in this section are the minimum that can jointly provide the means by which cooperating DLL entities can coordinate their transmission and their exchange of data on the shared communication medium. Synchronization of data exchange and related actions is also provided if needed.

NOTE 3 Proper layering requires that an (N+1)-layer entity be not concerned with, and that an (N)-service interface not overly constrain, the means by which an (N)-layer provides its (N)-services. Thus, the Ph-service interface does not require DLEs to be aware of internal details of the PhE (e.g. preamble, postamble and frame delimiter signal patterns, number of bits per baud), and should not prevent the PhE from using appropriate evolving technologies.

NOTE 4 A number of different DLL – PhL interfaces are specified, based on industry practice.

5.2 Type 1: Required services

5.2.1 Primitives of the PhS

5.2.1.1 General

The granularity of PhS-user data exchanged at the PhL – DLL interface is one octet.

5.2.1.2 Ph-CHARACTERISTICS Indication

The PhS shall provide the following service primitive to report essential PhS characteristics (which may be used in DLL transmission, reception, and scheduling activities):

Ph-CHARACTERISTICS indication (minimum-data-rate, framing-overhead)

where

minimum-data-rate – shall specify the effective minimum rate of data conveyance in bits/s, including any timing tolerances

NOTE 1 A PhE with a nominal data rate of 1 Mbit/s ± 0,01 % would specify a minimum data rate of 0,999 9 Mbit/s.

framing overhead – shall specify the maximum number of bit periods (where the period is the inverse of the data rate) used in any transmission for PhPDUs that do not directly convey data (e.g. PhPDUs conveying preamble, frame delimiters, postamble, inter-frame "silence", etc.).

NOTE 2 If the framing overhead is F and two DL message lengths are L_1 and L_2, then the time to send one message of length $L_1 + F + L_2$ will be at least as great as the time required to send two immediately consecutive messages of lengths L_1 and L_2.

5.2.1.3 PhS transmission and reception services

The PhS shall provide the following service primitives for transmission and reception:

PH-DATA request (class, data)

PH-DATA indication (class, data)

PH-DATA confirm (status)

where

class – shall specify the PhICI component of the PhIDU.

For a PH-DATA request, its possible values shall be:

START-OF-ACTIVITY – transmission of the PhPDUs which precede Ph-user data shall commence;

DATA – the single-octet value of the associated data parameter shall be transmitted as part of a continuous correctly formed transmission; and

END-OF-DATA-AND-ACTIVITY – the PhPDUs that terminate Ph-user data shall be transmitted after the last preceding octet of Ph-user data, culminating in the cessation of active transmission.

For a PH-DATA indication, its possible values shall be:

START-OF-ACTIVITY – reception of an apparent transmission from one or more PhEs has commenced;

DATA – the associated data parameter was received as part of a continuous correctly formed reception;

END-OF-DATA – the ongoing continuous correctly formed reception of Ph-user data has concluded with correct reception of PhPDUs implying END-OF-DATA;

END-OF-ACTIVITY – the ongoing reception (of an apparent transmission from one or more PhEs) has concluded, with no further evidence of PhE transmission; and

END-OF-DATA-AND-ACTIVITY – simultaneous occurrence of END-OF-DATA and END-OF-ACTIVITY.

data – shall specify the PhID component of the PhIDU. It consists of one octet of Ph-user-data to be transmitted (PH-DATA request) or which was received successfully (PH-DATA indication).

status – shall specify either success or the locally detected reason for inferring failure.

The PH-DATA confirm primitive shall provide the critical physical timing feedback necessary to inhibit the DLE from starting a second transmission before the first is complete. The final PH-DATA confirm of a transmission shall not be issued until the PhE has completed the transmission.

5.2.2 Notification of PhS characteristics

The PhE has the responsibility for notifying the DLE of those characteristics of the PhS that may be relevant to DLE operation. The PhE shall do this by issuing a single Ph-CHARACTERISTICS indication primitive at each of the PhEs PhSAPs at PhE start-up.

5.2.3 Transmission of Ph-user-data

The PhE shall determine the timing of all transmissions. When a DLE transmits a sequence of PhSDUs, the DLE shall send the sequence of PhSDUs by making a well-formed sequence of PH-DATA requests, consisting of a single request specifying START-OF-ACTIVITY, followed by 3 to 300 consecutive requests, inclusive, specifying DATA, each conveying a PhSDU, and concluded by a single request specifying END-OF-DATA-AND-ACTIVITY.

The PhE shall signal its completion of each PH-DATA request, and its readiness to accept a new PH-DATA request, by issuing a PH-DATA confirm primitive; the status parameter of the PH-DATA confirm primitive shall convey the success or failure of the associated PH-DATA request. A second PH-DATA request shall not be issued by the DLE until after the PH-DATA confirm corresponding to the first request has been issued by the PhE.

5.2.4 Reception of Ph-user-data

The PhE shall report a received transmission with a well-formed sequence of PH-DATA indications, which shall consist of

a) a single indication specifying START-OF-ACTIVITY; followed by consecutive indications specifying DATA, each conveying a PhSDU; followed by a single indication specifying END-OF-DATA; and concluded by a single indication specifying END-OF-ACTIVITY; or
b) a single indication specifying START-OF-ACTIVITY; followed by consecutive indications specifying DATA, each conveying a PhSDU; followed by a single indication specifying END-OF-DATA-AND-ACTIVITY; or
c) a single indication specifying START-OF-ACTIVITY; optionally followed by one or more consecutive indications specifying DATA, each conveying a PhSDU; and concluded by a single indication specifying END-OF-ACTIVITY.

This last sequence is indicative of an incomplete or incorrect reception. Detection of an error in the sequence of received PhPDUs, or in the PhEs reception process, shall disable further PH-DATA indications with a class parameter specifying DATA, END-OF-DATA, or END-OF-DATA-AND-ACTIVITY until after both the end of the current period of activity and the start of a subsequent period of activity have been reported by PH-DATA indications specifying END-OF-ACTIVITY and START-OF-ACTIVITY, respectively.

5.3 Type 2: Required services

5.3.1 General

Subclause 5.3 defines the required physical service (PhS) primitives and constraints on their use.

The DLL-PhL interface need not be exposed in the implementation of any PhL variant. This interface may be internal to the node and may be implemented as internal to a semiconductor device. If, however, conformance to the DLL–PhL interface is claimed, it shall conform to the requirements of 5.3.

5.3.2 M_symbols

The PhL Interface Data Units present at the DLL-PhL interface shall be M_symbols, as shown in Table 1. The M_ND symbols shall be used to create unique data patterns used for start and end delimiters.

Table 1 — Data encoding rules

Data bits (common name)	M_symbol representation
data “zero”	M_0 or {0}
data “one”	M_1 or {1}
“non_data+”	M_ND+ or {+}
“non_data–”	M_ND– or {–}

5.3.3 PH-LOCK indication

PH-LOCK indication shall provide an indication of either data lock or Ph-symbol synchronization by the MDS. Valid states for PH-LOCK indication shall be true and false. PH-LOCK indication shall be true whenever valid Ph-symbols are present at the MDS-MAU interface and the DLL-PhL interface timing of M_symbols conform to the requirements for clock accuracy. It shall be false between frames (when no Ph-symbols are present on the medium) or whenever data synchronization is lost or the timing fails to conform to the requirements for clock accuracy. PH-LOCK indication shall be true prior to the beginning of the start delimiter.

5.3.4 PH-FRAME indication

PH-FRAME indication shall provide an indication of a valid data frame from the MAU. Valid states for PH-FRAME indication shall be true and false. PH-FRAME indication shall be true upon PH-LOCK indication = true and reception of the first valid start delimiter. PH-FRAME indication shall be false at reception of next M_ND symbol (following the start delimiter) or PH-LOCK indication = false.

NOTE This signal provides octet synchronization to the DLL.

5.3.5 PH-CARRIER indication

PH-CARRIER indication shall represent the presence of a signal carrier on the medium. PH-CARRIER indication shall be true if RXCARRIER at the MDS-MAU interface has been true during any of the last 4 M_symbol times and it shall be false otherwise.

5.3.6 PH-DATA indication

PH-DATA indication shall represent the M_symbols shown in Table 1. Valid symbols shall be M_0, M_1, M_ND+ or M_ND– (or M_symbols). The PH-DATA indication shall represent the M_Symbols as decoded from the MAU whenever PH-LOCK indication is true.

5.3.7 PH-STATUS indication

PH-STATUS indication shall represent the status of the frame that was received from the MAU as shown in Table 2. Valid symbols shall be Normal, Abort, and Invalid. PH-STATUS indication shall indicate Normal after reception of a frame (PH-FRAME indication = true) composed of a start delimiter, valid Manchester encoded data (no M_ND symbols) and an end delimiter. PH-STATUS indication shall indicate Abort after reception of a frame (PH-FRAME indication = true) composed of a start delimiter, valid Manchester encoded data, and a second start delimiter. PH-STATUS indication shall indicate Invalid after reception of a frame (PH-FRAME indication = true) composed of a start delimiter and the detection of any M_ND symbol that was not part of a start or end delimiter.

Table 2 — Ph-STATUS indication truth table

Ph-STATUS indication	Ph-FRAME indication	Start delimiters in a single frame	End delimiter detection	Any non-delimiter Manchester violations
Normal	true	1	true	false
Abort	true	2	don't care	false
Invalid	true	1	don't care	true

5.3.8 PH-DATA request

PH-DATA request shall represent the M_symbols to be transmitted. Valid symbols shall be M_0, M_1, M_ND+ or M_ND– as shown in Table 1. PH-DATA request shall indicate M_0 when no data is to be transmitted (and PH-FRAME request = false).

5.3.9 PH-FRAME request

PH-FRAME request shall be true when PH-DATA request represents M_symbols to be encoded to the appropriate Ph-symbols and transferred to the MAU, and shall be false when no valid M_symbols are to be transferred to the MAU.

5.3.10 PH-JABBER indication

PH-JABBER indication shall be true if the MDS-MAU interface detects a single frame (PH-FRAME indication = true) that equals or exceeds 1 024 octets (8 192 M_symbols) and PH-JABBER-TYPE request is true. PH-JABBER indication shall be true if the MDS-MAU interface detects a single frame (PH-FRAME indication = true) that equals or exceeds 2 048 octets (16 384 M_symbols) and PH-JABBER-TYPE request is false. PH-JABBER indication shall be false otherwise. If PH-JABBER indication goes true, it shall be latched in this state by the MDS until the Ph-JABBER-CLEAR request is true or power to the node is removed and restored or the node is initialised.

5.3.11 Ph-JABBER-CLEAR request

Ph-JABBER-CLEAR request (optional) shall be false under normal operating conditions and shall be true to reset a PH-JABBER indication that has been latched in a true state.

5.3.12 Ph-JABBER-TYPE request

PH-JABBER-TYPE request shall be true if the node is the source of transmit data ("NODE") and shall be false if the node is retransmitting data received from another node (e.g. acting as a "REPEATER" of data from another node, see Annex G).

The combinations for PH-JABBER indication and PH-JABBER-TYPE request shall be as shown in Table 3.

Table 3 — Jabber indications

Ph-JABBER indication	Ph-JABBER-TYPE request	Frame length
true	true = "NODE"	≥ 1 024 octets
true	false = "REPEATER"	≥ 2 048 octets
false	true = "NODE"	< 1 024 octets
false	false = "REPEATER"	< 2 048 octets

5.4 Type 3: Required services

5.4.1 Synchronous transmission

The services specified for Type 1 shall be used (see 5.2).

5.4.2 Asynchronous transmission

5.4.2.1 PhS transmission and reception services

The data service for asynchronous transmission (Ph-ASYN-DATA) includes two service primitives. A request primitive is used to request a service by the DLE; an indication primitive is used to indicate a reception to the DLE. The names of the respective primitives are as follows:

Ph-ASYN-DATA request

Ph-ASYN-DATA indication

The temporal relationship of the primitives is shown in Figure 3.

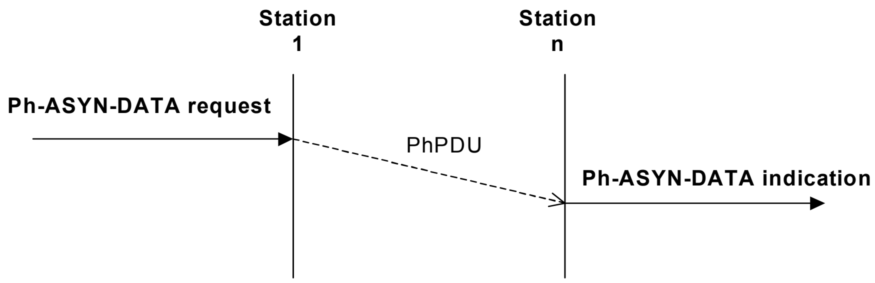


Figure 3 — Data service for asynchronous transmission

5.4.2.2 Detailed specification of the service and interaction

This subclause describes in detail the service primitives and the related parameter in an abstract way. The parameter contains the PhS-user data exchanged at the PhL – DLL interface with the granularity of one bit.

Parameters of the primitives:

Ph-ASYN-DATA request (DL_symbol)

The parameter DL_symbol shall have one of the following values specifying the PhID component of the PhIDU. Its possible values shall be:

a) ZERO corresponds to a binary "0";

b) ONE corresponds to a binary "1";

c) SILENCE disables the transmitter when no DL_symbol is to be transmitted.

The Ph-ASYN-DATA request primitive is passed from the DLE to the PhE to request that the given symbol shall be sent to the fieldbus medium.

The reception of this primitive shall cause the PhE to attempt encoding and transmission of the DL-symbol.

The Ph-ASYN-DATA request is a primitive, which shall only be generated once per DL-symbol period (t_{BIT}). The PhE may confirm this primitive with a locally defined confirmation primitive.

Ph-ASYN-DATA indication (DL_symbol).

The parameter DL_symbol shall have one of the following values:

a) ZERO corresponds to a binary "0";

b) ONE corresponds to a binary "1".

The Ph-ASYN-DATA indication primitive is passed from the PhE to the DLE to indicate that a DL-symbol was received from the fieldbus medium. The effect of receipt of this primitive by the DLE is not specified.

The Ph-ASYN-DATA indication is a primitive, which shall only be generated once per received DL-symbol period (t_{BIT}).

5.5 Type 4: Required services

5.5.1 General

PhIDUs shall be transferred between the DLL and the PhL in accordance with the requirements of ISO 7498.

5.5.2 Primitives of the PhS

5.5.2.1 General

The granularity of transmission in the fieldbus protocol is one octet. This is the granularity of PhS-user data exchanged at the PhL - DLL interface.

5.5.2.2 PhS Transmission and reception services

The PhS shall provide the following service primitives for transmission and reception:

PH-DATA request (class, data)

PH-DATA indication (class, data, status)

PH-DATA confirm (status)

where

class - specifies the Ph-interface-control-information (PhICI) component of the Ph-interface-data-unit (PhIDU).

For a PH-DATA request, its possible values are

START-OF-ACTIVITY-11 - the PhE shall initiate transmission by transmitting the associated data parameter as an "Address character". The PhE shall do this immediately, though not until the value of the PhEs idle counter has reached 11. This class only applies to half duplex mode.

START-OF-ACTIVITY-2 - the PhE shall enable its driver, and initiate transmission by transmitting the associated data parameter as an "Address character". The PhE shall do this immediately, though not until the value of the PhEs idle counter modulus 10 has reached 2 if in half duplex mode.

DATA - the PhE shall transmit the associated data parameter as a “Data character”.

END-OF-ACTIVITY – the PhE shall wait until transmission of all formerly received data from the DLE has finished, and then terminate transmission. The associated data parameter shall not be transmitted.

For a PH-DATA indication, its possible values are

START-OF-ACTIVITY – the PhE has received an "Address character", the value of which is reported in the associated data parameter. The associated status parameter specifies success or the locally detected reason for failure.

DATA – the PhE has received a "Data character", the value of which is reported in the associated data parameter. The associated status parameter specifies success or the locally detected reason for failure.

LINK-IDLE – the PhE has detected, that the signal level on the Link has been "Idle" for 30, 35, 40, 50, 60… bit periods. The associated status parameter specifies if the Link has been idle for 30 bit periods, for 35 bit periods, or for 40 or more bit periods. This class only applies to half duplex mode.

data – specifies the Ph-interface-data (PhID) component of the PhIDU. It consists of one octet of Ph-user data to be transmitted (PH-DATA request), or one octet of Ph-user data that was received (PH-DATA indication).

status – specifies either success or the locally detected reason for failure, or specifies if the associated LINK-IDLE indication indicates "30", "35" or "40 or more" bit periods of idle after Link activity.

The PH-DATA confirm primitive provides the feedback necessary to enable the DLE to report failures such as Link short-circuit or noise resulting in framing error to the DLS-user, and provides the critical physical timing necessary to prevent the DLE from starting a second transmission before the first is complete.

5.5.3 Transmission of Ph-user data

5.5.3.1 General

When a DLE has a DLPDU to transmit, and the Link-access system gives that DLE the right to transmit, then the DLE should send the DLPDU, including a concatenated FCS. Making a sequence of PH-DATA requests as follows does this:

a) In half duplex mode, the first request should specify START-OF-ACTIVITY-11 if the DLPDU to transmit is an Acknowledge or Immediate-reply DLPDU, or if the transmission is an immediate re-transmission of a Confirmed or Unconfirmed DLPDU. The first request should specify START-OF-ACTIVITY-2 if transmission of a Confirmed or Unconfirmed DLPDU from the queue is commenced. In full duplex mode, the first request should always specify START-OF-ACTIVITY-2.

b) This first request should be followed by consecutive requests specifying DATA, and concluded by a single request specifying END-OF-ACTIVITY.

The PhE signals its completion of each PH-DATA request, and its readiness to accept a new PH-DATA request, with a PH-DATA confirm primitive. The status parameter of the PH-DATA confirm primitive conveys the success or failure of the associated PH-DATA request.

5.5.3.2 Reception of Ph-user data

The PhE reports a received transmission with PH-DATA indications, which shall consist of either

– a single indication specifying START-OF-ACTIVITY, or

– a single indication specifying START-OF-ACTIVITY; followed by consecutive indications specifying DATA.

Each indication has an associated status parameter, specifying successful reception of the associated data, or the locally detected reason for failure.

5.6 Type 6: *This subclause has been removed*

NOTE This subclause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the subclause numbering of the prior edition.

5.7 Type 8: Required services

5.7.1 General

PhIDUs are exchanged between the DLL (DLL) and the PhL (PhL). For the data transfer, the DL-Ph interface (MAC-MIS interface) shall make the following service primitives available:

PH-DATA request

PH-DATA confirm

PH-DATA indication

5.7.2 Primitives of the PhS

5.7.2.1 PH-DATA request (PhICI, PhIDU)

This service primitive is used to transfer a data unit from the MAC sublayer to the MIS. The **PhICI** parameter determines the interface components of the interface data unit (PhIDU) to be transmitted and can contain the following values:

ID_transfer
The beginning of a data sequence for the transmission of identification/control data is requested.

data_transfer
The beginning of a data sequence for the transmission of user data is requested.

start_ID_cycle
The beginning of an identification cycle for the transmission of identification/control data is requested by the master.

start_data_cycle
The beginning of a data cycle for the transmission of user data is requested by the master.

user_data
The transmission of the data unit of user data defined by the PhIDU parameter (identification/control data or user data) is requested.

CRC_data
The transmission of the data unit of checksum data defined by the PhIDU parameter is requested.

CRC_status
The transmission of the data unit for the checksum status defined by the PhIDU parameter is requested.

user_data_idle
The transmission of user_data_idle messages is requested.

CRC_data_idle
The transmission of CRC_data_idle messages is requested.

CRC_status_idle
The transmission of CRC_status_idle messages is requested.

NOTE The start_data_cycle and start_ID_cycle parameters are supported by the MAC sublayer of a master only.

The **PhIDU** parameter defines the data component of the interface data unit to be transmitted. It consists of one bit, only if PhICI = user_data, CRC_data or CRC_status

5.7.2.2 PH-DATA confirm (status)

This service primitive is the acknowledgement to a PH-DATA request primitive and is used for synchronisation. The **status** parameter indicates whether the associated PH-DATA request primitive was executed successfully or not.

5.7.2.3 PH-DATA indication (PhICI, PhIDU)

This service primitive is used to transfer a data unit from the MIS to the MAC sublayer. The **PhICI** parameter defines the interface component of the interface data unit (PhIDU) to be transmitted and can assume the following values:

ID_transfer
Indicates the beginning of a data sequence for the transmission of identification/control data.

data_transfer
Indicates the beginning of a data sequence for the transmission of user data.

user_data
The correct receipt of the data unit for the transmission of user data (identification/control data or user data) defined by the PhIDU parameter is indicated.

CRC_data
The correct receipt of the data unit for transmission of the checksum defined by the PhIDU parameter is indicated.

CRC_status
The correct receipt of the data unit for the transmission of the checksum status defined by the PhIDU parameter is indicated.

user_data_idle
The receipt of user_data_idle messages is indicated.

CRC_data_idle
The receipt of CRC_data_idle messages is indicated.

CRC_status_idle
The receipt of CRC_status_idle messages is indicated.

The **PhIDU** parameter defines the data components of the received interface data unit. It consists of one bit.

5.7.3 Overview of the Interactions

NOTE For the data transfer via the DL-Ph interface, a difference is made between the data sequence (transmission of user or identification data) and the check sequence (transmission of checksum data).

The following apply to Figure 4 through Figure 7.

– If a data sequence of a data cycle is followed by a data sequence of an identification cycle, the interactions marked with (+) are omitted for an identification cycle.

– If a data sequence of an identification cycle is followed by a data sequence of a data cycle, the interactions marked with (+) are omitted for a data cycle.

5.7.3.1 Data Sequence

5.7.3.1.1 Master

Figure 4 and Figure 5 show the interactions for a data sequence (identification cycle and data cycle) at the DL-Ph interface of a master (controller board).

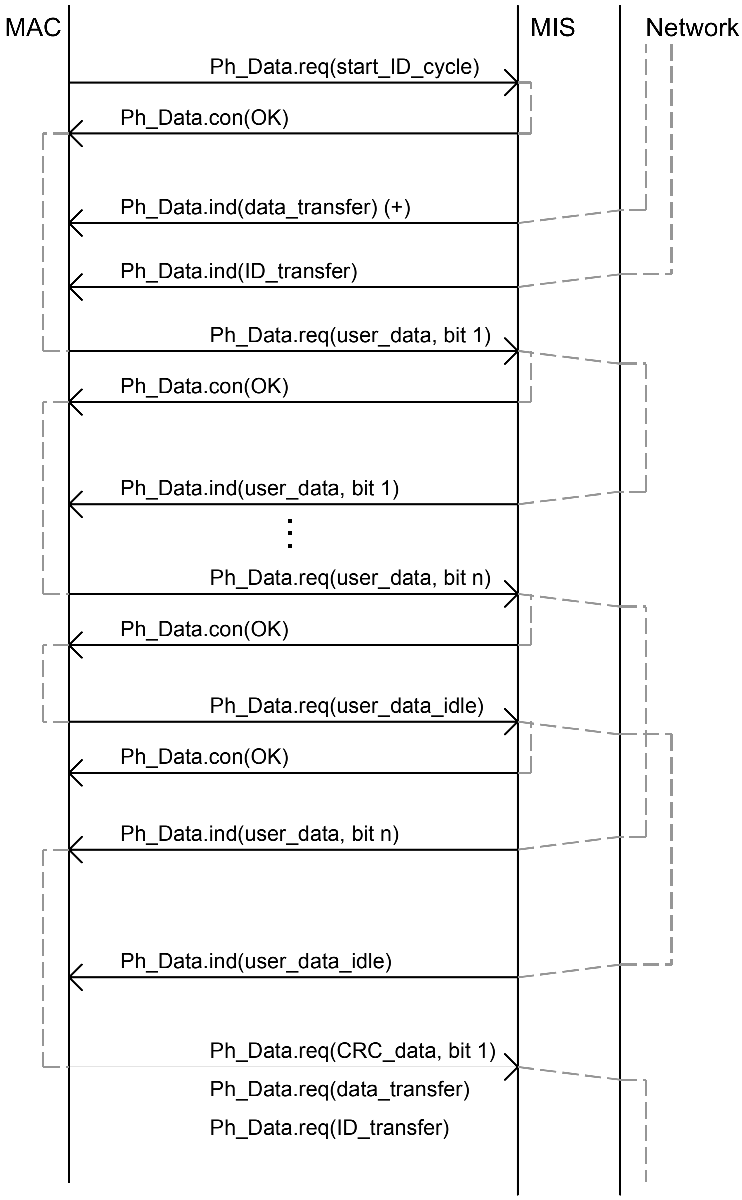


Figure 4 — Interactions for a data sequence of a master: identification cycle

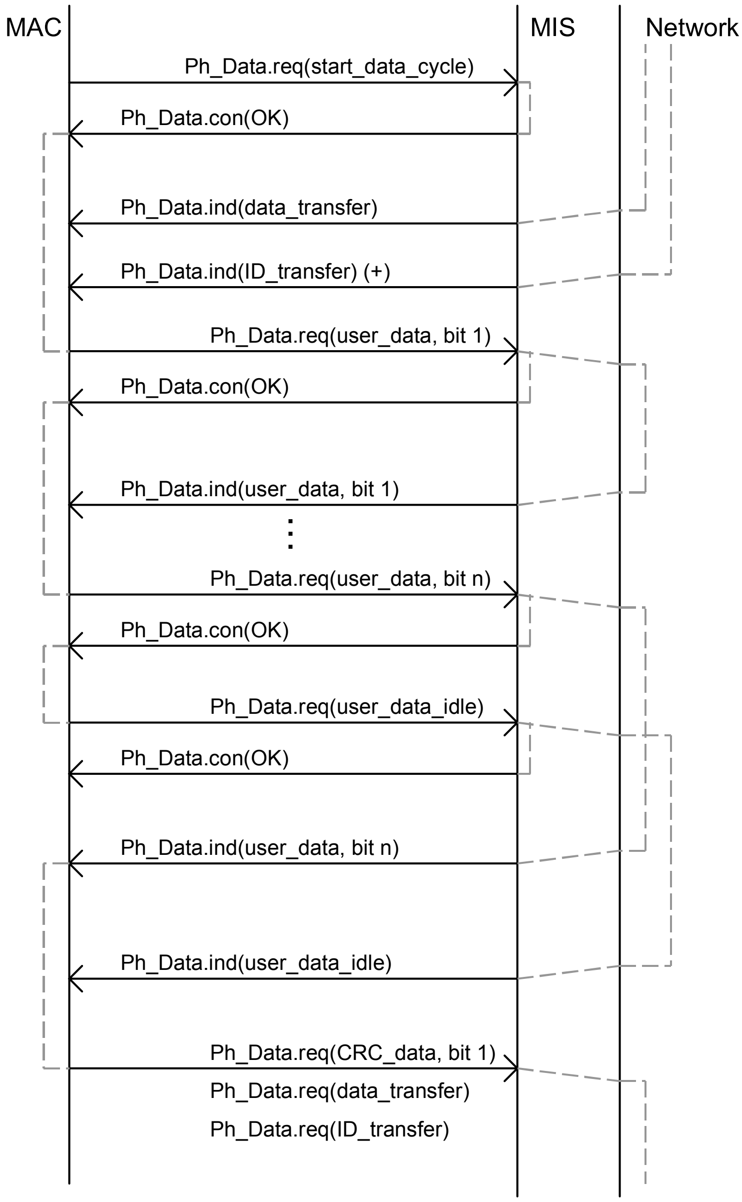


Figure 5 — Interactions for a data sequence of a master: data cycle

5.7.3.1.2 Slave

Figure 6 and Figure 7 show the interactions for a data sequence (identification cycle and data cycle) at the DL-Ph interface of a slave (remote bus device, local bus device or bus coupler).

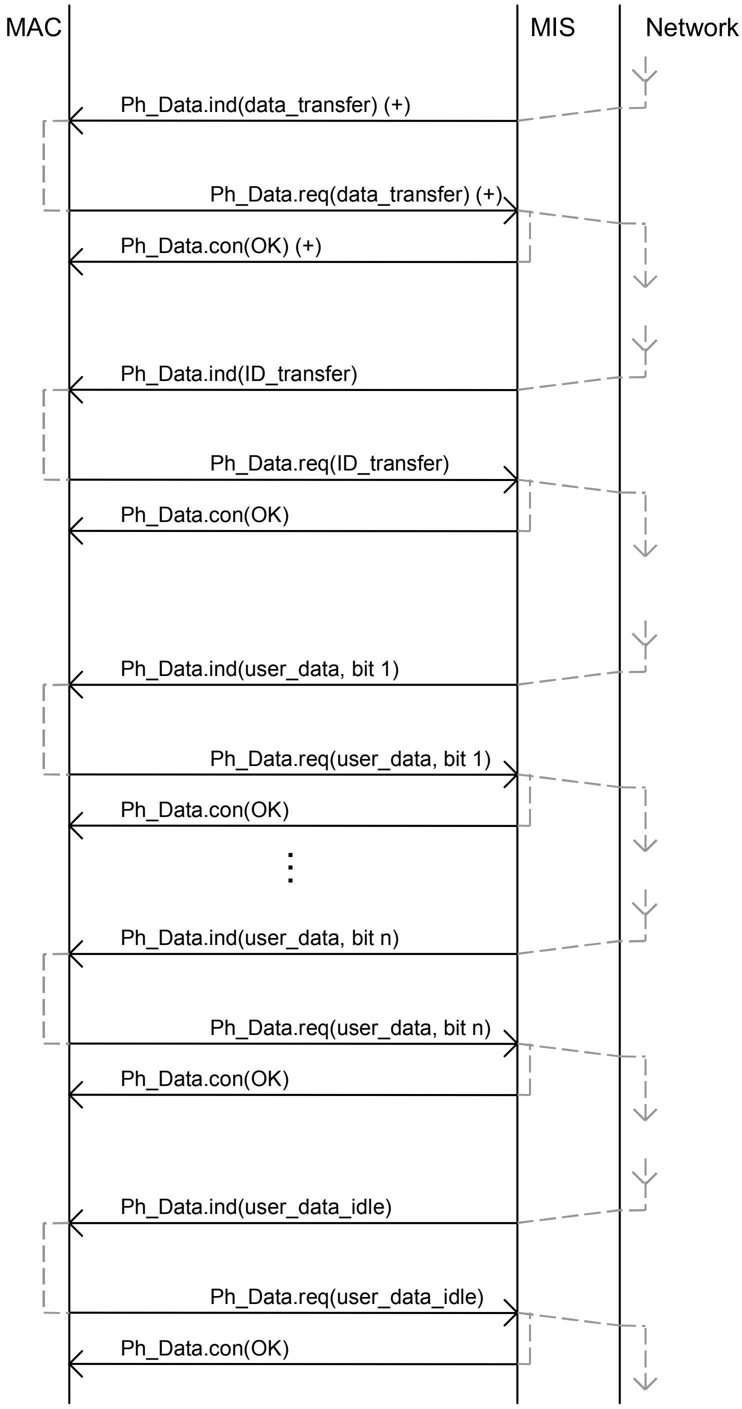


Figure 6 — Interactions for a data sequence of a slave: identification cycle

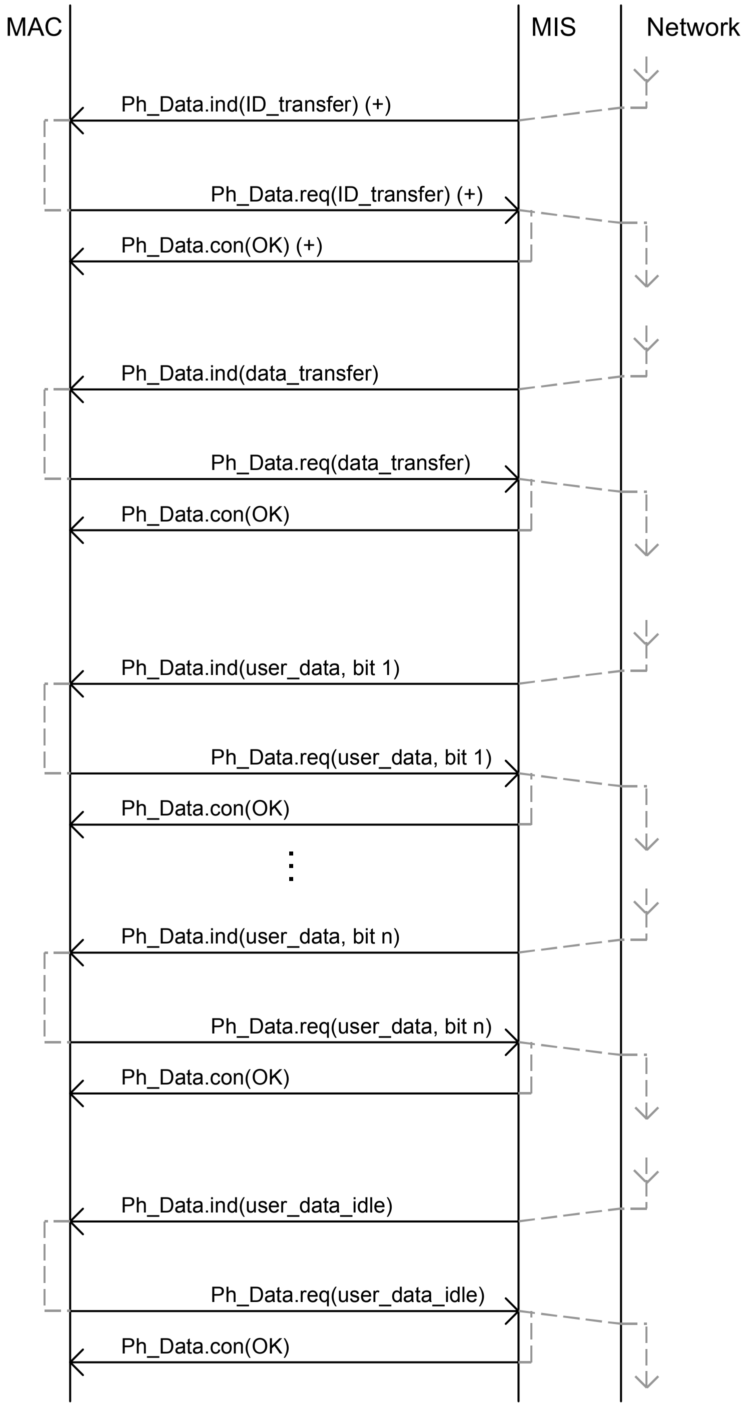


Figure 7 — Interactions for a data sequence of a slave: data cycle

5.7.3.2 Check sequence

5.7.3.2.1 Master

Figure 8 shows the interactions for a check sequence at the DL-Ph interface of a master.

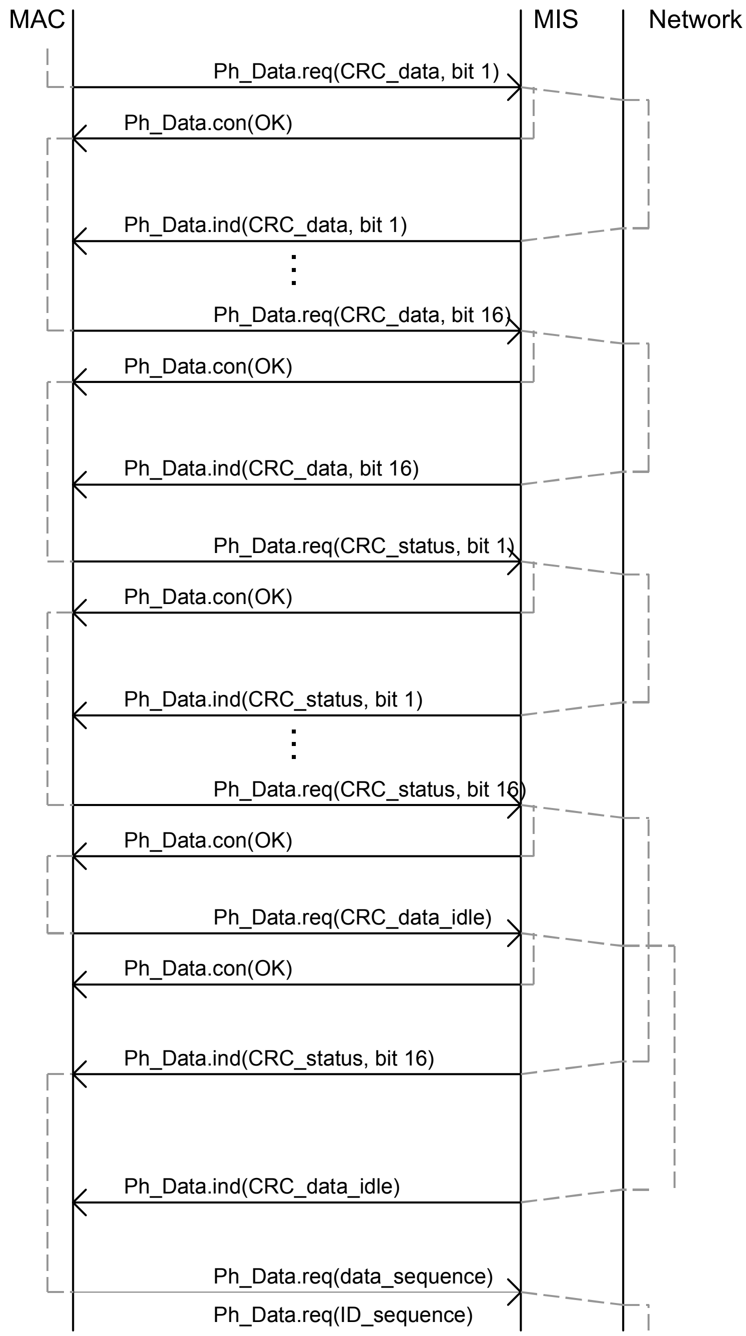


Figure 8 — Interactions for a check sequence of a master

5.7.3.3 Slave

Figure 9 shows the interactions for a check sequence at the DL-Ph interface of a slave.

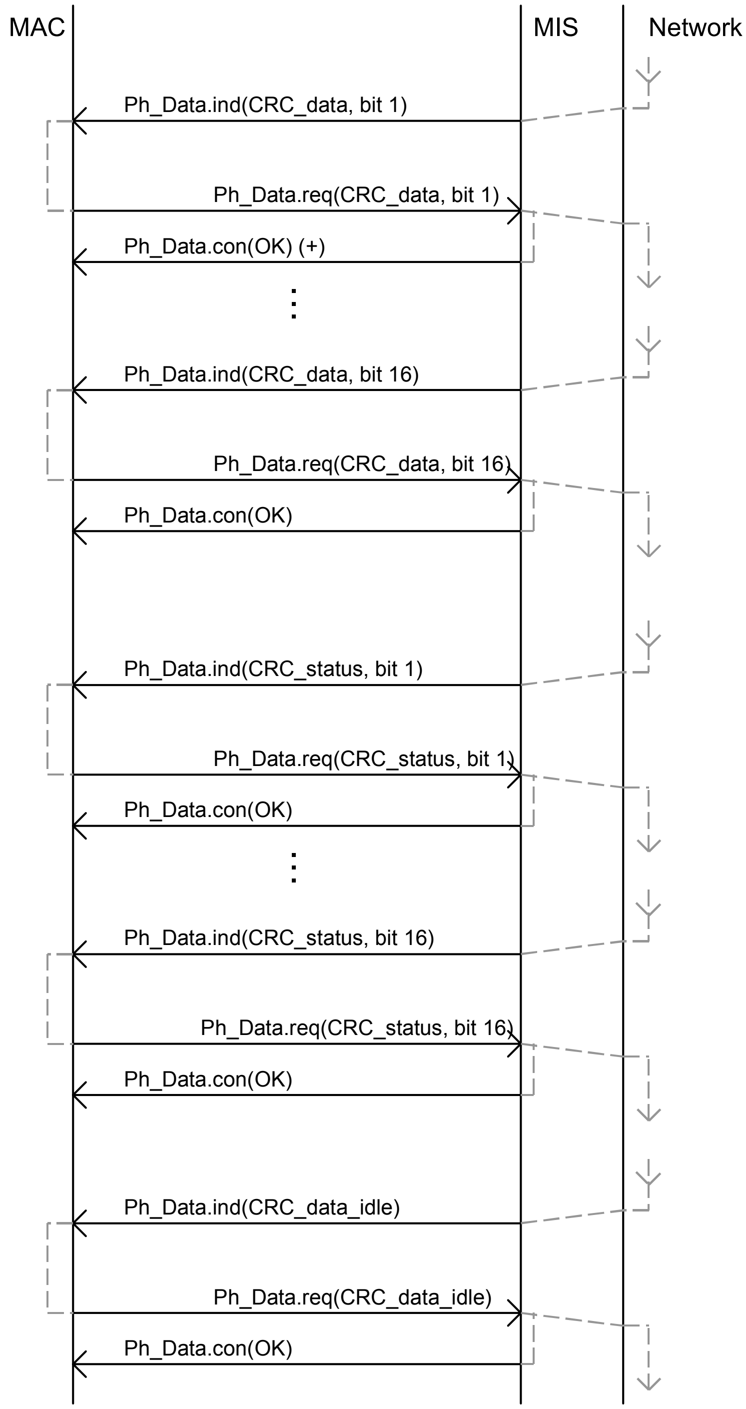


Figure 9 — Interactions for a check sequence of a slave

5.8 Type 12: Required services

5.8.1 Primitives of the PhS

5.8.1.1 General

The granularity of PhS-user data exchanged at the PhL – DLL interface is one octet.

5.8.1.2 Ph-CHARACTERISTICS Indication

The PhS shall provide the following service primitive to report essential PhS characteristics (which may be used in DLL transmission, reception, and scheduling activities):

— Ph-CHARACTERISTICS indication (minimum-data-rate, framing-overhead)

where

— minimum-data-rate – shall specify the effective minimum rate of data conveyance in bits per second, including any timing tolerances;

NOTE 1 A PhE with a nominal data rate of 100 Mbit/s ± 0,01 % would specify a minimum data rate of 99,99 Mbit/s.

— framing overhead – shall specify the maximum number of bit periods (where the period is the inverse of the data rate) used in any transmission for PhPDUs that do not directly convey data (e.g. PhPDUs conveying frame delimiters, inter-frame "silence", etc.).

NOTE 2 If the framing overhead is F and two DL message lengths are L_1 and L_2, then the time to send one message of length $L_1 + F + L_2$ will be at least as great as the time required to send two immediately consecutive messages of lengths L_1 and L_2.

5.8.1.3 PhS transmission and reception services

The PhS shall provide the following service primitives for transmission and reception:

— PH-DATA request (class, data);

— PH-DATA indication (class, data);

— PH-DATA confirm (status).

where

— class – shall specify the PhICI component of the PhIDU.

For a PH-DATA request, its possible values shall be:

— START-OF-FRAME – transmission of the PhPDUs which precede Ph-user data shall commence;

— DATA – the single-octet value of the associated data parameter shall be transmitted as part of a continuous correctly formed transmission; and

— END-OF-FRAME – the PhPDUs that terminate Ph-user data shall be transmitted after the last preceding octet of Ph-user data.

For a PH-DATA indication, its possible values shall be:

— START-OF-FRAME – reception of an apparent transmission from one or more PhEs has commenced;

— DATA – the associated data parameter was received as part of a continuous correctly formed reception;

— END-OF-FRAME – the ongoing continuous correctly formed reception of Ph-user data has concluded with correct reception of PhPDUs;

— END-W-ERROR – the ongoing continuous correctly formed reception of Ph-user data was disrupted with not correct formed reception implying END-OF-FRAME WITH ERROR;

— data – shall specify the PhID component of the PhIDU. It consists of one octet of Ph-user-data to be transmitted (PH-DATA request) or which was received successfully (PH-DATA indication);

— status – shall specify either success or the locally detected reason for inferring failure.

The PH-DATA confirm primitive shall provide the critical physical timing feedback necessary to inhibit the DLE from starting a second transmission before the first is complete. The final PH-DATA confirm of a transmission shall not be issued until the PhE has completed the transmission.

5.8.2 Notification of PhS characteristics

The PhE has the responsibility for notifying the DLE of those characteristics of the PhS that may be relevant to DLE operation. The PhE shall do this by issuing a single Ph-CHARACTERISTICS indication primitive at each of the PhEs at PhE start-up.

5.8.3 Transmission of Ph-user-data

The PhE shall determine the timing of all transmissions. When a DLE transmits a sequence of PhSDUs, the DLE shall send the sequence of PhSDUs by making a well-formed sequence of PH-DATA requests, consisting of a single request specifying START-OF-FRAME, followed by 72 to 1 535 consecutive requests, inclusive, specifying DATA, each conveying a PhSDU, and concluded by a single request specifying END-OF-FRAME.

The PhE shall signal its completion of each PH-DATA request, and its readiness to accept a new PH-DATA request, by issuing a PH-DATA confirm primitive; the status parameter of the PH-DATA confirm primitive shall convey the success or failure of the associated PH-DATA request. A second PH-DATA request shall not be issued by the DLE until after the PH-DATA confirm corresponding to the first request has been issued by the PhE.

5.8.4 Reception of Ph-user-data

The PhE shall report a received transmission with a well-formed sequence of PH-DATA indications, which shall consist of

a) a single indication specifying START-OF-FRAME; followed by consecutive indications specifying DATA, each conveying a PhSDU; and concluded by a single indication specifying END-OF-FRAME; or

b) a single indication specifying START-OF-FRAME; optionally followed by one or more consecutive indications specifying DATA, each conveying a PhSDU; and concluded by a single indication specifying END-W-ERROR.

This last sequence is indicative of an incomplete or incorrect reception. Detection of an error in the sequence of received PhPDUs, or in the PhEs reception process, shall disable further PH-DATA indications with a class parameter specifying DATA, or END-OF-FRAME until after both the end of the current period of activity and the start of a subsequent period of activity have been reported by PH-DATA indications specifying START-OF-FRAME.

5.9 Type 16: Required services

5.9.1 Primitives of the PhS

5.9.1.1 General

The granularity of PhS-user data exchanged at the PhL – DLL interface shall be one octet.

5.9.1.2 PhS transmission and reception services

The PhS shall provide the following service primitives for transmission and reception:

— Ph-Data request (class, data);

— Ph-Data indication (class, data);

— Ph-Data confirm (status)

where

— class – shall specify the PhICI component of the PhIDU.

For a Ph-Data request, its possible values shall be:

— start-of-activity – transmission of the PhPDUs which precede Ph-user data shall commence;

— data – the single-octet value of the associated data parameter shall be transmitted as part of a continuous correctly formed transmission; and

— end-of-data-and-activity – the PhPDUs that terminate Ph-user data shall be transmitted after the last preceding octet of Ph-user data, culminating in the cessation of active transmission.

For a Ph-Data indication, its possible values shall be:

— start-of-activity – reception of an apparent transmission from the PhE has commenced;

— data – the associated data parameter was received as part of a continuous correctly formed reception;

— end-of-data – the ongoing continuous correctly formed reception of Ph-user data has concluded with correct reception of PhPDUs implying end-of-data;

— data – shall specify the PhID component of the PhIDU. It consists of one octet of Ph-user-data to be transmitted (Ph-Data request) or which was received successfully (Ph-Data indication);

— status – shall specify either success or the locally detected reason for inferring failure.

The Ph-Data confirm primitive shall provide the critical physical timing feedback necessary to inhibit the DLE from starting a second transmission before the first is complete. The final Ph-Data confirm of a transmission shall not be issued until the PhE has completed the transmission.

5.9.2 Transmission of Ph-user-data

The PhE shall determine the timing of all transmissions. When the DLE transmits a sequence of PhSDUs, it shall send the sequence of PhSDUs by making a well-formed sequence of Ph-Data requests, consisting of a single request specifying start-of-activity, followed by the required number of consecutive requests, inclusive, specifying data, each conveying a PhSDU, and concluded by a single request specifying end-of-data-and-activity.

The PhE shall signal its completion of each Ph-Data request, and its readiness to accept a new Ph-Data request, by issuing a Ph-Data confirm primitive; the status parameter of the Ph-Data confirm primitive shall convey the success or failure of the associated Ph-Data request. A second Ph-Data request shall not be issued by the DLE until after the Ph-Data confirm corresponding to the first request has been issued by the PhE.

5.9.3 Reception of Ph-user-data

The PhE shall report a received transmission with a well-formed sequence of Ph-Data indications, which shall consist of

a) a single indication specifying start-of-activity; followed by consecutive indications specifying data, each conveying a PhSDU; followed by a single indication specifying end-of-data; and concluded by a single indication specifying end-of-activity; or
b) a single indication specifying start-of-activity; followed by consecutive indications specifying data, each conveying a PhSDU; followed by a single indication specifying end-of-data-and-activity; or
c) a single indication specifying start-of-activity; optionally followed by one or more consecutive indications specifying data, each conveying a PhSDU; and concluded by a single indication specifying end-of-activity.

This last sequence is indicative of an incomplete or incorrect reception. Detection of an error in the sequence of received PhPDUs, or in the PhEs reception process, shall disable further Ph-Data indications with a class parameter specifying data, end-of-data, or end-of-data-and-activity until after both the end of the current period of activity and the start of a subsequent period of activity have been reported by Ph-Data indications specifying end-of-activity and start-of-activity, respectively.

5.10 Type 18: Required services

5.10.1 General

The DLL-PhL interface need not be exposed in the implementation of a Type 18 PhE. This interface may be internal to the node and may be implemented as internal to a semiconductor device.

5.10.2 Primitives of the PhS

5.10.2.1 General

The granularity of PhS-user data exchanged at the DLL – PhL interface is one bit.

5.10.2.2 PhS transmission and reception services

The PhS shall provide the following service primitives for transmission and reception:

— PH-DATA request (class, data);

— PH-DATA indication (class, data);

— PH-DATA confirm (status).

where:

- **class** - specifies the Ph-interface-control-information (PhICI) component of the Ph-interface-data-unit (PhIDU).

For a PH-DATA request, possible values of class are:

— START-OF-ACTIVITY – transmission of the PhPDUs which precede Ph-user data shall commence;

— DATA – the single-bit value of the associated data parameter shall be transmitted as part of a continuous correctly formed transmission; and

— END-OF-ACTIVITY – the PhPDUs that terminate Ph-user data shall be transmitted after the last preceding bit of Ph-user data, culminating in the cessation of active transmission.

For a PH-DATA indication, possible values of class are:

— START-OF-ACTIVITY – reception of an apparent transmission from one or more PhEs has commenced;

— DATA – the associated data parameter was received as part of a continuous correctly formed reception;

— END-OF-ACTIVITY – the ongoing reception (of an apparent transmission from one or more PhEs) has concluded, with no further evidence of PhE transmission; and

- **data** – shall specify the PhID component of the PhIDU. It consists of one bit of Ph-user-data to be transmitted (PH-DATA request) or which was received successfully (PH-DATA indication).

  and

- **status** – shall specify either success or the locally detected reason for inferring failure.

The PH-DATA confirm primitive shall provide the critical physical timing feedback necessary to inhibit the DL-user from starting a second transmission before the first is complete. The final PH-DATA confirm of a transmission shall not be issued until the PhE has completed the transmission.

5.10.3 Transmission of Ph-user-data

The PhE shall determine the timing of all transmissions. When a DLE transmits a sequence of PhSDUs, the DLE shall send the sequence of PhSDUs by making a well-formed sequence of PH-DATA requests, consisting of a single request specifying START-OF-ACTIVITY, followed by a series of consecutive requests specifying DATA, each conveying a PhSDU, and concluded by a single request specifying END-OF-ACTIVITY.

The PhE shall signal its completion of each PH-DATA request, and its readiness to accept a new PH-DATA request, by issuing a PH-DATA confirm primitive; the status parameter of the PH-DATA confirm primitive shall convey the success or failure of the associated PH-DATA request. A second PH-DATA request shall not be issued by the DLE until after the PH-DATA confirm corresponding to the first request has been issued by the PhE.

5.10.4 Reception of Ph-user-data

The PhE shall report a received transmission with a well-formed sequence of PH-DATA indications, which shall consist of a single indication specifying START-OF-ACTIVITY; followed by consecutive indications specifying DATA, each conveying a PhSDU; followed by a single indication specifying END-OF-ACTIVITY.

6 Systems management – PhL interface

6.1 General

This interface provides services to the PhL, which are required for initialisation and selection of options.

One of the objectives of the PhL is to allow for future variations such as radio, fiber optics, redundant channels (e.g. cables), different modulation techniques, etc. A general form of Systems management – PhL Interface is specified which provides the services required by implementations of these variations. Services provided by this interface are specified in 6.2 through 6.5. The standard does not require this interface to be exposed.

The complete set of management services can only be used when the device is directly coupled to the medium. In the case of actively coupled equipment (e.g. active coupler, repeater, radio/telephone modem, opto-electronics, etc.) some of the services can be implicit to the active coupler. Moreover, each device can use a subset of the described primitives.

NOTE A number of different Systems management – PhL interfaces are specified, based on industry practice.

6.2 Type 1: Systems management – PhL interface

6.2.1 Required services

The minimum service primitive for PhL (PhL) management shall be:

a) PH-RESET request – reset of the Ph-Layer.

The following additional services may be provided:

b) Ph-SET-VALUE request/Ph-SET-VALUE confirm – set parameters;

c) Ph-GET-VALUE request/Ph-GET-VALUE confirm – read parameters;

d) Ph-EVENT indication – report Ph-Layer events.

6.2.2 Service primitive requirements

6.2.2.1 PH-RESET request

This primitive has no parameter. Upon reception of this primitive the PhL shall reset all its functions.

6.2.2.2 Ph-SET-VALUE request (parameter name, new value)

If this primitive is used it shall allow Systems management to modify the parameters of the PhL. Standard parameter names and value ranges are given in Table 4. The value assumed for each parameter at reset shall be the first of those shown for the parameter.

Table 4 — Parameter names and values for Ph-SET-VALUE request

Parameter name	Range of values
Interface mode	• FULL_DUPLEX • HALF_DUPLEX
Loop-back mode	• DISABLED • in MDS at DTE – DCE interface • in MAU near line connection
Preamble extension	• 0..7 (preamble extension sequences)
Post-transmission gap extension	• 0..7 (gap extension sequences)
Maximum inter-channel signal skew	• 0..7 (gap extension sequences)
Transmitter output channel *N* (1 ≤ *N* ≤ 8)	• ENABLED • DISABLED
Receiver input channel *N* (1 ≤ *N* ≤ 8)	• ENABLED • DISABLED
Preferred receive channel	• NONE • 1..8

NOTE 1 Not all implementations require every parameter, and some may need more.

NOTE 2 Each DCE standard specifies both the basic and extension sequences of PhPDUs to be sent as preamble. These extension sequences are always prefixed to the basic sequence.

NOTE 3 Each DCE standard specifies the lengths of both the basic and extension sequences of post-transmission gap during which the transmitter should be silent.

NOTE 4 From the above, the default value at reset is minimum preamble (no extension), minimum post-transmission gap (no extension), full-duplex interface mode, not in loopback, with all transmit and receive channels enabled, and with no preferred receive channel.

6.2.2.3 Ph-SET-VALUE confirm (status)

This primitive has a single parameter indicating the status of the request: Success or Failure. If this primitive is used it shall acknowledge completion of the Ph-SET-VALUE request in the PhL.

6.2.2.4 Ph-GET-VALUE request (parameter name)

If this primitive is used it shall allow the Systems management to read the parameters of the PhL. The parameter shall have one of the names given in Table 4.

6.2.2.5 Ph-GET-VALUE confirm (current value)

This primitive is the response of the PhL to the Ph-GET-VALUE request. If this primitive is used it shall have a single parameter reporting either the failure of the request – Failure – or the present value of the requested parameter. The current value shall be one of those permitted by 6.2.2.2.

6.2.2.6 Ph-EVENT indication (parameter name)

If this primitive is used it shall notify the Systems management of a PhL parameter modification which has not been requested by the Systems management. The parameter shall have one of the names given in Table 5, based on names specified in 8.2.

Table 5 — Parameter names for Ph-EVENT indication

Parameter name
DTE fault
DCE fault

NOTE Additions to Table 5 are possible if required by specific implementations.

6.3 Type 3: Systems management – PhL interface

6.3.1 Synchronous transmission

The services and the service primitive requirements specified for Type 1 shall be used (see 6.2).

6.3.2 Asynchronous transmission

6.3.2.1 General

This and the following subclauses describe the interface between the PhL asynchronous transmission and a PhMS-user and the associated service primitives and parameters.

The service model, service primitives, and time-sequence diagrams used are entirely abstract descriptions; they do not represent a specification for implementation.

Service primitives, used to represent service user/service provider interactions (see ISO/IEC 10731), convey parameters that indicate information available in the user/provider interaction.

This Type of this standard uses a tabular format to describe the component parameters of the PhMS primitives. Each table consists of up to three columns, containing the name of the service parameter, and a column each for those primitives and parameter-transfer directions used by the PhMS:

– the request primitive's input parameters;

– the indication primitive's output parameters; and

– the confirm primitive's output parameters.

One parameter (or part of it) is listed in each row of each table. Under the appropriate service primitive columns, a code is used to specify the type of usage of the parameter on the primitive and parameter direction specified in the column:

M – parameter is mandatory for the primitive.

(**blank**) – parameter is never present.

6.3.2.2 Facilities of the PhMS

Ph-management organizes the initialisation and the configuration of the PhE, and the event and error handling between the PhMS-user and the logical functions in the PhE. The following functions are provided to the PhMS-user.

a) Reset of the local PhE
b) Request for and modification of the actual operating parameters of the local PhE
c) Notification of unexpected events and status changes of the local PhE

6.3.2.3 Overview of services

Ph-management provides the following services to the PhMS-user:

a) Reset

The PhMS-user employs this service to cause Ph-management to reset the PhE. A reset is equivalent to power on. The PhMS-user receives a confirmation thereof.

b) Set Value

The PhMS-user employs this service to assign a new value to the variables of the PhE. The PhMS-user receives a confirmation whether the specified variables have been set to the new value.

c) Get Value

This service enables Ph-management to read the variables of the PhE. The response of the Ph-management returns the actual value of the specified variables.

d) Event

Ph-management employs this service to inform the PhMS-user about certain events or errors in the PhL.

The services Reset and Event are mandatory. The services Set Value and Get Value are optional.

6.3.2.4 Overview of interactions

Ph-management services and their primitives are summarized in Table 6.

Table 6 — Summary of Ph-management services and primitives

Service	Primitive	Possible for the following stations
Reset	PhM-RESET request PhM-RESET confirm	Master and slave
Set Value	PhM-SET-VALUE request PhM-SET-VALUE confirm	Master and slave
Get Value	PhM-GET-VALUE request PhM-GET-VALUE confirm	Master and slave
Event	PhM-EVENT indication	Master and slave

The temporal relationships of the Ph-management primitives are shown in Figure 10 and Figure 11.

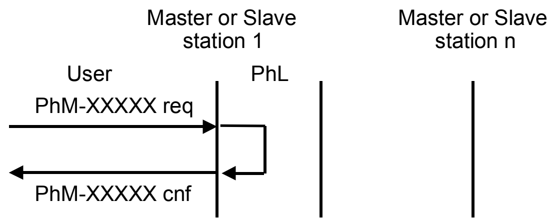


Figure 10 — Reset, Set-value, Get-value

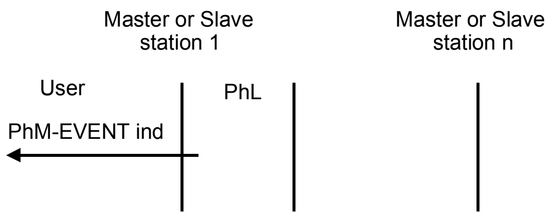


Figure 11 — Event service

6.3.2.5 Detailed specification of services and interactions

6.3.2.5.1 Reset

6.3.2.5.1.1 Function

The PhMS-user passes a PhM-RESET request primitive to Ph-management causing it to reset the PhE. This is carried out in the same manner as at a Power On (Transmitter_output: enabled; Receiver_signal_source: primary; Loop: disabled). As a result, Ph-management passes a PhM-RESET confirm primitive to the PhMS-user to indicate the success or failure of the corresponding service request.

6.3.2.5.1.2 Types of primitives and parameters

Table 7 indicates the primitives and parameters of the Reset service.

Table 7 — Reset primitives and parameters

PhM-RESET	Request	Confirm
Parameter name	**input**	**output**
PhM-STATUS		M
NOTE The method by which a confirm primitive is correlated with its corresponding preceding request primitive is a local matter.		

PhM-Status

This parameter specifies the status of the execution of the associated service request. Permitted values for this parameter are specified in Table 8.

Table 8 — Values of PhM-Status for the Reset service

Short name	Status	Definition	Temporary (t) or permanent (p)
OK	success	The Reset function was carried out successfully	--
NO	failure	The Reset function was not carried out successfully	t/p
IV	failure	Invalid parameters in request	--

6.3.2.5.2 Set Value

6.3.2.5.2.1 Function

The PhMS-user passes a PhM-SET-VALUE request primitive to Ph-management to assign a desired value to one or more specified variables of the PhE. After receiving this primitive Ph-management tries to select these variables and to set the new values. If the requested service was executed Ph-management passes a PhM-SET-VALUE confirm primitive to the PhMS-user to indicate the success or failure of the corresponding service request.

6.3.2.5.2.2 Types of primitives and parameters

Table 9 indicates the primitives and parameters of the Set Value service.

Table 9 — Set value primitives and parameters

PhM-SET-VALUE	Request	Confirm
Parameter name	**input**	**output**
Variable_name (1 to 3)	M	
Desired_value (1 to 3)	M	
PhM-STATUS (1 to 3)		M
NOTE The method by which a confirm primitive is correlated with its corresponding preceding request primitive is a local matter.		

Variable_name

This array parameter specifies one or more variables (1 to 3) that are to be assigned values from the corresponding elements of the Desired_value parameter. The selectable variables are operating parameters; they are specified in Table 10.

Table 10 — Mandatory PhE-variables

Operating parameters	
Name	**Definition**
Transmitter_output	Transmitter output
Receiver_signal_source	Receiver input
Loop	The transmitter output is directed to the receiver input and not to the medium

Desired_value

This array parameter specifies the actual value to be written to the variables (1 to 3) that are specified by the Variable_name parameter. This parameter specifies a list of one or more (1 to 3) new values for the specified PhE-variables. The permissible value or range of values for each of these variables is specified in Table 11.

Table 11 — Permissible values of PhE-variables

Operating parameters	
Variable	**Range of values**
Transmitter_output	enabled or disabled
Receiver_signal_source	primary: bus cable "a" (standard source) alternative: bus cable "b" (alternative source) random: either "a" or "b"
Loop	disabled or enabled

PhM-Status

This array parameter specifies, for each variable in the corresponding request, the status of that component of the requested service. Permitted values for the individual components of this array parameter are specified in Table 12.

Table 12 — Values of PhM-Status for the set-value service

Short name	Status	Definition	Temporary (t) or permanent (p)
OK	success	The variable has been set to the new value	--
NO	failure	The variable does not exist or could not be set to the new value	t/p
IV	failure	Invalid parameters in request	--

6.3.2.5.3 Get Value

6.3.2.5.3.1 Function

The PhMS-user passes a PhM-GET-VALUE request primitive to Ph-management to read the current value of one or more variables of the PhE. After receipt of this primitive Ph-management tries to select the specified variables and to deliver their current values and passes a PhM-GET-VALUE confirm primitive to the PhMS-user to indicate the success or failure of the corresponding service request. This primitive returns as a parameter one or more of the requested variable values.

6.3.2.5.3.2 Types of primitives and parameters

Table 13 indicates the primitives and parameters of the Get Value service.

Table 13 — Get value primitives and parameters

PhM-GET-VALUE	Request	Confirm
Parameter name	**input**	**output**
Variable_name (1 to 3)	M	
Current_value (1 to 3)		M
PhM-STATUS		M

NOTE The method by which a confirm primitive is correlated with its corresponding preceding request primitive is a local matter.

Variable_name

This array parameter specifies one or more variables (1 to 3) whose values are to be read. The variables that may be selected are specified in Table 10.

Current_value

This array parameter specifies the actual value of the (1 to 3) variables that were specified by the Variable_name parameter of the corresponding request. The permissible value, or range of values, for each of these variables is specified in Table 14.

Table 14 — Current values of PhE-variables

Operating parameters	
Variable	**Range of values**
Transmitter_output	enabled or disabled
Receiver_signal_source	primary or alternative
Loop	disabled or enabled

PhM-Status

This array parameter specifies for each variable in the corresponding request a confirmation about the execution of the service. Permitted values for this parameter are specified in Table 15.

Table 15 — Values of PhM-Status for the get value service

Short name	Status	Definition	Temporary (t) or permanent (p)
)OK	success	The variable could be read	--
NO	failure	The variable does not exist or could not be read. The corresponding value of Current_value is not defined	t/p
IV	failure	Invalid parameters in request	--

6.3.2.5.4 Event

6.3.2.5.4.1 Function

The PhE informs Ph-management that it has detected an event. After that, Ph-management passes a Ph-EVENT indication primitive to the PhMS-user to inform it about important events in the PhL.

6.3.2.5.4.2 Types of primitives and parameters

Table 16 indicates the primitive and parameters of the Event service.

Table 16 — Event primitive and parameters

PhM-EVENT	Indication
Parameter name	**output**
Variable_name (1 to 2)	M
New_value (1 to 2)	M

Variable_name

This array parameter specifies one or more variables (1 to 2) whose values were changed. The variables that may be present are specified in Table 10.

New_value

This parameter specifies the new value of the variable. The various values are shown in Table 17.

Table 17 — New values of PhE-variables

Variable	Range of values
Transmitter_output	enabled or disabled
Receiver_signal_source	primary or alternative

6.4 Type 4: Systems management – PhL interface

6.4.1 Required Services

The services specified in 6.2 are used.

6.4.2 Service primitive requirements

The service primitive requirements are specified in 6.2.2 with the following restriction:

The parameters specified in Table 4 are not supported.

The parameters that can be modified and read by the PhL management services are shown in Table 18. Supported values and default value for each parameter depend on the actual medium and implementation.

Table 18 — Parameter names and values for management

Parameter name	Range of values
Interface mode	HALF_DUPLEX FULL_DUPLEX_RS232 FULL_DUPLEX_UDP
Baud rate (kbaud/s)	230 400 76 800 38 400 19 200 9 600

6.5 Type 6: *This subclause has been removed*

NOTE This subclause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the subclause numbering of the prior edition.

6.6 Type 8: Systems management – PhL interface

6.6.1 Functionality of the PhL Management

The management of the PhL is the part of the PhL that produces the management functionality of the PhL that are demanded by the PNM1. The management of the PhL handles the initialisation, the monitoring, and the error recovery in the PhL.

6.6.2 PhL-PNM1 Interface

6.6.2.1 General

This subclause defines the administrative PhL management services that are available to the PNM1, together with their service primitives and associated parameters. Figure 12 shows the interface between PhL and PNM1 in the layer model.

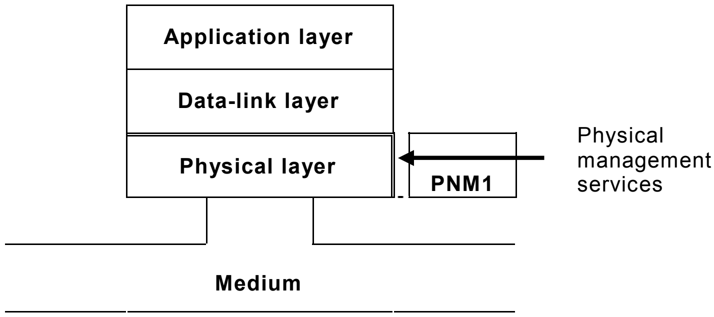


Figure 12 — Interface between PhL and PNM1 in the layer model

The service interface between PhL and PNM1 provides the following functions:

— Reset of the PhL
— Request and change of the current operating parameters of the PhL
— Indication of unexpected events, errors and status changes, which occurred or were detected in the PhL

6.6.2.2 Overview of the Services

The PhL makes the following services available to the PNM1:

— Reset PhL
— Set Value PhL or Get Value PhL
— Event PhL

Reset PhL (mandatory)

The PNM1 uses this service to reset the PhL. The reset is equivalent to power on. Upon execution of the service, the PNM1 receives a confirmation.

Set Value PhL (optional)

The PNM1 uses this service to set new values to the PhL variables. Upon completion, the PNM1 of the PhL receives a confirmation whether the defined variables assumed the new values.

Get Value PhL (optional)

The PNM1 uses this service to read out variables of the PhL. The current value of the defined variable is returned in the response of the PhL.

Event PhL (mandatory)

The PhL uses this service to inform the PNM1 user about certain events or errors in the PhL.

6.6.2.3 Overview of the Interactions

The PhL services are described by the following primitives (beginning with Ph-…):

Reset PhL

PH-RESET request
PH-RESET confirm

Set Value PhL

Ph-SET-VALUE request
Ph-SET-VALUE confirm

Get Value PhL

Ph-GET-VALUE request
Ph-GET-VALUE confirm

Event PhL
Ph-Event indication

Figure 13 and Figure 14 show the time relations of the service primitives.

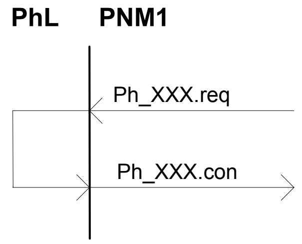


Figure 13 — Reset, Set-value, Get-value PhL services

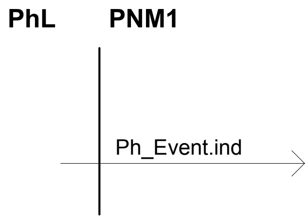


Figure 14 — Event PhL service

6.6.2.4 Detailed definitions of the services and Interactions

6.6.2.4.1 PH-RESET

The PH-RESET service is mandatory. The PNM1 transfers a PH-RESET request primitive to the PhL to reset it (see Table 19).

Table 19 — PH-RESET

Parameter name	Request	Confirm
Argument	M	
Result(+)		M

6.6.2.4.2 Ph-SET-VALUE

The Ph-SET-VALUE service is optional. The PNM1 transfers a Ph-SET-VALUE request primitive to the PhL, to set a defined Ph variable to a desired value. After receipt of this primitive, the PhL tries to select the variable and to set the new value. Upon completion, the PhL transfers a Ph-SET-VALUE confirm primitive to the PNM1 (see Table 20).

Table 20 — Ph-SET-VALUE

Parameter name	Request	Confirm
Argument	M	
variable_name	M	
desired_value	M	
Result(+)		M

variable_name:

This parameter defines the PhL variable that is set to a new value.

desired_value:

This parameter declares the new value for the PhL variable.

Table 21 provides information on which PhL variable may be set to which new value.

Table 21 — PhL variables

Name of PhL variable
loopback_mode
medium_attachment
bus_ interfaces
short_ bus_reset_time
long_bus_reset_time
data_select

loopback_mode:

This parameter defines whether the receive circuit of the MAU is connected to the send circuit or to the medium.

Parameter structure:

— interface number
  Defines the number of the incoming and outgoing interface (see Figure 15).

— status
  This parameter defines whether the receive circuit of the MAU is connected (enabled) or not (disabled). After power on this value is equivalent to "enabled".

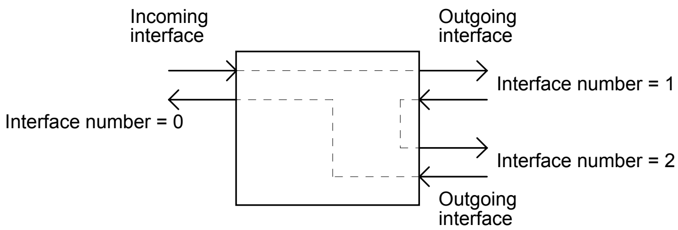


Figure 15 — Allocation of the interface number

NOTE A master has always the interface number = 2.

medium_attachment:

This parameter indicates whether the MAU is coupled to the transmission medium. This is done by detecting whether a connector is plugged to the outgoing interface.

Parameter structure:

— interface number
  Declares the number of the bus interface (see Figure 15).

— attachment
  This parameter defines whether the interface is connected to the transmission medium.

bus_interfaces:

— interface number
  Declares the number of the bus interface (see Figure 15).

— interface type
  Defines the type of the physical interface and the transmission medium:

- Incoming interface, 2-wire
- Outgoing interface, 2-wire

short_bus_reset_time:

This parameter defines the duration of the short reset. The value after power on is 5 ms.

long_bus_reset_time:

This parameter defines the duration of the long reset. The value after power on is 100 ms.

data_select:

This parameter indicates a Reset_PhPDU or a medium_activity_status_PhPDU is sent on the transmission medium for a passive outgoing MAU (loopback mode= disable)

Parameter structure

— interface number
Defines the number of the bus interface (see Figure 15). Value range (1 to 2)

— coupling
Disable: A reset PHPDU is transmitted on the transmission medium;
Enable: The medium activity status PhPDU is transmitted on the transmission medium after "power on" this value is "disable".

6.6.2.4.3 Ph-GET-VALUE

The Ph-GET-VALUE service is optional. The PNM1 transfers a Ph-GET-VALUE request primitive to the PhL to read out the current value of a defined PhL variable. After the PhL has received this primitive it tries to select the defined variable and to transfer the present value to the PNM1 by means of a Ph-GET-VALUE confirm primitive (see Table 22).

Table 22 — Ph-GET-VALUE

Parameter name	Request	Confirm
Argument	M	
variable_name	M	
Result(+)		M
current_value		M

variable_name:

This parameter defines the PhL variable the value of which is to be read out.

current_value:

This parameter contains the read-out value of the PhL variable. The PhL variables to be read are those variables that can be written to with the Ph-SET-VALUE.

6.6.2.4.4 Ph-EVENT

The Ph-EVENT service is mandatory. The PhL transfers a Ph-EVENT indication primitive to the PNM1, to inform it about important events or errors in the PhL (see Table 23).

Table 23 — Ph-EVENT

Parameter name	Indication
Argument	M
event	M

event:

This parameter defines the event that occurred or the error source in the PhL and may according to Table 24 have the following values:

Table 24 — PhL events

Name	Meaning
stop_bit_error	Stop bit error detected in the MDS sublayer
medium_attachment	The medium attachment changed at an outgoing MAU

6.7 Type 12: Systems management – PhL interface

6.7.1 Required service

The minimum service primitive for PhL (PhL) management shall be:

PH-RESET request – reset of the Ph-Layer.

6.7.2 Service primitive PH-RESET request

This primitive has no parameter. Upon reception of this primitive the PhL shall reset all its functions.

6.8 Type 18: Systems management – PhL interface

6.8.1 General

The Systems management – PhL interface need not be exposed in the implementation of a Type 18 PhE. This interface may be internal to the node and may be implemented as internal to a semiconductor device.

6.8.2 Required services

The minimum service primitive for PhL management shall be:

a) PH-RESET request – reset of the Ph-Layer;
b) Ph-SET-VALUE request – set parameters.

6.8.3 Service primitive requirements

6.8.3.1 PH-RESET request

This primitive has no parameter. Upon reception of this primitive the PhL shall reset all its functions.

6.8.3.2 Ph-SET-VALUE request (parameter name, new value)

This primitive shall allow Systems management to modify the parameters of the PhL. Standard parameter names and value ranges are given in Table 4.

Not all values are supported by all Type 18 PhE variants. Baud rate limitations are associated with the Type 18 MAU variant implemented.

Table 25 — Parameter names and values for Ph-SET-VALUE request

Parameter name	Range of values
Baud rate (kbaud/s)	10 000 5 000 2 500 625 156

7 DCE independent sublayer (DIS)

7.1 General

The PhL entity is partitioned into a Data Terminal Equipment (DTE) component and a Data Communication Equipment (DCE) component. The DTE component interfaces with the DLL entity, and forms the DCE Independent Sublayer (DIS). It exchanges Interface Data Units across the DL – Ph interface defined in Clause 5, and provides the basic conversions between the PhIDU "at-a-time" viewpoint of the DL – Ph interface and the bit serial viewpoint required for physical transmission and reception.

This sublayer is independent of all the PhL variations, including encoding and/or modulation, speed, voltage/current/optical mode, medium etc. All these variations are grouped under the designation Data Communication Equipment (DCE).

NOTE A number of different DIS entities are specified, based on industry practice.

7.2 Type 1: DIS

The DIS shall sequence the transmission of the PhID as a sequence of serial PhSDUs. Similarly, the DIS shall form the PhID to be reported to the DLL from the sequence of received serial PhSDUs.

The PhID shall be converted to a sequence of PhSDUs for serial transmission in octets up to a maximum of 300 octets. A PhSDU representing more significant octets of the PhID shall be sent before or at the same time as a PhSDU representing less significant octets and such that within each octet, a PhSDU representing a more significant bit will be transmitted before or at the same time as a PhSDU representing a less significant bit. On reception, each sequence of PhSDUs shall be converted to PhID such that, in the absence of errors, the PhIDU indicated to the receiving DLL entity shall be unchanged from the PhIDU whose transmission was requested by the originating DLL entity.

NOTE This is a guarantee of transparency.

7.3 Type 3: DIS

7.3.1 Synchronous transmission

The DCE Independent Sublayer (DIS) specified for Type 1 shall be used (see 7.2).

7.3.2 Asynchronous transmission

There is no DCE Independent Sublayer (DIS) for asynchronous transmission.

7.4 Type 6: *This subclause has been removed*

NOTE This subclause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the subclause numbering of the prior edition.

7.5 Type 8: DIS

7.5.1 General

The PhL is subdivided into a medium-independent sublayer (MIS), a medium-dependent sublayer (MDS) and the medium attachment unit (MAU). The MIS is independent of all characteristics of the PhL, such as coding, transmission method, transmission speed, and the type of transmission medium. All these instances are described by the sublayers MDS and MAU.

7.5.2 Function

On the one hand, the MIS has to transmit the PhSDU which was received by the MAC sublayer through the DL-Ph-interface in the form of a PhIDU via the MIS-MDS interface to the MDS. On the other hand, it forms the PhIDU of a PhSDU, which has been received through the MIS-MDS interface, and transfers it via the DL-Ph interface to the MAC sublayer.

In addition, the MIS allows transmitting a PhSDU between two MDSs through the MIS-MDS interface (MDS coupling).

The MIS may consist of several channels that are configured correspondingly. One channel is used to transmit the PhSDU to the MDS and to transmit one PhSDU through a PhIDU to the MAC sublayer. All other channels are used to transmit a PhSDU between two MDS sublayers.

7.5.3 Serial transmission

For the serial transmission a sequence of PhIDUs shall be converted into a sequence of PhSDUs. A PhSDU that represents a more significant bit is transferred after a PhSDU that represents a less significant bit.

When it is received each sequence of PhSDUs shall be converted into a sequence of PhIDUs so that the sequence of PhIDUs formed in such a way corresponds to the one that is transmitted from the MAC sublayer to the PhL.

7.5.4 MDS coupling

When MDSs are coupled in pairs and have the same or different characteristics (alternative type of transmission) each PhSDU that is received from a MDS through the MIS-MDS interface is sent unchanged via the MIS-MDS interface to another MDS.

In this case, it is allowed to buffer a received PhSDU.

Figure 16, Figure 17 and Figure 18 show possible configurations for the bus master and slaves using the 2-wire medium and an alternative type of transmission.

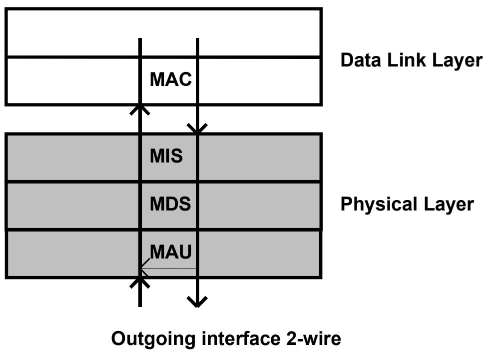


Figure 16 — Configuration of a master

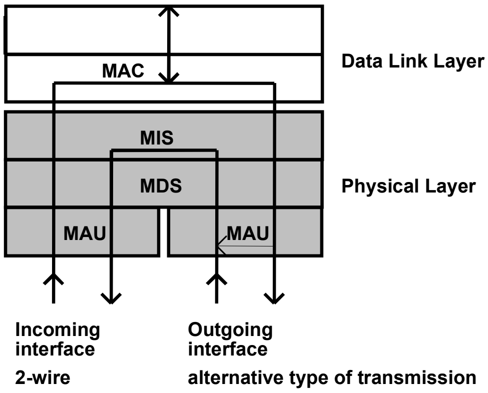


Figure 17 — Configuration of a slave with an alternative type of transmission

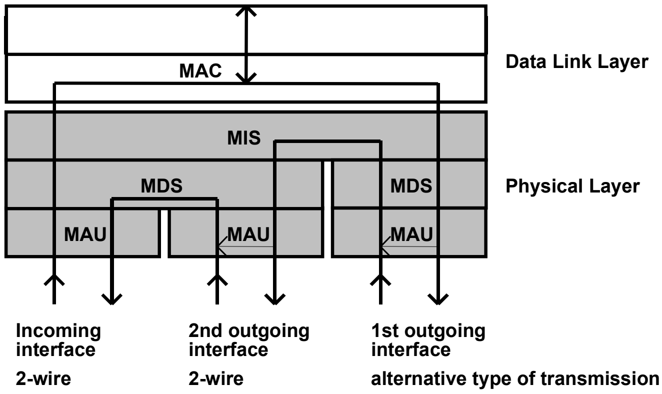


Figure 18 — Configuration of a bus coupler with an alternative type of transmission

7.6 Type 12: DIS

The DIS shall sequence the transmission of the PhID as a sequence of serial PhSDUs. Similarly, the DIS shall form the PhID to be reported to the DLL from the sequence of received serial PhSDUs.

The PhID shall be converted to a sequence of PhSDUs for serial transmission in octets from a minimum of 72 octets up to a maximum of 1 535 octets.

For the serial transmission a sequence of PhIDUs shall be converted into a sequence of PhSDUs. A PhSDU that represents a more significant bit is transferred after a PhSDU that represents a less significant bit.

When it is received each sequence of PhSDUs shall be converted into a sequence of PhIDUs so that the sequence of PhIDUs formed in such a way corresponds to the one that is transmitted from the MAC sublayer to the PhL.

8 DTE – DCE interface and MIS-specific functions

8.1 General

The PhL entity is partitioned into a Data Terminal Equipment (DTE) component containing the DIS, and a Data Communication Equipment (DCE) component containing the MDS and lower sublayers. The DTE – DCE interface connects these two physical components, and is itself within the MIS. (See Figure 1.)

NOTE A number of different DTE – DCE interfaces are specified, based on industry practice.

It is not mandatory for the DTE – DCE interface, or any other interface, to be exposed.

For Type 3 synchronous transmission mode, Type 1 and Type 7, the DTE – DCE interface is a functional and electrical, but not mechanical, interface that supports a set of services. Each of these services is implemented by a sequence of defined signaling interactions at the interface.

8.2 Type 1: DTE – DCE interface

8.2.1 Services

8.2.1.1 Overview

The following services, defined in this subclause, shall be supported by the DTE – DCE interface:

a) DTE to DCE reset service;

b) DTE to DCE configuration service;

c) DTE to DCE message-transmission service;

d) DCE to DTE fault notification service;

e) DCE to DTE media-activity indication service;

f) DCE to DTE message-reporting service.

8.2.1.2 DTE to DCE reset service

This service shall provide a means by which the DTE, at any time, can reset the DCE to its initial (power-on) state.

8.2.1.3 DTE to DCE configuration service

This service shall provide a means by which the DTE can configure various characteristics of the DCE, including those characteristics which systems management can adjust via Ph-SET-VALUE requests (see Table 4). It shall also provide a DCE-optional means by which the DTE can initiate reporting of DCE status by pre-emptive use of the DCE to DTE message-reporting service.

8.2.1.4 DTE to DCE message-transmission service

This service shall provide a means by which the DTE can transmit a message through the DCE to either the connected medium (media), or back to the DTE, or both, as determined by the current operational values of the parameters specified in Table 4. The DCE shall provide the pacing for this service.

This service is invoked upon receipt of a PH-DATA request specifying START-OF-ACTIVITY at the PhL service interface, and runs until receipt of and completion of the PH-DATA request specifying END-OF-DATA-AND-ACTIVITY.

8.2.1.5 DCE to DTE fault notification service

This service shall provide a means by which the DCE, at any time, can report a fault. The specific nature of the fault is not reported by this service, but may be determinable by use of the DTE to DCE configuration service to initiate a DCE-optional DCE status report.

8.2.1.6 DCE to DTE media-activity indication service

This service shall provide a means by which the DCE reports the inferred detection, on any of its connected media for which receiving is enabled (see Table 4), of signaling from itself or other Ph-Layer entities. While loopback is enabled, this service reports only the signaling of the DCE itself.

When the DTE – DCE interface is in half-duplex mode and loopback is not enabled, this service need not report media activity resulting directly from the DTE to DCE message-transmission service.

8.2.1.7 DCE to DTE message-reporting service

This service shall provide a means by which the DCE reports the receipt of a sequence of PhPDUs from any one of the connected media for which receiving is enabled. This service terminates with an indication of whether the sequence of received PhPDUs was well formed. Errors in the sequence, including number of PhPDUs such that they could not have been a correct transmission resulting from an invocation of the DCE to DTE message-transmission service shall be reported as a malformed (erroneous) sequence.

NOTE Errors in the octet alignment of a received end delimiter with respect to the preceding start delimiter (i.e., not separated by an integral number of octets of data bits) must be reported as a malformed sequence.

When the DTE – DCE interface is in half-duplex mode and loopback is not enabled, this service need not report the message transmitted by the DCE to DTE message-transmission service.

8.2.2 Signaling interfaces

8.2.2.1 Overview

Two signaling interfaces are defined for Type 1 PhLs. The first interface existed in prior editions of this standard and is retained for compatibility, although there are no known implementations. It is defined in 8.2.2.2 through 8.2.2.4.

The second interface uses the well-known serial peripheral interface (SPI) protocol and signals, or equivalent, in which octet registers and FIFOs in the DCE are read and written by the DTE and in which the DCE can interrupt the DTE.

NOTE There is no formal standard for the SPI protocol, although it is used by many electronics vendors.

8.2.2.2 Interface signals (historic version from prior editions)

8.2.2.2.1 Overview

If the DTE – DCE interface is exposed it shall provide the signals specified in Table 26.

Table 26 — Signals at DTE – DCE interface

Signal	Abbreviation	Source
Transmit Clock	TxC	DCE
Request-to-send	RTS	DTE
Clear-to-send	CTS	DCE
Transmit Data	TxD	DTE
Receive Clock	RxC	DCE
Receive Activity	RxA	DCE
Receive Data and Framing	RDF	DCE

The signal levels shall be as shown in Table 27. In general, both sides of the interface shall operate with the same approximate value of V_{DD}. However, it is recognized that a DTE and a DCE with separate power supplies may not both reach operational V_{DD} simultaneously. It is desirable, but not mandatory, that the DTE to DCE reset service be operational when the DCE has not yet reached operational V_{DD}. It is also desirable that the DTE invoke this service whenever its own V_{DD} is below operational margins.

Table 27 — Signal levels for an exposed DTE – DCE interface

Symbol	Parameter	Condition	Limit	Unit	Remark
V_{OL}	Maximum low-level output voltage	I_{out} = ±100 µA	0,1	V	see Note 1
		I_{out} = +1,6 mA	0,4	V	
V_{OH}	Min. high-level output voltage	I_{out} = ±100 µA	V_{DD} – 0,1	V	see Note 1
		I_{out} = –0,8 mA	V_{DD} – 0,8	V	see Note 2
V_{IL}	Max. low-level input voltage		0,2 V_{DD}	V	
V_{IH}	Min. high-level input voltage		0,7 V_{DD}	V	see Note 3

NOTE 1 Provides the capability to drive two typical CMOS loads.

NOTE 2 CMOS input compatibility with TTL output requires a "pull-up" resistor from signal input to V_{DD}.

NOTE 3 Compatible with CMOS output for 3,0 V ≤ V_{DD} ≤ 5,5 V. Compatibility with TTL output (4,75 V ≤ V_{DD} ≤ 5,25 V) requires a "pull-up" resistor from signal input to V_{DD}.

The timing characteristics of these signals shall be at least equal to those specified for the relevant DCE in the requirements of this standard. However, in no case shall the transition time between 0,3 V_{DD} and 0,6 V_{DD} be greater than either 100 ns or 0,025 *P*, whichever is smaller. *P* is defined as the nominal period of octet transmission – the inverse of the nominal PhSDU rate.

An implementation of the DTE – DCE interface shall function correctly with transmit and receive (TxC and RxC) clock frequencies between 1 kHz and 8,8 times the highest supported PhSDU rate of the DTE or DCE implementation.

NOTE The PhSDU and equivalent bit data rates available in an implementation are stated in the Protocol Implementation Conformance Statement (PICS).

8.2.2.2.2 Transmit clock (TxC)

The Transmit Clock signal (TxC) shall provide the DTE with a continuous timing signal, such that any eight consecutive full cycles of this signal shall have the same octet period as the nominal transmit period for one data octet. The DCE shall source this nominally two-phase signal such that each phase has duration of at least 0,04 *P*.

NOTE This specification permits TxC to be a continuous, constant-period clock at the nominal bit rate (8 times the nominal octet rate) with a duty cycle of 32 % to 68 %, or for TxC to be a higher-frequency clock with some cycles omitted and with a duty cycle closer to 50 %. This permits, for example, simple clocking in a DCE that recodes each 4 bits into 5 bauds; the DCE could have a clock 10 times the nominal octet rate, with a duty cycle of between 40 % and 60 %, and would omit (the same) two cycles every octet.

TxC supports the DTE to DCE configuration and message-transmission services.

8.2.2.2.3 Request-to-send (RTS)

The request-to-send (RTS) signal supports the DTE to DCE reset, configuration, and message-transmission services. The DTE shall source this signal. The initial (power-on) and idle (no DTE to DCE service active) state of this signal shall be low.

When referenced to TxC at the DTE – DCE interface, this signal shall have a minimum setup time of the smaller of either 100 ns or 0,025 *P*; the hold time shall be zero or greater.

8.2.2.2.4 Clear-to-send (CTS)

The clear-to-send (CTS) signal supports the DTE to DCE configuration and message-transmission services. The DCE shall source this signal. The initial (power-on) and idle (no DTE to DCE service active) state of this signal shall be low.

When referenced to TxC at the DTE – DCE interface, this signal shall have a minimum setup time of the smaller of either 100 ns or 0,025 *P*; the hold time shall be zero or greater.

8.2.2.2.5 Transmit Data (TxD)

The Transmit Data (TxD) signal supports the DTE to DCE reset, configuration, and message-transmission services. Binary data is transmitted from DTE to DCE during one phase of the latter two services, and during this phase a binary 0 is represented by a low level on TxD and a binary 1 by a high level on TxD, both sampled at the falling edge of TxC.

The DTE shall source this signal. The initial (power-on) and idle (no DTE to DCE service active) state of this signal shall be high.

When referenced to TxC at the DTE – DCE interface, this signal shall have a minimum setup time of the smaller of either 100 ns or 0,025 *P*; the hold time shall be zero or greater.

8.2.2.2.6 Receive Clock (RxC)

The Receive Clock signal (RxC) shall provide the DTE with an intermittent (semi-continuous) nominally two-phase timing signal that defines the timing of information being reported via the RDF signal. The DCE shall source this signal such that, where RxC is defined to be meaningful (see 8.2.2.3.7), each phase has duration of at least 0,04 *P*.

NOTE This specification permits RxC to be a recovered clock at the nominal bit rate (8 times the nominal octet rate) with a duty cycle of 32 % to 68 %, or to be a higher-frequency clock with some cycles omitted and with a duty cycle closer to 50 %. This permits, for example, simple clocking in a DCE that decodes 4 bits from each received 5 bauds; the DCE could have a clock 10 times the nominal octet rate, with a duty cycle of between 40 % and 60 %, and would omit two cycles every octet.

This specification also permits the DCE to omit cycles of RxC during recognition of long end-delimiter sequences of PhPDUs, so that the delimiter can be reported in real time using 8 or fewer cycles of RxC (see 8.2.2.3.7).

RxC shall support the DCE to DTE message-reporting service.

8.2.2.2.7 Receive Activity (RxA)

The Receive Activity (RxA) signal shall support the DCE to DTE fault notification, media-activity indication, and message-reporting services. The DCE shall source this signal. The initial (power-on) and idle (no DCE to DTE service active) state of this signal shall be low.

8.2.2.2.8 Receive Data and Framing (RDF)

The Receive Data and Framing (RDF) signal shall support the DCE to DTE fault notification and message-reporting services. Binary data is transmitted from DCE to DTE during some phases of the latter service, and during these phases a binary 0 is represented by a low level on RDF and a binary 1 by a high level on RDF, both sampled at the falling edge of RxC.

The DCE shall source this signal. The initial (power-on) and idle (no DCE to DTE service active) state of this signal shall be high.

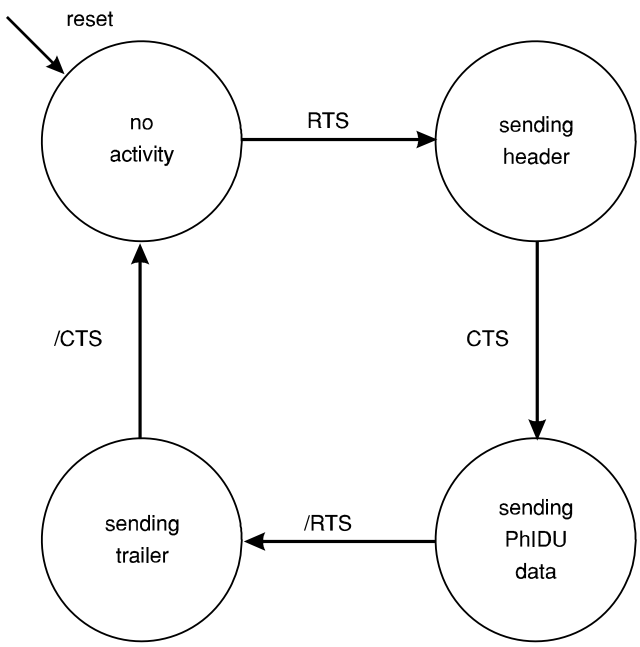
When referenced to RxC at the DTE – DCE interface, this signal shall have a minimum setup time of the smaller of either 100 ns or 0,025 *P*; the hold time shall be zero or greater.

8.2.2.3 Encoding of services in signals

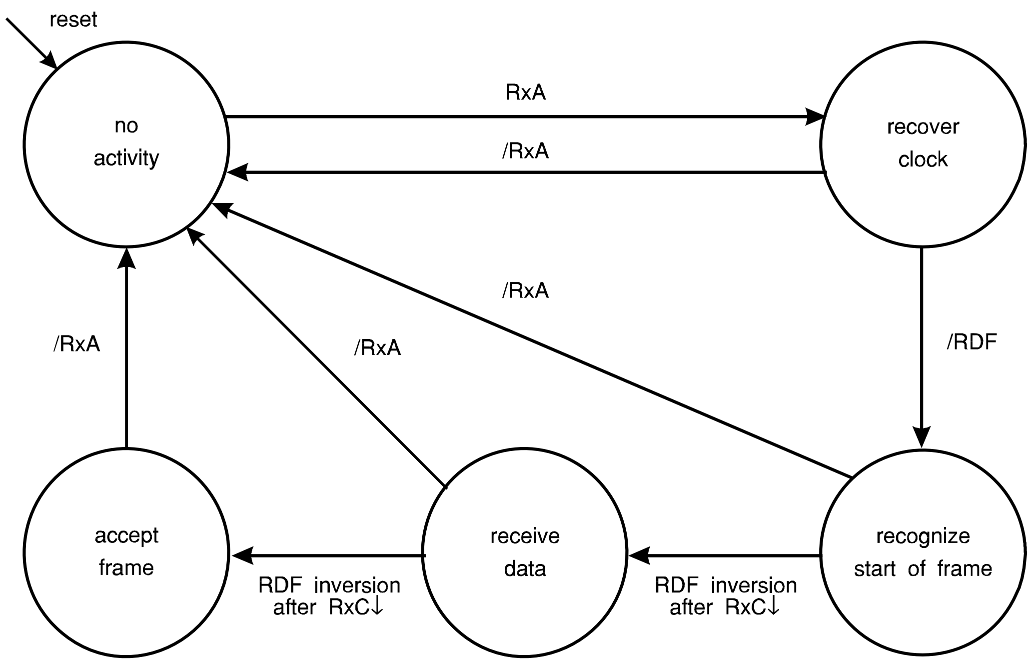
8.2.2.3.1 Summary

The services of 8.1 shall be implemented by the following sequences and combinations of the signals of 8.2.

NOTE Typical transmit and receive sequencing machines are shown in Figure 19, which is included in this standard for explanatory purposes and does not imply a specific implementation.



Transmit machine



Receive machine

Figure 19 — DTE/DCE sequencing machines

8.2.2.3.2 DTE to DCE reset service

This service shall be mutually exclusive with the DTE to DCE configuration and message-transmission services; at most one of them may be active at any given time. This service may pre-empt the DTE to DCE configuration and message-transmission services at any time.

This service shall be encoded as a simultaneous low level on both RTS and TxD. When asserted by the DTE, this simultaneous low level shall be held for at least the nominal transmission period of two PhSDUs (octets).

NOTE 1 This is an asynchronous service, and is not referenced to TxC.

NOTE 2 When a DTE is itself being reset, possibly during power-up, it should attempt to reset the DCE even when the DTEs own V_{DD} is below normal operational limits.

NOTE 3 This reset is under the control of the DTE. It does not preclude the existence of a separate reset pin on the DCE.

If the DTE concurrently changes both RTS and TxD during the implementation of either the DTE to DCE configuration or message-transmission services, then the DTE shall ensure that an interval of at least the minimum required setup time exists between changing the one signal to a high level, and subsequently changing the other signal to a low level, to eliminate potential logic hazards in the DCEs implementation of the DTE to DCE reset service.

8.2.2.3.3 DTE to DCE configuration service

This service is mutually exclusive with the DTE to DCE reset and message-transmission services; at most one of them may be active at any given time. This service may initiate the DCE to DTE message-reporting service to report DCE-internal status. The DTE to DCE reset service may pre-empt this service at any time.

This service shall be implemented in three phases; each of the latter two phases shall follow immediately upon completion of the prior phase.

NOTE 1 These phases can be implemented as a minor variation on the three phases specified for the DTE to DCE message-transmission service. As a result, the DTE to DCE configuration service induces very little added complexity on the DTE and DCE.

1) The DTE shall assert (raise) RTS after the falling edge, and before the rising edge, of TxC. The DCE shall respond by anticipating configuration data.
2) When it is ready for configuration data from the DTE, the DCE shall raise CTS before the falling edge of TxC. The DTE shall respond by encoding the first bit of configuration data (1 as high, 0 as low) on TxD before the falling edge of the next TxC, and shall continue this process without interruption until between 2 and 200 bits of data (see 8.2.2.4) have been so encoded. The DTE shall then assert (raise) TxD and negate (lower) RTS before the falling edge of the next TxC.

NOTE 2 The DTE should ensure that TxD is raised at least one setup time before RTS is lowered, to avoid potential logic hazards in the DCE implementation of the DTE to DCE reset service.

3) The DCE shall conclude any necessary reconfiguration before negating (lowering) CTS, which shall occur between two consecutive falling edges of TxC.

Both standardized and extendible configuration messages are defined in 8.2.2.4. Standardized messages cover the ranges of application of this interface that are anticipated to be most cost sensitive. Extendible messages permit differing forms of DCE configuration where required, and can serve to initiate the DCE to DTE message-reporting service to report DCE-internal status (a DCE option further described in 8.2.2.4).

8.2.2.3.4 DTE to DCE message-transmission service

This service is mutually exclusive with the DTE to DCE reset and configuration services; at most one of them may be active at any given time. The DTE to DCE reset service may pre-empt this service at any time.

This service shall be implemented in three phases; each of the latter two phases shall follow immediately upon completion of the prior phase.

a) The DTE shall assert (raise) RTS after the rising edge, and before the falling edge, of TxC. The DCE shall respond by generating and transmitting the appropriate-length sequence of preamble and start delimiter PhPDUs.
b) When it is ready for transparent data from the DTE, the DCE shall raise CTS before the falling edge of TxC. The DTE shall respond by encoding the first bit of transparent data (1 as high, 0 as low) on TxD before the next falling edge of TxC, and shall continue this process without interruption until between 3 and 300 integral octets of data have been so encoded. The DTE shall then assert (raise) TxD and negate (lower) RTS before the next falling edge of TxC.

NOTE The DTE shall ensure that TxD is raised at least one setup time before RTS is lowered, to avoid potential logic hazards in the DCE implementation of the DTE to DCE reset service.

c) The DCE shall conclude transmission of all of the encoded transparent data received from the DTE, shall then generate and transmit the appropriate-length sequence of end delimiter PhPDUs, and shall then cease transmission. The DCE shall then wait an amount of time equal to the configured minimum post-transmission gap (see Table 4) before negating (lowering) CTS, which shall occur after a falling edge, and before the next falling edge, of TxC.

8.2.2.3.5 DCE to DTE fault notification service

This service shall be mutually exclusive with the DCE to DTE media-activity indication and message-reporting services; at most one of them may be active at any given time. This service may pre-empt the DCE to DTE media-activity indication and message-reporting services at any time.

This service shall be encoded as a simultaneous low level on both RxA and RDF. Once asserted by the DCE, this simultaneous low level shall be held until activation of either the DTE to DCE reset or configuration services.

NOTE This is an asynchronous service, and is not referenced to RxC.

The DCE may concurrently change both RxA and RDF during the concurrent termination of the DCE to DTE media-activity indication and message-reporting services. The DTE is responsible for avoiding any logic hazards induced by this concurrent change.

8.2.2.3.6 DCE to DTE media-activity indication service

This service is mutually exclusive with the DCE to DTE fault notification service; at most one of them may be active at any given time. The DCE to DTE fault notification service may pre-empt this service at any time.

This service shall be encoded as a high level on RxA. Once asserted by the DCE, this high level enables recognition of a high-to-low transition on RDF to initiate the DCE to DTE message-reporting service. Any subsequent high-to-low transition on RxA terminates that DCE to DTE message-reporting service.

NOTE The DCE to DTE media-activity indication service is an asynchronous service, and is not referenced to RxC.

8.2.2.3.7 DCE to DTE message-reporting service

This service is mutually exclusive with the DCE to DTE fault notification service; at most one of them may be active at any given time. This service can only occur while the DCE to DTE media-activity indication service is active. The DCE to DTE fault notification service may pre-empt this service at any time.

8.2.2.3.7.1 Non-erroneous reception

This service shall be implemented in four phases when reporting a well-formed message, each of which shall follow immediately upon completion of the prior phase.

The following description applies to DCEs which have end delimiter sequences of eight PhPDUs or less, and which do not require any extra decoding delay for an FEC (forward error correcting) code. DCEs that do not meet these conditions may introduce extra delay into their decoding and reporting processes so that, with respect to signaling on RxC and RDF, they do meet these conditions.

a) After detecting received signaling, training on that signaling, and recovering a data clock from that signaling whose nominal octet frequency is the same as TxC, the DCE shall initiate the DCE to DTE message-reporting service by sourcing that recovered clock on RxC and then negating (lowering) RDF after the rising edge, and before the next falling edge, of RxC.

NOTE 1 RxA is already asserted at this time.

b) The DCE shall continue training and attempting to match the received signaling against its expected preamble and start delimiter PhPDUs.

   If the DCE supports *N* channels of redundant media, then it may report on RDF the identity of the channel from which the signaling is being received by encoding that channel number, in the range 0 to *N*–1, as a binary number which is reported most significant bit first during reception of the last three of those start delimiter PhPDUs. The bits reported on RDF shall be presented in series after successive rising edges of RxC, each before the immediately subsequent falling edge of RxC.

   Upon detecting an exact match between the received signaling and the expected start delimiter, the DCE shall invert RDF after the falling edge, and before the next rising edge, of RxC.

NOTE 2 If the identity of the receiving channel was being reported on RDF, then this inversion will occur during the low phase of \1,\2 which immediately follows the high phase (of \1,\2) during which the last (low-order) bit of the channel number was reported.

c) The DCE shall continue reception and attempting to match the received signaling against potential data and expected end delimiter PhPDUs.

   The DCE shall report each data bit decoded from the received signaling on RDF. The bits reported on RDF shall be presented in series after successive rising edges of \1,\2, each before the immediately subsequent falling edge of RxC. In the absence of errors these bits shall be reported in the same order and with the same values as they were transmitted by a peer PhL entity.

NOTE 3 This is a guarantee of transparency.

   An end delimiter may be composed of both data and non-data PhPDUs. The DCE may report similarly on RDF each data bit decoded from an end delimiter, and may report also on RDF an appropriate number of data values for the non-data PhPDUs decoded from an end delimiter, except that

   1) the total number of "bits" so reported shall be seven or less, and

   2) upon detecting an exact match between the received signaling and the expected end delimiter, the DCE shall not report on RDF another bit corresponding to the end delimiter's last "bit", but rather shall first assert (raise) RDF after the rising edge, and before the next falling edge, of RxC, and then shall negate (lower) RDF after the falling edge, and before the next rising edge, of RxC.

NOTE 4 Most implementations will decode, and report on RDF as data, any initial data PhPDUs in a received end-delimiter sequence. The first non-data PhPDU, and subsequent PhPDUs, need not be reported. However, a final report will be made on RDF, indicating correct end-delimiter recognition.

NOTE 5 Each reported bit, except the last, is maintained on RDF for a full cycle of RxC. The last bit is replaced by a high-low sequence, each of which is maintained for just one phase of RxC.

NOTE 6 This terminating high-low sequence will occur during the first eight "bit" reports which occur after the last (pre-delimiter) data bit was reported. That last (pre-delimiter) data bit will have been the 8*N*'th data bit so reported in this phase, where *N* should be at least three and no greater than 300.

d) The DCE shall assert (raise) RDF before the next falling edge of RxC and shall not initiate another instance of the DCE to DTE message-reporting service until after the conclusion of the current DCE to DTE media-activity indication service.

8.2.2.3.7.2 Erroneous reception

An error may be detected during any phase of the reception process described in 8.2.2.3.7.1. When that occurs, the DCE shall modify its sequencing of those phases as follows.

If the DCE should detect invalid PhPDUs, or an invalid sequence of PhPDUs, or a valid end delimiter sequence of PhPDUs which is not separated from the start delimiter PhPDUs by an integral number of data-octets of PhPDUs; and if the DCE can establish a valid signal on RxC (for example, by substituting TxC or some other local signal for the recovered clock source, if necessary); then

a) if phase 2 has not already been initiated, the DCE shall immediately initiate phase 2;
b) if phase 2 has not already been concluded, the DCE shall immediately conclude phase 2 as rapidly as possible, ignoring the requirement for matching of the start delimiter PhPDU sequence;
c) otherwise, the DCE shall immediately negate (lower) RDF after the rising edge, and before the next falling edge, of RxC, and then shall assert (raise) RDF after the falling edge, and before the next rising edge, of RxC.

NOTE This sequence permits the DCE to

– enable DTE use of RxC;
– identify the channel with the erroneous signaling; and
– indicate a reception error.

When the DCE has completed as many of the above steps a), b) and c) as appropriate and possible, the DCE shall immediately initiate phase 4.

8.2.2.4 DCE configuration messages

8.2.2.4.1 Summary

This subclause defines both standardized configuration messages, and the standardized portion of extendible configuration messages. Standardized messages cover the ranges of application of this interface that are anticipated to be most commonly used. Extendible messages permit differing forms of DCE configuration where required, and can serve to initiate the DCE to DTE message-reporting service to report DCE-internal status (a DCE option).

Two standardized messages, and two classes of extendible messages, are defined. All messages are transmitted across the interface in the order in which the bits are defined. Integers are transmitted most significant bit (MSB) first.

The two standardized messages and two classes of extendible messages are distinguished by the first two data bits of the configuration message, as follows:

00 – basic configuration message;

01 – path-diversity control message;

10 – extendible configuration message;

11 – extendible status-report invocation message.

8.2.2.4.2 Basic configuration message

Following its initial two bits of (00), the basic configuration message specifies operational aspects common to most DCEs. The defined components of this message are, in order of transmission:

a) the operational mode of the DCE, encoded in one data bit as shown. The value for this parameter after activation of the DTE to DCE reset service is 0;

   0 Two-way simultaneous (full-duplex), where each invocation of the DTE to DCE message-transmission service automatically activates the DCE to DTE media-activity indication and message-reporting services;

NOTE 1 This mode is desirable for dual-channel media such as fiber-optic-pair cabling. Some DTEs may only be able to operate in this mode.

   1 Two-way alternate (half-duplex), where an invocation of the DTE to DCE message-transmission service does not automatically activate the DCE to DTE media-activity indication and message-reporting services;

NOTE 2 This mode minimizes DCE and DTE – DCE interface power consumption. Some DTEs may only be able to operate in this mode.

b) the selection of the DCE-internal data source for the message-reporting service, encoded in two data bits as shown (see Table 4). The value for this parameter after activation of the DTE to DCE reset service is 00. When this selection is non-zero, transmission on all attached media shall be disabled and the DTE – DCE interface shall operate in two-way simultaneous (full-duplex) mode;

   00 decoded signaling, received from one of the attached media as specified in 8.2.2.4.3 b) and c). The interface mode is as specified in 8.2.2.4.2 a);

   01 internal-status reporting, see 8.2.2.5.1 and 8.2.2.6;

   10 loopback as close as possible to the DTE – DCE interface, with no transmission to connected media, where each invocation of the DTE to DCE message-transmission service automatically activates the DCE to DTE media-activity indication and message-reporting services;

NOTE 3 This mode is desirable for DCE vs. DTE vs. inter-connect fault localization.

   11 loopback as close as possible to the media interface(s), with no transmission to connected media, where each invocation of the DTE to DCE message-transmission service automatically activates the DCE to DTE media-activity indication and message-reporting services.

NOTE 4 This mode is desirable for self-assessment before entry to an operating network.

c) the amount by which the preamble, which is the initial sequence of PhPDUs in each transmission, should be extended. Its range is zero to seven units of extension, encoded in three data bits as 0 (000) to 7 (111). The value for this parameter after activation of the DTE to DCE reset service is 0 (000) (see note 2 of 6.2.2.2);

d) the amount by which the mandatory post-transmission gap, which is the period of non-transmission between successive sequences of PhPDUs, should be extended. Its range is zero to seven units of extension, encoded in three data bits as 0 (000) to 7 (111). The value for this parameter after activation of the DTE to DCE reset service is 0 (000) (see note 3 of 6.2.2.2).

8.2.2.4.3 Path-diversity control message

Following its initial two bits of (01), the path-diversity control message specifies additional configuration data commonly required for management and fault-assessment of redundant paths: separate transmission and reception controls for each of the attached redundant media (channels and paths). The defined components of this message are, in order of transmission:

a) two bits of zero (00), which provide quartet and octet alignment within the message for the following fields;

b) the algorithm for choosing between redundant media as the source of received signaling when more than one of the media is enabled for reception, coded in four bits as shown. The value for this parameter after activation of the DTE to DCE reset service is 0000;

   0000 – The medium selected for reception should be the first medium on which signaling which is suitable for receiver-training is detected;

   1000 to 1111 (= 7 + *N*, 1 ≤ *N* ≤ 8) – The *N*th medium should be selected, except when signaling suitable for receiver-training has been detected on another medium for a period of time equal to the extra period of inter-frame-gap extension specified in 8.2.2.4.2 d), in which case that other medium should be selected;

c) the selection of whether reception is enabled (0) or inhibited (1) on each of eight or fewer redundant media, coded in eight consecutive bits for channels 1 through 8, respectively (see Table 4). The value for this parameter after activation of the DTE to DCE reset service is 0000 0000;

d) the selection of whether transmission is enabled (0) or inhibited (1) on each of eight or fewer redundant media, coded in eight consecutive bits for channels 1 through 8, respectively (see Table 4). The value for this parameter after activation of the DTE to DCE reset service is 0000 0000;

e) the amount of post-transmission gap extension due to potential signal skew between redundant media. Its range is zero to seven units of extension, encoded in three data bits as 0 (000) to 7 (111). The value for this parameter after activation of the DTE to DCE reset service is 0 (000) (see 8.2.2.4.2 d), 8.2.2.4.3 b), and note 3 of 6.2.2.2).

8.2.2.5 Extendible configuration messages

Following its initial two bits of (10), the coding of extendible configuration messages may be implementation dependent. The structure and form of extendible configuration messages shall be the same as the basic configuration message specified in 8.2.2.4.2.

8.2.2.5.1 Extendible status-report invocation messages

Following its initial two bits of (11), the coding of extendible status-report invocation messages may be implementation dependent. The structure and form of extendible status-report invocation messages shall be the same as the basic configuration message specified in 8.2.2.4.2. The information specified shall select some DCE-internal source of received signaling, and if the DCE-internal-data-source mode is status-reporting (see 8.2.2.4.2 b)), then the DCE shall generate a multi-data-octet message, padded as necessary to an octet multiple, and shall report it using the DCE to DTE media-activity indication and message-reporting services.

8.2.2.6 DCE-generated status reports

These reports are generated within the DCE upon request, and reported when the DCE-internal-data-source is internal-status report (see 8.2.2.4.2 b)).

8.3 Type 3: DTE – DCE interface

8.3.1 Synchronous transmission

The DTE – DCE interface specified for Type 1 shall be used (see 8.2).

8.3.2 Asynchronous transmission

The DTE – DCE interface is not exposed for asynchronous transmission.

8.4 Type 8: MIS – MDS interface

8.4.1 General

The PhL is subdivided into a medium-independent sublayer (MIS) and a medium-dependent sublayer (MDS). The MIS-MDS interface connects these two sublayers.

The MIS-MDS interface is a functional interface that supports certain services; it is not mandatory to implement this interface electrically. Each of these services is implemented through a sequence of interactions of the interface signals.

8.4.2 Services

8.4.2.1 General

The MIS-MDS interface supports the services listed below:

- ID cycle request service
- Data cycle request service
- Data sequence classification service
- Data sequence identification service
- Message transmission service
- Message receipt service
- Bus reset

8.4.2.2 ID cycle request service

With this service the MIS starts a data sequence to transmit identification and control data (identification cycle).

NOTE This service is used by a master only.

8.4.2.3 Data cycle request service

With this service, the MIS starts a data sequence for the transmission of user data (data cycle).

NOTE This service is used by a master only.

8.4.2.4 Data sequence classification service

With this service the MIS starts an identification or data cycle.

NOTE This service is used by a bus coupler or a slave only.

8.4.2.5 Data sequence identification service

With this service the MDS indicates the beginning of an identification or data cycle.

8.4.2.6 Message transmission service

With this service the MIS sends a message via the MDS either to the connected medium or via the MDS back to another MDS. The MDS determines how fast this service is executed.

NOTE 1 This service transmits the PhIDUs that were passed on to the PhL.

NOTE 2 This service runs simultaneously with the message receipt service.

8.4.2.7 Message receipt service

With this service the MDS indicates receipt of a message to the MIS or another connected MDS. The service ends with the indication whether the received PhPDU was correctly formed.

NOTE This service shall be preceded by a data sequence identification service.

8.4.2.8 Bus reset

A reset is sent to and received from all slaves with this service. Table 28 shows the parameter of the MDS bus reset.

Table 28 — MDS bus reset

Service parameter	Request	Indication
reset_type	M	M

reset_type:

This service parameter defines whether the reset is short or long.

Value range: short, long

NOTE This service is used by a master only.

8.4.3 Interface signals

The MIS-MDS interface makes signals available that are listed in Table 29.

Table 29 — Signals at the MIS-MDS interface

Interface signal	Mnemonic	Source
Transmit Clock	TxC	MIS
Request-to-send	RTS	MIS
Clear-to-send	CTS	MDS
Transmit Sequence	TxS	MIS
Transmit Select Line	TxSL	MIS
Transmit Control Line	TxCR	MIS
Transmit Data	TxD	MIS
Request Delay 1	RqDly1	MIS
Request Delay 2	RqDly2	MIS
Busy	BSY	MDS
Receive Clock	RxC	MDS
Receive Activity	RxA	MDS
Receive Sequence	RxS	MDS
Receive Select Line	RxSL	MDS
Receive Control Line	RxCR	MDS
Receive Data	RxD	MDS
Reset Out	RO	MIS
Reset In	RI	MDS

8.4.4 Converting the services to the interface signals

8.4.4.1 General

The services of the MIS-MDS interface are represented by the protocol machines and signal sequences described in 8.4.4.1 through 8.4.4.8.

NOTE The following applies to the state diagrams shown in Figure 20 to Figure 28:
The symbol "*" corresponds to "logically and", the symbol "/" corresponds to "negated".

8.4.4.2 Identification cycle request service

Figure 20 describes this service with the four services marked in grey and their transitions.

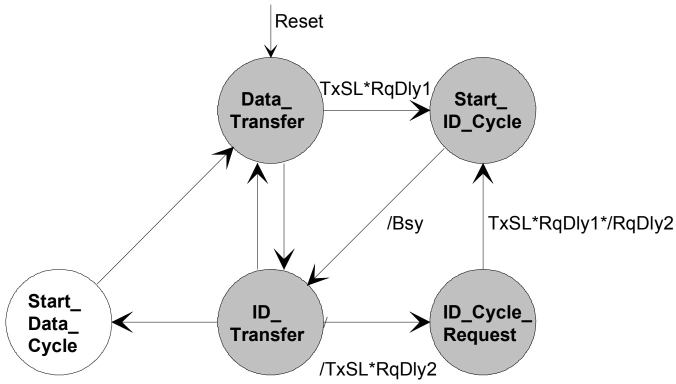


Figure 20 — State transitions with the ID cycle request service

NOTE 1 Transitions not shown in Figure 20 are used for other services see Figure 23 and Figure 25 for the states and transitions.

The identification cycle was preceded by a data cycle or a reset:

Data_Transfer state:
The MIS initiates an identification cycle request service by changing the TxSL signal from logical 0 to logical 1 and at the same time the RqDly1 signal from logical 0 to logical 1.

Start_ID_Cycle state:
After that, the MDS transmits the corresponding status PhPDU, starts a timer with the duration t1 and sets the BSY signal from logical 0 to logical 1. The MIS resets the RqDly1 signal to logical 0.

After the time t1 has elapsed, the MDS sets the BSY signal to logical 0 and terminates the identification cycle request service. The MIS communicates this to the DLL through a PH-DATA confirm primitive and assumes the ID_Transfer state.

The minimum time for t1 is 5 bit times.

Figure 21 shows the corresponding signal forms at the MIS-MDS interface for an identification cycle request service after a preceding data cycle.

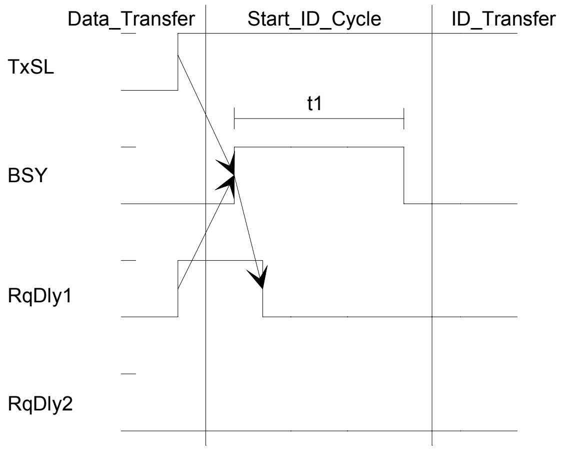


Figure 21 — MIS-MDS interface: identification cycle request service

The identification cycle was preceded by an identification cycle:

ID_Transfer state:
The MIS initiates an identification cycle request service by changing the TxSL signal from logical 1 to logical 0 and at the same time the RqDly2 signal from logical 0 to logical 1.

ID_Cycle_Request state:
After that, the MDS transmits the corresponding status PhPDU, starts a timer with the duration t2 and sets the BSY signal from logical 0 to logical 1. The MIS resets the RqDly2 signal to logical 0.

After the time t2 has elapsed, the MDS sets the BSY signal to logical 0. The MIS sublayer then changes the TxSL signal from logical 0 to logical 1 and at the same time the RqDly1 signal from logical 0 to logical 1.

The minimum time for t2 is 25 bit times.

Start_ID_Cycle state:
After that, the MDS transfers the corresponding status PhPDU, starts a timer with the duration T1 and sets the BSY signal from logical 0 to logical 1. The MIS then resets the RqDly1 signal to logical 0.

After the time t1 has elapsed, the MDS sets the BSY signal to logical 0 and terminates the identification cycle request service. The MIS communicates this to the DLL by means of a PH-DATA confirm primitive and assumes the ID_Transfer state.

Figure 22 shows the corresponding signal forms at the MIS-MDS interface for an identification cycle request service after a preceding identification cycle.

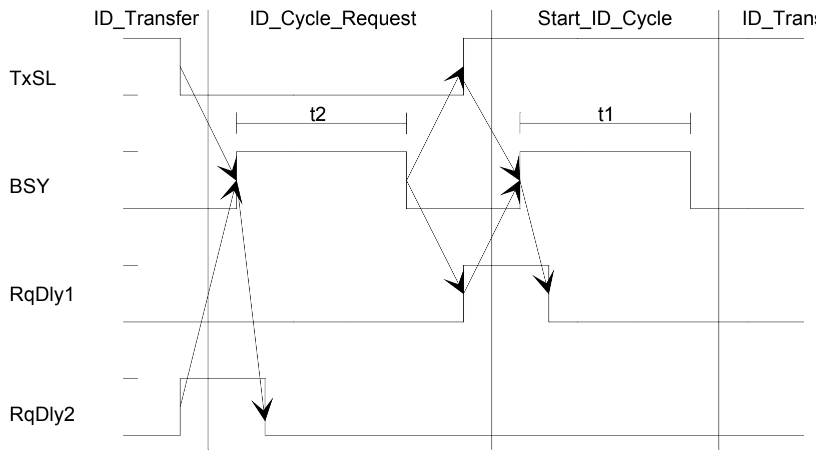


Figure 22 — MIS-MDS interface: identification cycle request service

NOTE 2 The identification cycle request service is an asynchronous service and is not related to TxC.

8.4.4.3 Data cycle request service

Figure 23 describes this service with the three states marked in grey and their transitions.

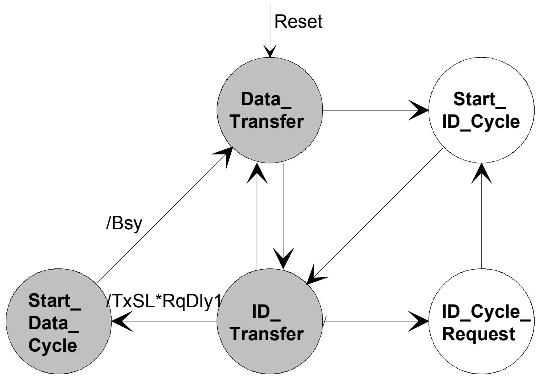


Figure 23 — State transitions with the data cycle request service

NOTE 1 Transitions not shown in Figure 23 are used for other services see Figure 20 and Figure 25 for the states and transitions.

The data cycle was preceded by an identification cycle:

ID_Transfer state:
The MIS initiates a data cycle request service by changing the TxSL signal from logical 1 to logical 0 and at the same time the RqDly1 signal from logical 0 to logical 1.

Start_Data_Cycle state:
After that, the MDS transmits the corresponding status PhPDU, starts a timer with the duration t1 and sets the BSY signal from logical 0 to logical 1. The MIS resets the RqDly1 signal to logical 0.

After the time t1 has elapsed, the MDS sets the BSY signal to logical 0 and terminates the data cycle request service. The MIS communicates this to the DLL by means of a PH-DATA confirm primitive and assumes the Data_Transfer state.

Figure 24 shows the corresponding signal forms at the MIS-MDS interface for a data cycle request service after a preceding identification cycle.

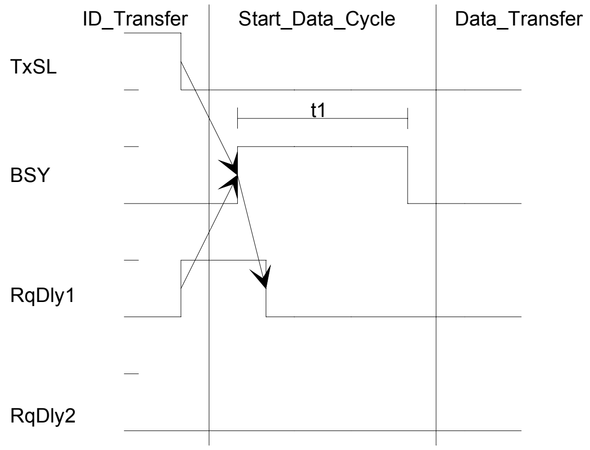


Figure 24 — MIS-MDS interface: data cycle request service

The data cycle was preceded by a data cycle:

If the DLL requests the beginning of a data cycle with a PH-DATA request primitive (PhICI=start_data_cycle), and the DLL did not request the beginning of an identification cycle by means of an PH-DATA request primitive (PhICI=start_ID_cycle) before, the MIS communicates to the DLL the end of the data cycle request service with a PH-DATA confirm primitive. The status of the signals TxSL, RqDly1 and RqDly2 remains unchanged.

NOTE 2 The data cycle request service is an asynchronous service and is not related to TxC.

8.4.4.4 Data sequence classification service

Figure 25 describes this service with the two states marked in grey and their transitions.

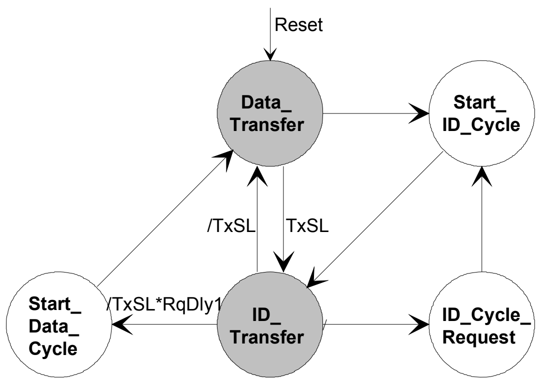


Figure 25 — State transitions with the data sequence classification service

NOTE 1 Transitions not shown in Figure 25 are used for other services see Figure 20 and Figure 23 for the states and transitions.

Data_Transfer state:
The MIS initiates an identification cycle (transmission of identification and control data in the PhPDU) by changing the TxSL signal from logical 0 to logical 1.

ID_Transfer state
The MIS initiates a data cycle (transmission of user data in PhPDU) by changing the signal from logical 1 to logical 0.

NOTE 2 The data sequence classification service is an asynchronous service and is not related to TxC.

8.4.4.5 Message transmission service

Figure 26 describes this service with the six states and their transitions.

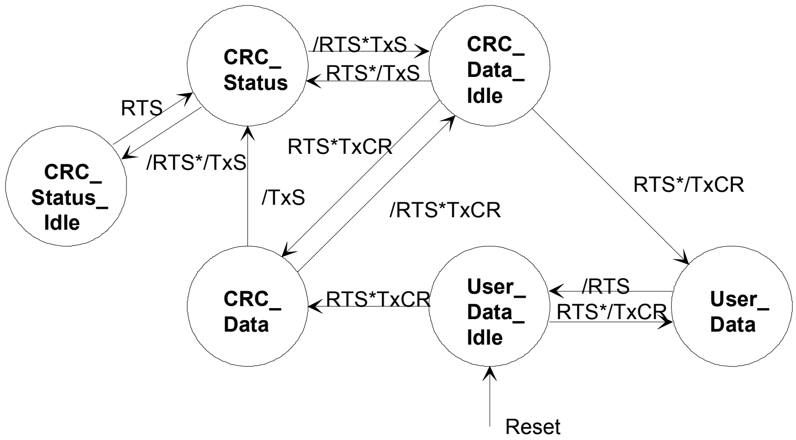


Figure 26 — Protocol machine for the message transmission service

NOTE 1 A data bit sequence is transmitted in multiples of octets. After the MIS has set its RTS interface signal from logical 1 to logical 0, it waits for a falling edge of the active low CTS signal from the MDS. The MIS communicates this to the DLL by means of a PH-DATA confirm primitive (mandatory for the master only).

CRC_Data_Idle state:
The MIS initiates a message transmission service by setting the RTS signal to logical 1 during the rising edge of TxC, at the same time setting the TxCR signal to logical 0, and transmitting with the TxD signal the first data bit within an octet to the MDS.

NOTE 2 Instead of initiating a message transmission service the MIS can start to transmit the checksum status by setting the RTS signal to logical 1 during the following rising edge of TxC, at the same time setting the TxS signal to logical 0 and transmitting the first bit of the checksum status with the TxD signal to the MDS.

User_Data state:
The MIS shall continue data transmission by transmitting the next data bit within an octet with the TxD signal to the MDS during each rising edge of TxC. The MIS completes the data transmission by setting the RTS signal to logical 0 after the last bit has been transmitted and before the next falling edge of TxC.

NOTE 3 The MIS continues data transmission by setting the RTS signal to logical 1 during the rising edge of TxC and at the same time transmitting with the TxD signal the first bit within an octet to the MDS.

User_Data_Idle state:
The MIS starts the check sequence by setting the RTS signal to logical 1 during the rising edge of TxC, at the same time setting the TxCR signal to logical 1, and transmitting the first bit of the checksum (CRC data) with the TxD signal to the MDS.

NOTE 4 Instead of the check sequence the MIS can initiate a new message transmission service by setting the RTS signal to logical 1 during the rising edge of TxC, and at the same time transmitting with the TxD signal the first data bit to the MDS. This is equivalent to a continuation of the message transmission service.

CRC_Data state:
The MIS shall continue to transmit the checksum data by transmitting the next data bit within an octet with the TxD signal to the MDS during each rising edge of TxC.

After the transmission of checksum data has been completed, the MIS starts the transmission of the checksum status (CRC status) by transmitting the TxS signal to logical 0 during the rising edge of TxC and at the same time transmitting with the TxD signal the first bit of the checksum status to the MDS.

NOTE 5 The MIS continues the transmission of the checksum by setting the RTS signal to logical 1 before the falling edge of TxC and at the same time transmitting with the TXD signal the first bit of the next octet of the checksum to the MDS.

NOTE 6 The MIS starts with the transmission of the checksum status by setting the RTS signal to logical 1 during the rising edge of TxC, at the same time setting the TxS signal to logical 0, and transmitting the first bit of the checksum status to the MDS.

CRC_Status state:
The MIS shall continue checksum status transmission by transmitting the next bit within an octet with the TxD signal to the MDS during each rising edge of TxC. The MIS terminates the transmission of the checksum status by setting the RTS signal to logical 0 and the TxS signal to logical 1 before the falling edge of TxC and after the last bit of the octet to be transmitted.

CRC_Status_Idle state:
The MIS continues the transmission of the checksum status by setting the RTS signal to logical 1 during the rising edge of TxC, and at the same time transmitting with the TxD signal the first bit of the next octet to the MDS.

8.4.4.6 Data sequence identification service

Figure 27 describes this service with the two states and their transitions.

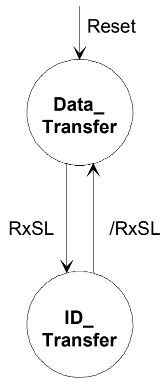


Figure 27 — Protocol machine for the data sequence identification service

Data_Transfer state:
The beginning of an identification cycle (transmission of identification data or control data in the received PhPDU) is indicated to the MIS by a change of the RxSL signal from logical 1 to logical 0.

ID_Transfer state:
The beginning of a data cycle (transmission of user data in the received PhPDU) is indicated to the MIS by a change of the RxSL signal from logical 1 to logical 0.

NOTE The data sequence identification service is an asynchronous service and not related to RxC.

8.4.4.7 Message receipt service

Figure 28 describes this service with the six states and their transitions.

NOTE 1 Data is received in multiples of octets.

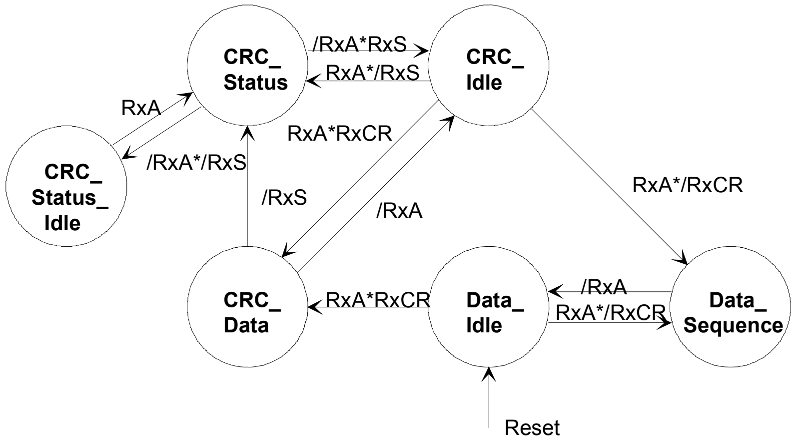


Figure 28 — Protocol machine for the message receipt service

CRC_Idle state:
If the MDS recognises the beginning of a data sequence PhPDU, it initiates the message receipt service by adapting the time pulses transmitted with the RxC signal to the received ones and at the same time during the rising edge of the RxC signal setting the RxA signal to logical 1, the RxCR signal to logical 0, as well as transmitting the first decoded data bit of an octet with the RxD signal to the MIS.

NOTE 2 If the MDS recognises the beginning of a checksum status in a check sequence PhPDU instead of the beginning of a data sequence PhPDU, is sets the RxA signal to logical 1, at the same time the RxS signal to logical 0, and transmits the first decoded bit with the RxD signal to the MIS.

NOTE 3 As long as the MDS recognises the CRC_Idle state it shall retain the RxA signal at logical 0 and the RxCR signal at logical 1.

Data_Sequence state:
The MDS shall continue to transmit the received and decoded data with the RxD signal to the MIS, and at the same time adapt the transmitted time pulses to the received ones with the RxC signal. If the MDS recognises the Data_Idle state after it has received the last data bit within an octet, it shall set the RxA signal to logical 0 during the falling edge of RxC.

Data_Idle state:
As long as the MDS recognises the Data_Idle state, it shall retain the RxA signal at logical 0 and the RxCR signal at logical 0.

If the MDS recognises the beginning of a check sequence PhPDU, it adapts the time pulses transmitted with the RxC signal to the received ones, sets the RxA signal to logical 1 during the rising edge of RxC, at the same time sets the RxCR signal to logical 1 and transmits with the RxD signal the decoded first received bit of the checksum (CRC data) to the MIS.

If the MDS recognises the first bit within an octet of a data sequence PhPDU instead of the beginning of a check sequence, it continues to receive the data sequence by adapting the transmitted time pulses to the received ones with the RxC signal and at the same time setting the RxA signal to logical 1 during the rising edge of RxC and transmitting the received and decoded data bit with the RxD signal to the MIS.

CRC_Data state:
The MDS shall continue to transmit the received and decoded checksum data with the RxD signal to the MIS and to adapt with the RxC signal the transmitted time pulses to the received ones.

If the MDS recognises the first bit of the checksum status after it has received the checksum data completely, it shall adapt the time pulses transmitted with the RxC signal, set the RxS signal during the rising edge of RxC to logical 0, and at the same time transmit the received and decoded bit of the checksum status with the RxD signal to the MIS.

NOTE 4 If the MDS recognises the CRC_Idle state after it has received the last bit within an octet it shall set the RxA signal to logical 0 during the falling edge of RxC.

NOTE 5 If the MDS recognises the first bit within an octet of the checksum data, it shall continue to receive the checksum data by adapting the time transmitted pulses to the received ones with the RxC signal, setting the RxA signal during the rising edge of RxC to logical 1 and at the same time transmitting with the RxD signal the received and decoded checksum bit to the MIS.

CRC_Status state:
The MDS shall continue to transmit the received and decoded checksum status with the RxD signal to the MIS and, at the same time adapt the transmitted time pulses to the received ones with the RxC signal. After it has completely received the checksum status, the MDS sets the RxA signal to logical 0 during the falling edge of RxC and at the same time sets the RxS signal to logical 1.

NOTE 6 If the MDS recognises the CRC_Idle state after it has received the last bit within an octet it shall set the RxA signal to logical 0 during the falling edge of RxC.

CRC_Status_Idle state:
If the MDS recognises the first bit within an octet of the checksum data, it shall continue to receive the checksum status by adapting the time pulses transmitted with the RxC signal to the received ones, setting the RxA signal during the rising edge of RxC to logical 1 and at the same time transmitting with the RxD signal the received and decoded bit of the checksum status to the MIS.

8.4.4.8 Reset service

This service is sent from the MIS to the MDS by setting the RO signal. The receipt of a reset is passed from the MDS to the MIS with the RI signal. Value ranges: short, long

8.5 Type 12: DTE – DCE interface

The DTE – DCE interface is not exposed for Type 12 transmission.

9 Medium dependent sublayer (MDS)

9.1 General

The medium dependent sublayer (MDS) is part of the data communication equipment (DCE). (See Figure 1.) It exchanges information across the DTE – DCE interface specified in clause 8 and it communicates encoded Ph-symbols across the MDS – MAU interface specified in clause 10. The MDS functions are logical encoding and decoding for transmission and reception respectively and the addition/removal of preamble and delimiters together with timing and synchronization functions.

NOTE A number of different MDS sublayer entities are specified, based on industry practice.

9.2 Type 1: MDS: Wire and optical media

9.2.1 PhPDU

The MDS shall produce the PhPDU shown in Figure 29 by adding preamble and delimiters to frame the serial sequence of PhSDUs (bits) transferred from the DIS across the DTE – DCE interface. Transmission sequence shall be from left to right as shown in Figure 29, i.e. preamble first, followed by start delimiter, PhSDU sequence and finally end delimiter.

PREAMBLE	START DELIMITER	PhSDU SEQUENCE	END DELIMITER

Figure 29 — Protocol data unit (PhPDU)

Conversely, the MDS shall remove preamble and delimiters from a received PhPDU to produce a corresponding serial sequence of PhSDUs. If a non-binary data unit is detected in the received PhSDU sequence, the MDS shall immediately stop transferring PhSDUs to the DIS, the MDS shall report an error, and the MDS shall indicate the end of activity to the DIS when it happens.

9.2.2 Encoding and decoding

Data units shall be encoded by the MDS for application to the MAU using the code shown in Figure 30 (Manchester Biphase L). The encoding rules are formally given in Figure 31 and Table 30.

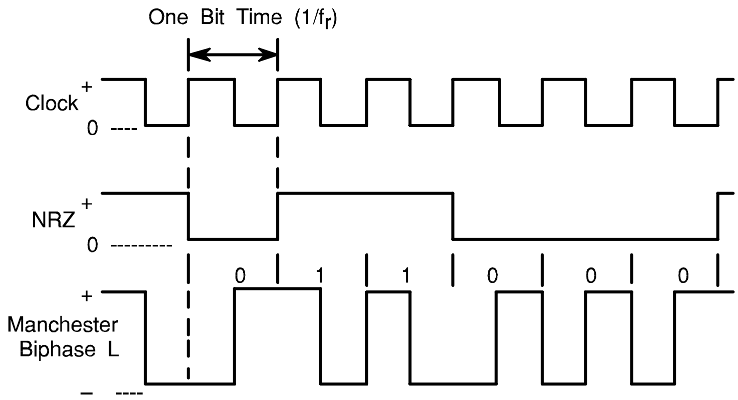


Figure 30 — PhSDU encoding and decoding

NOTE Figure 30 is included for explanatory purposes and does not imply a specific implementation.

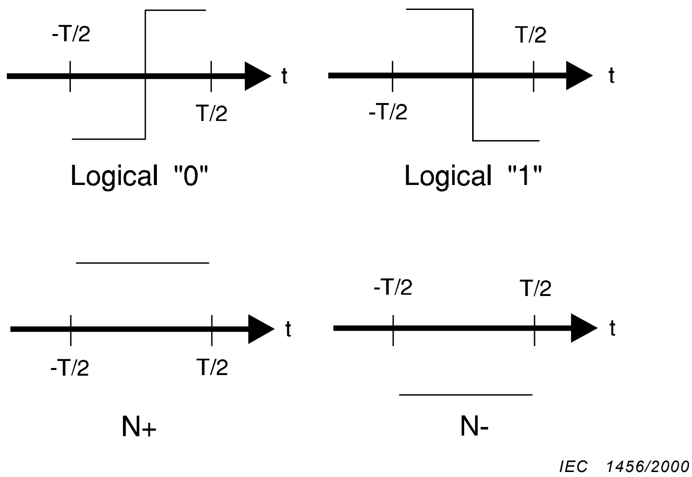


Figure 31 — Manchester encoding rules

Table 30 — Manchester encoding rules

Symbols	Encoding
1 (ONE)	Hi–Lo transition (mid-bit)
0 (ZERO)	Lo–Hi transition (mid-bit)
N+ (NON-DATA PLUS)	Hi (No transition)
N– (NON-DATA MINUS)	Lo (No transition)
NOTE It may be seen that data symbols (1 and 0, conveyed by PhSDUs) are encoded to always contain a mid-bit transition. Non-data symbols (N+ and N–) are encoded so that they never have a mid-bit transition. Frame delimiters (see 9.2.4 and 9.2.5) are constructed so that non-data symbols are conveyed in pairs of opposite polarity.	

Decoding shall normally be the opposite of encoding. At reception, the MDS shall verify that each symbol is encoded in accordance with Figure 31 and Table 30 and shall detect the following errors:

a) invalid Manchester code;

b) half-bit-slip errors.

Any of these errors shall be reported as PH-DATA indication (PhIDU, error).

9.2.3 Polarity detection

The option of automatic polarity detection of the received Manchester encoded signal shall be required where it is specified in the relevant MAU.

9.2.4 Start of frame delimiter

The following sequence of symbols, shown from left to right in order of transmission, shall immediately precede the PhSDU sequence to delimit the start of a frame:

1, N+, N–, 1, 0, N–, N+, 0.

(shown as a waveform in Figure 32)

The MDS shall only accept a received signal burst as a PhPDU after verifying this sequence and shall remove this sequence before transferring the PhSDU sequence to the DIS.

9.2.5 End of frame delimiter

The following sequence of symbols, shown from left to right in order of transmission, shall immediately follow the PhSDU sequence to delimit the end of a frame:

1, N+, N–, N+, N–, 1, 0, 1.

(shown as a waveform in Figure 32)

The MDS shall remove this sequence from the PhPDU before transferring the PhSDU sequence to the DIS. The MDS shall report to the corresponding DLL entity any frames received via the medium which do not include this sequence within 300 octets of start of frame (from beginning of start delimiter) as PH-DATA indication (PhIDU, frame_too_long). The MDS shall report to the corresponding DLL entity, via the corresponding DIS, any frames received via the medium that have an end delimiter which is not located at an octet boundary as PH-DATA indication (PhIDU, received_timing_error).

9.2.6 Preamble

In order to synchronize bit times a preamble shall be transmitted at the beginning of each PhPDU consisting of the following sequence of bits, shown from left to right in order of transmission:

1, 0, 1, 0, 1, 0, 1, 0.

(shown as a waveform in Figure 32)

NOTE 1 Received preamble can contain as few as four bits due to loss of one bit through each of four repeaters (as specified in the MAU Network Configuration Rules).

The period may be extended, but not reduced, by Systems management as given in Table 4. A preamble extension sequence as listed in Table 4 shall be defined as the following sequence of bits, shown from left to right in order of transmission:

1, 0, 1, 0, 1, 0, 1, 0.

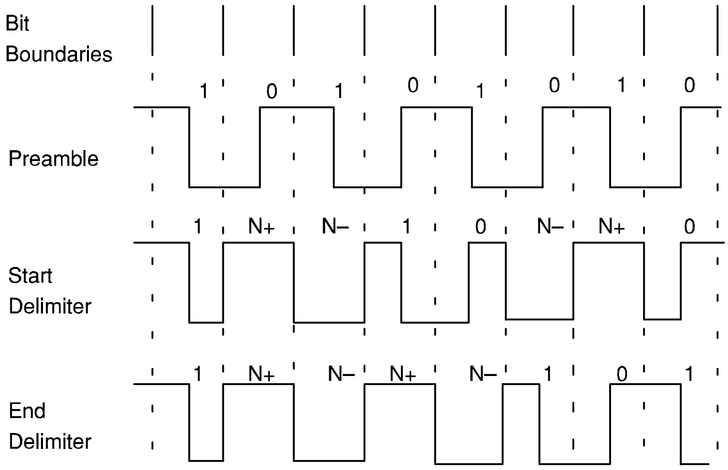


Figure 32 — Preamble and delimiters

NOTE 2 These waveforms do not extend the frequency range outside the band required for transmission of binary PhSDUs (conveying data symbols) in accordance with Figure 31 and Table 30.

9.2.7 Synchronization

After the reception of the fourth bit of the frame and until end of frame or frame termination the receiver shall detect and report half-bit-slip errors.

NOTE 1 This synchronization specification allows the loss of 4 bits of the preamble.

After the preamble, half-bit-slip errors shall be reported as PH-DATA indication (PhIDU, error).

NOTE 2 Half-bit-slip errors can be detected as excessive bit cell jitter and/or excessive variation in bit period.

9.2.8 Post-transmission gap

After transmission of a PhPDU there shall be a minimum period during which a subsequent transmission shall not commence. For the same minimum period after reception of a PhPDU the receiving PhL entity shall ignore all received signaling. An MDS entity shall set a minimum post transmission period of four nominal bit times. The period may be extended, but not reduced, by Systems management as given in Table 4 or by an associated MAU entity. A gap extension sequence as listed in Table 4 shall be defined as four nominal bit times.

NOTE The MAU transmit enable/disable time may reduce the duration of silence between frames.

9.2.9 Inter-channel signal skew

If the device is configured (by Systems management) to receive concurrently on more than one channel, then the maximum accepted differential delay between any two active channels, as measured from the first PhPDU of a start delimiter, shall not exceed five nominal bit times. This period may be extended, but not reduced, by Systems management as given in Table 4. A gap extension sequence as listed in Table 4 shall be defined as four nominal bit times. The value of post-transmission gap shall be greater than the value of inter-channel skew.

9.3 Type 1: MDS: Radio media

NOTE This subclause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the subclause numbering of the prior edition. The internal structure and method of operation of a Type 1 radio DCE is not specified by this standard.

9.4 Type 2: MDS: Wire and optical media

NOTE The Medium Dependent Sublayer (MDS) is part of the Data Communication Equipment (DCE). It communicates encoded bits across the MDS - MAU interface specified in 10.3.

9.4.1 Clock accuracy

The timing specifications for PhL Signaling shall be as defined in Table 31.

Table 31 — MDS timing characteristics

Specification	Limits / characteristics	Comments
Bit Rate	5 Mbit/s ± CA	Also called M-symbol rate, *data 'zero' or 'one'*
Bit Time	200 ns ± CA	Also called M-symbol time, *data 'zero' or 'one'*
PhL symbol time	100 ns ± CA	Also called Ph-symbol time, see data encoding rules
Clock Accuracy (CA)	± 150 ppm max.	Including temperature, long term and short term stability

9.4.2 Data recovery

The signals at the DLL to PhL interface shall be synchronized to the local bit rate as shown in Table 31. Each PhL implementation shall provide a data recovery mechanism that recovers or reconstructs the data received from the appropriate medium to meet the timing requirements shown in Table 31. When data synchronization has been attained by the MDS, PH-LOCK indication shall be true.

A portion of the received data frame may be lost or discarded in the process of attaining data synchronization. The specification for data timing shown in Table 31 shall be achieved prior to the beginning of the start delimiter (see IEC 61158-4-2).

9.4.3 Data encoding rules

The M_symbols present at the DLL to PhL interface shall be encoded into the appropriate Ph-symbols as shown in Table 32 and Figure 33. The M_0 and M_1 symbols shall be encoded into Ph-symbols that represent Manchester Biphase L data encoding rules as shown in Table 32. The M_ND symbols shall be used to create unique data patterns used for start and end delimiters. The signal voltage waveform (from the MAU) is shown in an idealized form in Figure 33 to provide an example of the data encoding rules shown in Table 32.

Table 32 — MDS data encoding rules

Data bits (common name)	M_symbol representation	Ph-symbol encoding	Manchester encoded
data 'zero'	M_0 or {0}	{L,H}	0
data 'one'	M_1 or {1}	{H,L}	1
'non_data+'	M_ND+ or {+}	{H,H}	no data
'non_data–'	M_ND– or {–}	{L,L}	no data

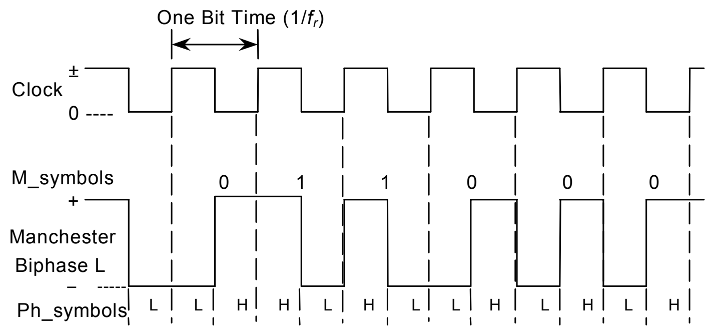


Figure 33 — Manchester coded symbols

9.5 Type 3: MDS: Wire and optical media

9.5.1 Synchronous transmission

The Medium Dependent Sublayer (MDS) specified for Type 1 shall be used (see 9.2).

9.5.2 Asynchronous transmission

There is no Medium Dependent Sublayer (MDS) for asynchronous transmission.

9.6 Type 4: MDS: Wire medium

9.6.1 Half-duplex

9.6.1.1 Overview

NOTE 1 The PhL entity is partitioned into a Data Terminal Equipment (DTE) component containing the MDS, and a Data Communication Equipment (DCE) component containing the MAU.

NOTE 2 The functionality of the MDS is similar to the functionality of what is commonly known as a UART. In addition the half duplex MDS has some timing functionality. The functionality of the MAU is similar to the functionality of what is commonly known as a driver circuitry.

The half-duplex MDS shall sequence the transmission of the PhID as a sequence of bits. Similarly, the MDS shall form the PhID to be reported to the DLL from the sequence of received bits. Bits are sent and received in NRZ code (non-return-to-zero).

The PhID shall be converted to a sequence of bits for serial transmission in PhPDUs. Within each PhPDU, a bit representing a more significant bit shall be transmitted before a bit representing a less significant bit. On reception, each sequence of bits shall be converted to PhID such that, in the absence of errors, the PhID indicated to the receiving DLL entity is unchanged from the PhID whose transmission was requested by the originating DLL entity.

The MDS receives a single PhID or a sequence of PhID octets from the DLE. The first octet is received from the DLE by one of the services **START-OF-ACTIVITY-11** or **START-OF-ACTIVITY-2**. The remaining octets are received from the DLE by the service **DATA**. End of transmission is indicated by the service **END-OF-ACTIVITY**. From each PhID octet the MDS shall form a PhPDU and transmit the formed PhPDU as a sequence of bits to the MAU. Each PhPDU shall consist of 1 start bit, 8 data bit, 1 address/data bit, and finally 1 stop-bit. This is indicated in Figure 34.

Start	Data8 ... Data1	Address/data	Stop
0	X....X	1 for first octet, 0 for remaining	1

Figure 34 — PhPDU format, half duplex

The MDS shall report when the signal level on the attached medium has been idle for 30, 35 and 40 or more bit periods, by **LINK-IDLE** indications to the DLE.

The transmitted bit rate shall be that of the selected baud rate, ± 0,2 %.

9.6.1.2 Transmission

9.6.1.2.1 START-OF-ACTIVITY-11

The following shall be performed as a result of the DLE issuing a **START-OF-ACTIVITY-11** PH-DATA request:

a) wait for Idle counter equal to or higher than 11;
b) form first PhPDU with Address/data bit = “1” and data = data parameter of **START-OF-ACTIVITY-11** request;
c) confirm reception to DLE to enable the DLE to issue the next transmission request;
d) activate Transmit Enable (TxE);
e) start transmitting the PhPDU to the MAU.

9.6.1.2.2 START-OF-ACTIVITY-2

The following shall be performed as a result of the DLE issuing a **START-OF-ACTIVITY-2** PH-DATA request:

a) wait for Idle counter modulus 10 equal to or higher than 2;

b) form first PhPDU with Address/data bit = “1” and data = data parameter of **START-OF-ACTIVITY-2** request;

c) confirm reception to DLE to enable the DLE to issue the next transmission request;

d) activate Transmit Enable (TxE);

e) start transmitting the PhPDU to the MAU.

9.6.1.2.3 DATA

The following shall be performed as a result of the DLE issuing a **DATA** PH-DATA request:

a) wait till transmission of former PhPDUs has finished;

b) form a new PhPDU with Address/data bit = “0” and data = data parameter of **DATA** request;

c) confirm reception to DLE to enable the DLE to issue the next transmission request;

d) start transmitting the PhPDU to the MAU.

It shall be ensured, that there are no idle periods between transmissions of PhPDUs. The DLE should issue the next transmission request within 11 bit periods after confirmation of the former.

9.6.1.2.4 END-OF-ACTIVITY

The following shall be performed as a result of the DLE issuing an **END-OF-ACTIVITY** PH-DATA request:

a) wait till transmission of former PhPDU has finished;

b) wait for minimum 3, maximum 10 bit periods;

c) deactivate Transmit Enable (TxE).

9.6.1.3 Reception

9.6.1.3.1 START-OF-ACTIVITY

As a result of receiving a frame from the MAU with address/data bit = “1”, or receiving a frame when the value of the Idle counter is higher than or equal to 11, the MDS shall issue a PH-DATA indication of class **START-OF-ACTIVITY**. The associated data parameter shall hold the received data. The value of the associated status parameter shall be set according to the following:

a) receiving a frame with address/data bit = “1” and stop bit = “1”, when the value of the Idle counter is higher than or equal to 11 shall result in an associated status parameter indicating SUCCESS;

b) receiving a frame with stop bit = “0”, shall result in an associated status parameter indicating FRAMING_ERROR;

c) receiving a frame with address/data bit = “1”, but when the value of the Idle counter is lower than 11 shall result in an associated status parameter indicating IDLE_ERROR;

d) receiving a frame with address/data bit = “0”, but when the value of the Idle counter is higher than or equal to 11 shall result in an associated status parameter indicating ADDRESS_DATA_ERROR.

9.6.1.3.2 DATA

As a result of receiving a frame from the MAU with address/data bit = “0”, when the value of the Idle counter is lower than 11, the MDS shall issue a PH-DATA indication of class **DATA**. The associated data parameter shall hold the received data. The value of the associated status parameter shall be set according to the following:

a) receiving a frame with stop bit = "1" from the MAU shall result in an associated status parameter indicating SUCCESS;
b) receiving a frame with stop bit = "0", shall result in an associated status parameter indicating FRAMING_ERROR.

9.6.1.4 Idle counter

The MDS holds an idle counter. This counter is incremented by one for each bit period, and is cleared each time a bit with value "0" is sent to or received from the MAU. When the Idle counter reaches 30, the MDS shall report this with a PH-DATA indication of class LINK-IDLE, and associated status indicating 30 bit periods. 5 bit periods later, if the Link is still idle, the PhE reports this with another PH-DATA indication of class LINK-IDLE, and associated status indicating 35 bit periods. 5 bit periods later, if the Link is still idle, the PhE reports this with another PH-DATA indication of class LINK-IDLE, and associated status indicating 40 or more bit periods. This goes on for each 10 bit periods with indications specifying 40 or more bit periods. The speed of the idle counter shall be that of the selected baud rate, ± 0,2 %.

9.6.2 Full-duplex

9.6.2.1 Overview

NOTE 1 The PhL entity is partitioned into a Data Terminal Equipment (DTE) component containing the MDS, and a Data Communication Equipment (DCE) component containing the MAU.

NOTE 2 The functionality of the MDS is similar to the functionality of what is commonly known as a UART. In addition the full duplex MDS has some "byte stuffing" functionality. The functionality of the MAU is similar to the functionality of what is commonly known as a driver circuitry.

The full duplex MDS shall sequence the transmission of the PhID as a sequence of bits. Similarly, the MDS shall form the PhID to be reported to the DLL from the sequence of received bits. Bits are sent and received in NRZ code (non-return-to-zero).

The PhID shall be converted to a sequence of bits for serial transmission in PhPDUs. Within each PhPDU, a bit representing a more significant bit shall be transmitted before a bit representing a less significant bit. On reception, each sequence of bits shall be converted to PhID such that, in the absence of errors, the PhID indicated to the receiving DLL entity is unchanged from the PhID whose transmission was requested by the originating DLL entity.

The MDS receives a single PhID or a sequence of PhID octets from the DLE. The first octet is received from the DLE by the service **START-OF-ACTIVITY-2**. The remaining octets are received from the DLE by the service **DATA**. End of transmission is indicated by the service **END-OF-ACTIVITY**. From each PhID octet the MDS shall form a PhPDU and transmit the formed PhPDU as a sequence of bits to the MAU. Each PhPDU shall consist of 1 start bit, 8 data bit, and finally 1 stop-bit. This is indicated in Figure 35.

Start	Data8 ... Data1	Stop
0	X....X	1

Figure 35 — PhPDU format, full duplex

9.6.2.2 Transmission

9.6.2.2.1 START-OF-ACTIVITY-2

The following shall be performed as a result of the DLE issuing a **START-OF-ACTIVITY-2** PH-DATA request:

a) form first PhPDU with data = $D7 (hex);
b) form second PhPDU with data = data parameter of **START-OF-ACTIVITY-2** request;

c) confirm reception to DLE to enable the DLE to issue the next transmission request;

d) activate request-to-send signal (RTS);

e) wait for clear-to-send signal (CTS) to be activated;

f) start transmitting the formed PhPDUs to the MAU.

9.6.2.2.2 DATA

The following shall be performed as a result of the DLE issuing a **DATA** PH-DATA request:

a) wait till transmission of former PhPDUs is finished;

b) wait for clear-to-send signal (CTS) to be active;

c) form new PhPDU(s) with data according to the following:

d) if the value of data parameter of **DATA** request = $D7 (hex), form a PhPDU with the data value $D9 (hex), followed by an additional PhPDU with the data value $00;

e) if the value of data parameter of **DATA** request = $D9 (hex), form a PhPDU with the data value $D9 (hex), followed by an additional PhPDU with the data value $01;

f) if the value of data parameter of **DATA** request is different from $D7 (hex) and $D9 (hex), form a PhPDU with the data value = data parameter of **DATA** request;

g) confirm reception to DLE to enable the DLE to issue the next transmission service;

h) start transmitting the PhPDU(s) to the MAU.

9.6.2.2.3 END-OF-ACTIVITY

The following shall be performed as a result of the DLE issuing an **END-OF-ACTIVITY** PH-DATA request:

a) wait till transmission of former PhPDUs has finished;

b) deactivate request-to-send (RTS) signal.

9.6.2.3 Reception

9.6.2.3.1 START-OF-ACTIVITY

As a result of receiving a PhPDU from the MAU with a data value of $D7 (hex), the MDS shall wait for the following PhPDU, and when this PhPDU is received issue a PH-DATA indication of class **START-OF-ACTIVITY**. The associated data parameter shall hold the received data from the PhPDU following $D7 (hex). The value of the associated status parameter shall be set according to the following:

a) receiving a PhPDU with stop bit = “1” shall result in an associated status parameter indicating SUCCESS;

b) receiving a PhPDU with stop bit = “0”, shall result in an associated status parameter indicating FRAMING_ERROR.

9.6.2.3.2 DATA

Receiving a PhPDU from the MAU with a data value different from $D7 (hex) shall result in the following:

receiving a PhPDU with stop bit = “1” and a data value = $D9 (hex), shall result in the MDS waiting for the following PhPDU from the MAU. The result of receiving the following PhPDU shall be:

a) if the data value of the following PhPDU is $00 (hex), and the stop bit is = “1”, issue a PH-DATA indication of class **DATA**. The associated data parameter shall hold the value $D7. The value of the associated status parameter shall indicate SUCCESS.

b) if the data value of the following PhPDU is $01 (hex), and the stop bit is = "1", issue a PH-DATA indication of class **DATA**. The associated data parameter shall hold the value $D9. The value of the associated status parameter shall indicate SUCCESS.

c) if the data value of the following PhPDU is different from $00 (hex) and from $01 (hex), and the stop bit is = "1", issue a PH-DATA indication of class **DATA**. The associated data parameter shall hold the received data value. The value of the associated status parameter shall indicate BYTE_STUFFING_ERROR.

d) if the stop bit is "0", issue a PH-DATA indication of class **DATA**. The associated data parameter shall hold the received value. The value of the associated status parameter shall indicate FRAMING_ERROR.

e) receiving a PhPDU with stop bit = "1" and a data value different from $D9 (hex), shall result in the MDS issuing a PH-DATA indication of class **DATA**. The associated data parameter shall hold the received value. The value of the associated status parameter shall indicate SUCCESS;

f) receiving a PhPDU with stop bit = "0" shall result in the MIS issuing a PH-DATA indication of class **DATA**. The associated data parameter shall hold the received value. The value of the associated status parameter shall indicate FRAMING_ERROR.

9.6.3 Full-duplex UDP

9.6.3.1 Overview

The PhID shall be sent in accordance with ISO/IEC 8802-3.

The MDS receives a single PhID or a sequence of PhID octets from the DLE. The first octet is received from the DLE by the service **START-OF-ACTIVITY-2**. The remaining octets are received from the DLE by the service **DATA**. End of transmission is indicated by the service **END-OF-ACTIVITY**.

9.6.3.2 Transmission

9.6.3.2.1 START-OF-ACTIVITY-2

The following shall be performed as a result of the DLE issuing a **START-OF-ACTIVITY-2** PH-DATA request:

a) reserve MAC sublayer packet;
b) form PhPDU with data = data parameter of **START-OF-ACTIVITY-2** request;
c) insert the formed PhPDU at the first location in the reserved packet;
d) confirm reception to DLE to enable the DLE to issue the next transmission request;

The following shall be performed as a result of the DLE issuing a **DATA** PH-DATA request:

a) form PhPDU with data = data parameter of the **DATA** request;
b) insert the formed PhPDU at the next location in the reserved packet;
c) confirm reception to DLE to enable the DLE to issue the next transmission service;

9.6.3.2.2 END-OF-ACTIVITY

The following shall be performed as a result of the DLE issuing an **END-OF-ACTIVITY** PH-DATA request:

a) transfer the reserved packet to the MAC sublayer.

9.6.3.3 Reception

9.6.3.3.1 START-OF-ACTIVITY

As a result of receiving a packet from the MAC sublayer, issue a PH-DATA indication of class **START-OF-ACTIVITY**. The associated data parameter shall hold the first octet of the received packet. The value of the associated status parameter shall be set to SUCCESS.

9.6.3.3.2 DATA

The following data in the received packet shall result in the MDS issuing PH-DATA indications of class **DATA**. The associated data parameters shall hold the received values. The value of the associated status parameters shall indicate SUCCESS.

9.7 Type 6: *This subclause has been removed*

NOTE This subclause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the subclause numbering of the prior edition.

9.8 Type 8: MDS: Wire and optical media

9.8.1 Function

The medium-dependent sublayer (MDS) exchanges PhSDU sequences via the MIS-MDS interface, as described in 6.5, and transmits the PhPDU via the MDS-MAU interface as described in clause 9. The MDS encodes and decodes the PhSDU, adds and removes the transmission frame (header and stop bit) for the PhSDU subsequences to be transmitted and received, synchronises the MIS-MDS interface and the MDS-MAU interface and the PhPDUs, time functions, and directly transmits a PhPDU between MAUs via the MDS-MAU interface (MAU coupling).

The MDS may consist of several channels. The PhPDU shall generate one channel of the MDS corresponding to the PhSDU sequences transmitted via the MIS-MDS interface and encode the PhSDU sequence accordingly. Conversely, this channel shall recognise the format of the received PhPDU and transmit the decoded PhSDU sequence via the MIS-MDS interface to the MIS. All other channels are used to directly transfer a PhPDU between two MAUs.

The channel of the MDS of a slave, which has an interface to the MIS shall have the following relation between the send and receive direction: If the MIS-MDS interface signal RTS is 0, the contents of DI is transmitted on the MDS-MAU interface signal DO with a delay time of exactly one bit time. If RTS is 1, DO is coupled to TxD (only applicable when there is no MDS coupling).

In the MDS of a master it is possible that a sequence of 8 PhSDUs is first buffered and then a corresponding data sequence or check sequence PhPDU is generated.

9.8.2 PhPDU formats

The MDS can recognise and generate the following PhPDU formats: **data sequence PhPDU**, **check sequence PhPDU**, **status PhPDU** and **reset PhPDU**.

9.8.2.1 Data sequence PhPDU

The MDS generates data sequence PhPDU by adding a start bit, header, and stop bit to the data unit. The data unit itself consists of eight PhSDUs that, as a PhSDU sequence, have been transmitted as a part of the data sequence DLPDU via the MIS-MDS interface with the message transmission service. Figure 36 shows the structure of the data sequence PhPDU.

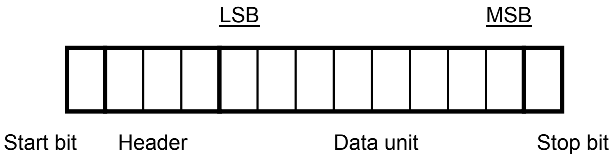


Figure 36 — Data sequence PhPDU

The data sequence PhPDU thus generated is transmitted from left to right via the MDS-MAU interface in the following order: start bit, header, data unit, stop bit. The PhSDUs of the data unit are transmitted via the MDS-MAU interface in the order in which they have been transmitted through the MIS-MDS interface.

According to Figure 36, a data sequence PhPDU is received from left to right and in the order: start bit, header, data unit, stop bit. The MDS removes start bit, stop bit and header and transmits the PhSDU sequence contained in the data unit with the message receipt service as a part of a data sequence DLPDU through the MIS-MDS interface to the MIS. The transmission begins with the first PhSDU that follows the header and ends with the last PhSDU before the stop bit.

NOTE 1 Each data sequence PhPDU begins with a start bit and ends with a stop bit.

NOTE 2 A data sequence DLPDU is transmitted by a sequence of data sequence PhPDUs.

The header in a data sequence PhPDU is structured as shown in Figure 37.

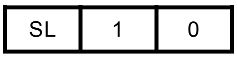


Figure 37 — Structure of the header in a data sequence PhPDU

The header of the data sequence PhPDU is transmitted and received from left to right via the MDS-MAU interface, beginning with the SL bit.

For a data sequence PhPDU to be sent, the logical symbol which is transferred in the SL bit is equivalent to the negated logical state of the TxSL signal of the MIS-MDS interface at the time at which the data sequence PhPDU is to be transmitted via the MDS-MAU interface to the MAU (see Table 33):

Table 33 — SL bit and TxSL signal assignment

TxSL signal	SL bit
Logical 1	0
Logical 0	1

For a received data sequence PhPDU the logical state of the RxSL signal of the MIS-MDS interface is equivalent to the negated logical symbol that is transmitted in the SL bit (see Table 34).

Table 34 — SL bit and RxSL signal assignment

SL bit	RxSL signal
0	Logical 1
1	Logical 0

9.8.2.2 Check sequence PhPDU

The MDS generates the check sequence PhPDU by adding a start bit, header and stop bit to the data unit. The data unit itself consists of eight PhSDUs that have been transmitted as a PhSDU sequence with a message transmission service as a part of a check sequence DLPDU via the MIS-MDS interface. Figure 38 shows the structure of the check sequence PhPDU.

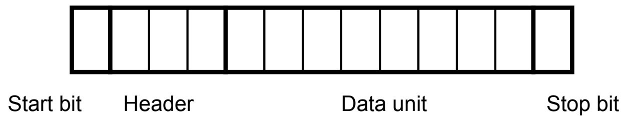


Figure 38 — Check sequence PhPDU

A check sequence PhPDU thus generated is transmitted from left to right via the MDS-MAU interface in the following order: start bit, header, data unit, stop bit. The PhSDUs of the data unit are transmitted via the MDS-MAU interface in the order in which they have been transmitted through the MIS-MDS interface.

A check sequence PhPDU is received, according to Figure 38, from left to right and in the order: start bit, header, data unit, stop bit. The MDS removes start bit, stop bit and header and transmits the PhSDU sequence contained in the data unit with the message receipt service as a part of a check sequence DLPDU via the MIS-MDS interface to the MIS. The transmission starts with the first PhSDU that follows the header and ends with the last PhSDU before the stop bit.

NOTE 1 Each check sequence PhPDU begins with a start bit and ends with a stop bit.

NOTE 2 A check sequence DLPDU is transmitted with a series of four check sequence PhPDUs.

The header in a check sequence PhPDU is structured according to Figure 39.

SL	0	0

Figure 39 — Structure of a headers in a check sequence PhPDU

The header of the check sequence PhPDU is transmitted and received from left to right via the MDS-MAU interface, beginning with the SL bit.

For a check sequence PhPDU to be sent, the logical symbol to be transferred in the SL bit is equivalent to the negated logical state of the TxSL signal of the MIS-MDS interface at the time at which the check sequence PhPDU is to be transmitted via the MDS-MAU interface to the MAU (see Table 35).

Table 35 — SL bit and TxSL signal assignment

TxSL signal	SL bit
Logical 1	0
Logical 0	1

For a received check sequence PhPDU the logical state of the RxSL signal of the MIS-MDS interface is equivalent to the negated logical symbol that is transmitted in the SL bit (see Table 36).

Table 36 — SL bit and RxSL signal assignment

SL bit	RxSL signal
0	Logical 1
1	Logical 0

9.8.2.3 Status PhPDU

The status PhPDU which is formed by the MDS consists of a start bit, the header, and a stop bit. The status PhPDU is structured as shown in Figure 40.

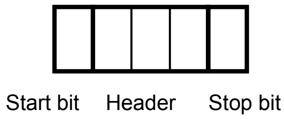


Figure 40 — Structure of the status PhPDU

The status PhPDU is transmitted and received via the MDS-MAU interface from left to right beginning with the stop bit, followed by the header and ending with the stop bit.

The header in a status PhPDU is structured according to Figure 41.

SL	0/1	1

Figure 41 — Structure of the header in a status PhPDU

According to Figure 41 the header is transmitted and received from left to right via the MDS-MAU interface, starting with the SL bit. The state of the bit which comes after the SL bit is not defined and can assume the values "0" or "1".

For a status PhPDU to be sent the logical symbol to be transmitted in the SL bit is equivalent to the negated logical state of the TxSL signals of the MIS-MDS interface at the time at which the status PhPDU is to be transmitted through the MDS-MAU interface to the MAU (see Table 37).

Table 37 — SL bit and TxSL signal assignment

TxSL signal	SL bit
Logical 1	0
Logical 0	1

For a received status PhPDU the logical state of the RxSL signal of the MIS-MDS interface is equivalent to the negated logical symbol that is transmitted in the SL bit (see Table 38).

Table 38 — SL bit and RxSL signal assignment

SL bit	RxSL signal
0	Logical 1
1	Logical 0

NOTE 1 Each status PhPDU begins with a start bit and ends with a stop bit.

NOTE 2 If no sequences of PhSDUs are transmitted to the MDS via the MIS-MDS interface, the MDS automatically begins to transmit successive status PhPDUs. Idle states may be generated between two successive status PhPDUs. The transmission of status PhPDUs is terminated synchronously to the message as soon as the first PhSDU of a data sequence or check sequence PhPDU was transmitted from MIS to the MDS.

NOTE 3 The status PhPDUs are transmitted after a reset PhPDU, if no check sequence PhPDU or data sequence PhPDU is to be transmitted.

NOTE 4 receipt of a status PhPDU does not change the logical state of the RxCR signal of the MIS-MDS interface.

9.8.2.4 Medium activity status PhPDU

The medium activity status PhPDU that is formed by the MDS consists of a start bit, the header, and a stop bit. The medium activity status PhPDU is structured as shown in Figure 42.

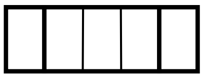


Figure 42 — Structure of the medium activity status PhPDU

The header in a medium activity status PhPDU is structured according to Figure 43.

1	1	1

Figure 43 — Structure of the header in a medium activity status PhPDU

According to Figure 43 the header is transmitted and received from left to right via the MDS-MAU interface. The medium activity status PhPDU is only transmitted via an outgoing passive MAU (loopback mode = disable) when the systems management set the variable data select = enable.

9.8.2.5 Coding and decoding

Coding and decoding is done in accordance with the rules in Table 39.

Table 39 — Coding and decoding rules

Logical symbol bit	Coding DO, DI
1	High level
0	Low level

NOTE 1 The high and low levels shall each be taken from the beginning of a bit for the duration of one bit time.

NOTE 2 For the coding the logical symbols are converted to the corresponding state of the DO signal of the MDS-MAU interface.

NOTE 3 For the decoding the status of the DI signal of the MDS-MAU interface is converted to the corresponding logical symbol.

9.8.2.6 Start bit

The start bit corresponds to the logical symbol "1".

NOTE The MDS shall synchronise its receive clock with the beginning of the start bits (low-high transitions).

9.8.2.7 Stop bit

The stop bit corresponds to the logical symbol "0".

NOTE The MDS may synchronise its receive clock to a newly arriving start bit only after a stop bit (low-high transition).

9.8.3 Idle states

The sender of the bus master may generate idle states during the transitions of status PhPDUs to data sequence PhPDUs or check sequence PhPDUs. Idle states have always a low level on DO. The maximum length of the idle states shall not exceed 26 bit times. The decoding rules for idle states recognised on the medium are given in Table 40.

Table 40 — Decoding rules for the idle states

Idle state	State RxCR	Decoding DI
Data_Idle	Logical 0	Low level
CRC_Idle	Logical 1	Low level
CRC_Status_Idle	Logical 1	Low level

9.8.4 Reset PhPDU

9.8.4.1 Structure of the Reset PhPDU

The reset PhPDU transmits the logical symbols "short reset" or "long reset". Figure 44 shows the structure of the reset PhPDU.

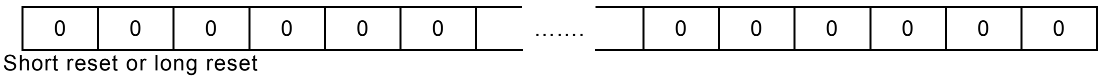


Figure 44 — Reset PhPDU

NOTE The symbols "short reset" and "long reset" only differ in the time during which the signals DO or DI of the MDS-MAU interface transmit a low level.

9.8.4.2 Coding and decoding

The coding rules for the reset PhPDU are given in Table 41 and Table 42.

Table 41 — Coding rules for the reset PhPDU

Logical symbol	Time interval	Coding DO
Short bus reset	2 ms ≤ T_{Rst} < 25,6 ms	Low level
Long bus reset	T_{Rst} ≥ 25,6 ms	Low level

Table 42 — Decoding rules of the reset PhPDU

DI	Time interval	Logical symbol
Low level	2 ms ≤ T_{Rst} < 25,6 ms	Short bus reset
Low level	T_{Rst} ≥ 25,6 ms	Long bus reset

NOTE 1 A reset PhPDU is terminated with the start bit of a data sequence PhPDU, a check sequence PhPDU or a status PhPDU.

NOTE 2 During the coding, the logical symbols are converted to the corresponding state of the DO signal of the MDS-MAU interface during the time T_{Rst}.

NOTE 3 During the decoding, in the time T_{Rst} the state of the DI signal of the MDS-MAU interface is converted to the corresponding logical symbol.

NOTE 4 The times given in Table 41 and Table 42 do not apply to the sender of the master. For the sender of the bus master the corresponding reset PhPDU shall be generated upon request of the RO service in accordance with the definitions specified in the PhL variables *short bus reset time* and *long bus reset time*.

NOTE 5 The encoding rules for the reset PhPDU apply only to a MDS coupling in the MIS.

9.8.5 MAU coupling

When MAUs of the same type are coupled pairs, each PhPDU and all idle states are transmitted unchanged between two MAUs. Figure 45, Figure 46 and Figure 47 show possible configurations for the bus devices when the 2-wire medium is used.

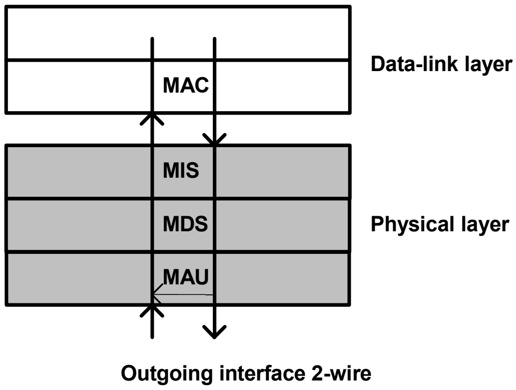


Figure 45 — Configuration of a master

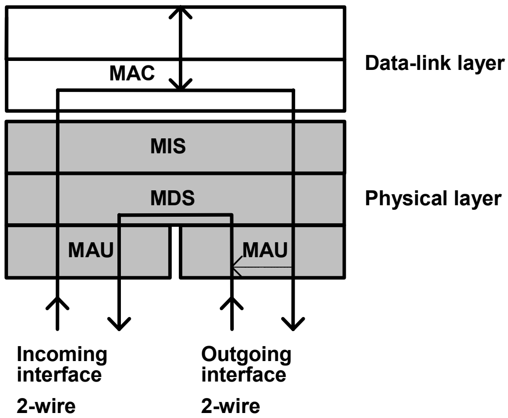


Figure 46 — Configuration of a slave

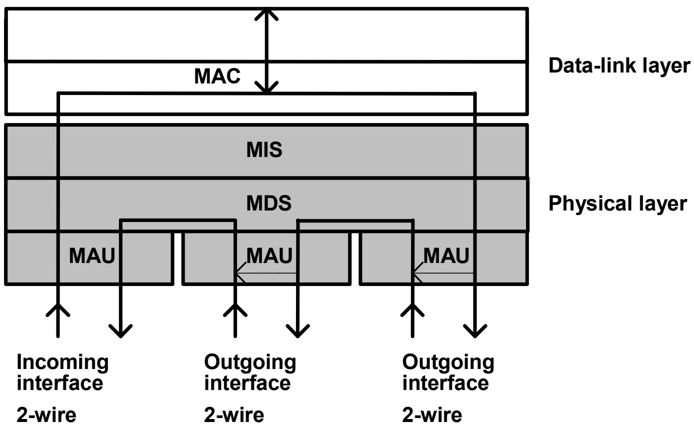


Figure 47 — Configuration of a bus coupler

NOTE When two MAUs are directly coupled, code-transparent repeaters may be used for the time regeneration.

9.9 Type 12: MDS: Wire media

9.9.1 PhPDU

The MDS shall produce the PhPDU shown in Figure 29 by adding delimiters and minimal idle sequences to frame the serial sequence of PhSDUs (bits) transferred from the DIS across the DTE – DCE interface. Transmission sequence shall be from left to right as shown in Figure 29, i.e. SOF first, followed by PhSDU sequence and finally EOF.

idle	SOF	PhSDU SEQUENCE	EOF	idle

Figure 48 — Protocol data unit

Conversely, the MDS shall remove idle, SOF and EOF from a received PhPDU to produce a corresponding serial sequence of PhSDUs. If a non-binary data unit is detected in the received PhSDU sequence, the MDS shall immediately stop transferring PhSDUs to the DIS, the MDS shall report an error, and the MDS shall indicate the end of activity to the DIS when it happens.

9.9.2 Encoding and decoding

Data units shall be encoded by the MDS for application to the MAU using the code shown in Figure 49 (Manchester Biphase L). The encoding rules are given formally in Figure 50 and Table 43.

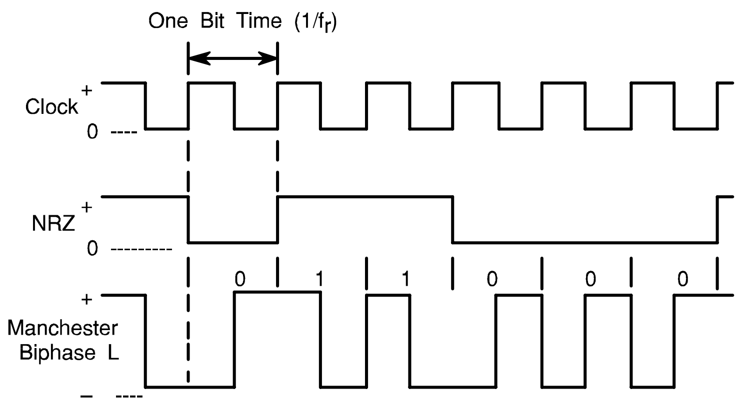
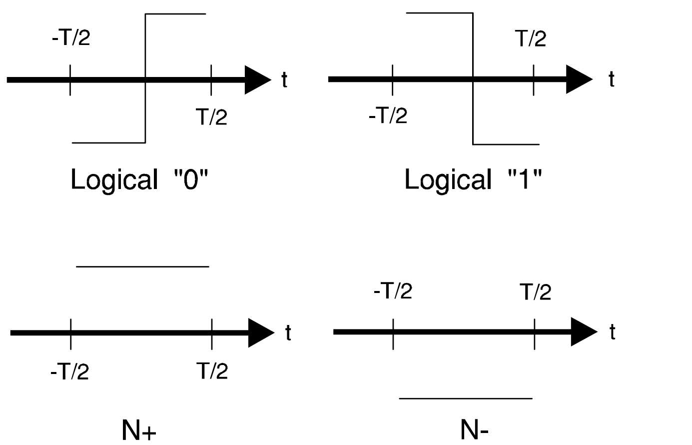


Figure 49 — PhSDU encoding and decoding

NOTE Figure 49 is included for explanatory purposes and does not imply a specific implementation.



IEC 1456/2000

Figure 50 — Manchester encoding rules

Table 43 — Manchester encoding rules

Symbols	Encoding
1 (ONE)	Hi–Lo transition (mid-bit)
0 (ZERO)	Lo–Hi transition (mid-bit)
N+ (NON-DATA PLUS)	Hi (No transition)
N– (NON-DATA MINUS)	Lo (No transition)
NOTE It may be seen that data symbols (1 and 0, conveyed by PhSDUs) are encoded to always contain a mid-bit transition. Non-data symbols (N+ and N–) are encoded so that they never have a mid-bit transition.	

Decoding shall normally be the opposite of encoding. At reception, the MDS shall verify that each symbol is encoded in accordance with Figure 50 and Table 43 and shall detect the following errors:

a) invalid Manchester code;

b) half-bit-slip errors;

c) misalignment of EOF (number of bits is not a multiple of 8).

Any of these errors shall be reported as:

PH-DATA indication (class=END-W-ERROR, data=error).

9.9.3 Polarity detection

There is no automatic polarity detection of the received Manchester Biphase L encoded signal.

9.9.4 SOF

The following sequence of symbols, shown from left to right in order of transmission, shall immediately precede the PhSDU sequence to delimit the start of a frame:

0, N+

The MDS shall only accept a received signal burst as a PhPDU after verifying this sequence and shall remove this sequence before transferring the PhSDU sequence to the DIS.

9.9.5 EOF

The following sequence of symbols, shown from left to right in order of transmission, shall immediately follow the PhSDU sequence to delimit the end of a frame:

N–, 0

The MDS shall remove this sequence from the PhPDU before transferring the PhSDU sequence to the DIS. The MDS shall report to the corresponding DLL entity any frames received via the medium which do not include this sequence within 1 535 octets of start of frame (from end of SOF) as:

PH-DATA indication (class=END-W-ERROR, data=frame_too_long).

The MDS shall report to the corresponding DLL entity, via the corresponding DIS, any frames received via the medium that have an end delimiter which is not located at an octet boundary as:

PH-DATA indication (class=END-W-ERROR, data=alignment_error).

9.9.6 Idle

In order to synchronize bit times an idle sequence shall be send out if no PhSDU or SOF/EOF are transmitted:

0

An idle sequence is always bit aligned.

NOTE A series of 1 in a PhSDU can be interpreted as idle. Following 0-symbols or EOF will readjust bit cell detection.

9.9.7 Synchronization

After activation and reception of a sufficient number of signals the receiver shall detect and report half-bit-slip errors.

NOTE 1 This synchronization specification allows the loss of 4 bits of the preamble.

After SOF, half-bit-slip errors shall be reported as:

PH-DATA indication (class=END-W-ERROR, data=half_bit_slip_error).

NOTE 2 Half-bit-slip errors can be detected as excessive bit cell jitter and/or excessive variation in bit period.

9.9.8 Inter frame gap

After transmission of a PhPDU there shall be a minimum period during which a subsequent transmission shall not commence. For the same minimum period after reception of a PhPDU the receiving PhL entity shall ignore all received signaling. An MDS entity shall set a minimum post transmission period of 92 nominal bit times (96 with SOF, EOF). The period may be extended, but not reduced, by systems management.

9.10 Type 16: MDS: Optical media

9.10.1 Data encoding rules

Signals on the transmission lines shall be NRZI-coded. Signal changes are only allowed to take place in synchronization with the transmitting clock. Every time a 0 is transmitted, the signal shall change its status in synchronization with the transmitting clock, whereas the signal shall remain unchanged when a 1 is transmitted.

By a suitable method (i.e., bit-stuffing), the transmitter shall ensure that enough zeros occur in the transmitted bit stream. This generates additional signal changes. In this way, conditions are created which make it possible to retrieve a receiving clock from the received signal. The retrieved receiving clock shall also have a fixed phase position with respect to the clock of the transmitter. The clock shall be retrievable by means of a digital phase locked loop (DPLL) which shall be synchronized to the signal change of the received signal transformed to an electrical signal. Figure 51d) is an example of a NRZI-coded signal. Therefore, the transmitting clock provides the pattern for the system timing via the signal transitions.

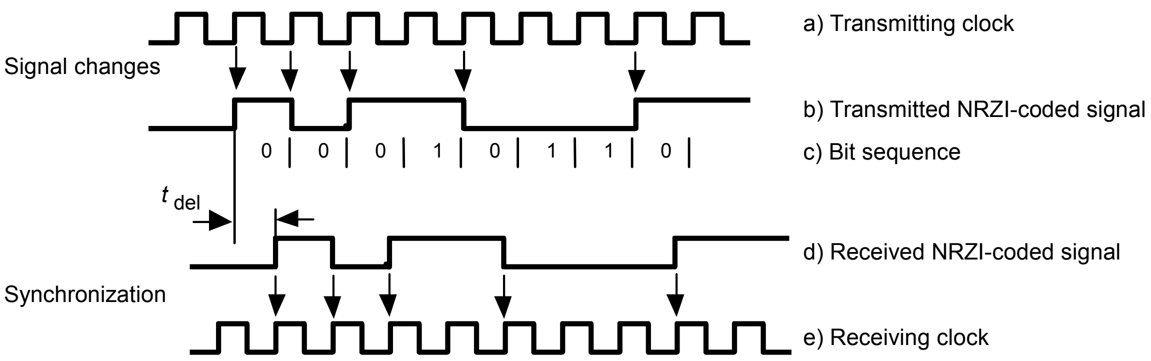


Figure 51 — Example of an NRZI-coded signal

9.10.2 Telegrams and fill characters

On the physical level, it is sufficient to know that a telegram shall start and end with the bit sequence 0111 1110. This bit sequence is also known as a delimiter. Due to bit-stuffing, this bit sequence is prevented from occurring inside the telegram.

Other fields of the telegram belong to higher protocol layers and are discussed elsewhere.

If a unit does not place its own telegram on the network, two possibilities arise:

a) the master shall transmit a so-called fill signal (fill bits) between its own telegrams. It shall consist of a sequence of one binary 0 and seven binary 1's (i.e., 0111 1111). This generates a symmetric fill signal with 16 times the period of the transmitting clock, due to NRZI-coding (see Figure 52);

b) between its own telegrams, a slave shall transmit with its synchronized local clock the physically regenerated, received signals (repeater mode).

During the transition from telegram to fill signal (master) or from telegram to repeater mode (slave), signal changes shall follow the pattern of the current clock.

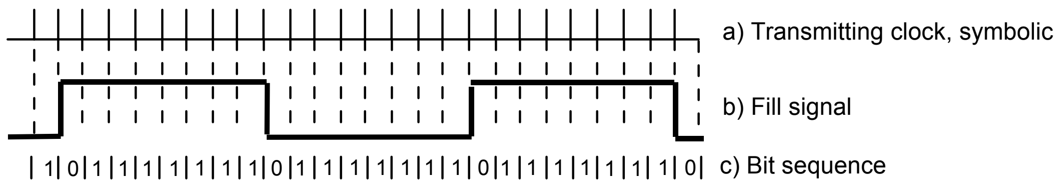


Figure 52 — Fill signal

NOTE Due to bit-stuffing and a), the slave physically located first in the network can derive its local clock from its received signal at any time. Because of b), this is also the case for all subsequent units, all the way to the receiver of the master. In this way, digital phase locked loops, which are eventually used to obtain the local clock, remain locked on, preventing time-consuming synchronization before the start of the actual telegram.

9.11 Type 18: MDS: Wire media

9.11.1 Overview

The type 18 MDS shall be able to sense the initiation and subsequent termination of data reception, the means of which are beyond the scope of this specification.

9.11.2 Transmission

Data transmission is started upon receipt of a PH-DATA (START-OF-ACTIVITY) request from the DL-user. This is translated by the MDS into a TRANSMIT-ENABLE signal assertion with the value specified in the DATA field being transmitted on the TRANSMIT-SIGNAL.

The MDS shall issue a PH-DATA (SUCCESS) confirmation and must receive the next PH-DATA (DATA) request before the expiration of the MDS baud rate bit timer. It is not until this request is acted upon that the subsequent PH-DATA (SUCCESS) confirmation is produced. In this way, the MDS baud rate timer regulates the flow rate of data.

Upon receipt of a PH-DATA (END-OF-ACTIVITY) request from the DL-user, the MDS completes the transmission in process and concludes with a TRANSMIT-ENABLE signal deassertion.

9.11.3 Reception

Upon receipt of data activity, the MDS issues a PH-DATA (START-OF-ACTIVITY) indication with the DATA value received. Each subsequent datum received results in a PH-DATA (DATA) indication with the DATA value received. Upon completion of the data reception, the MDS issues a PH-DATA (END-OF-ACTIVITY) indication to the DL-user.

10 MDS — MAU interface

10.1 General

The medium attachment unit (MAU) is an optionally separate part of a communication element that connects to the medium directly or via passive components. (See Figure 1.) For electrical signaling variants the MAU is the transceiver, which provides level shifting and wave shaping for transmitted and received signals. The MDS – MAU interface links the MAU to the MDS. The services are defined as physical signals to facilitate this interface optionally being exposed. The following subclauses list for each Type specifies the minimum set of required services at the MDS – MAU interface. See Clause 6 for management services.

NOTE A number of different MDS – MAU interfaces are specified, based on industry practice.

10.2 Type 1: MDS – MAU interface: Wire and optical media

10.2.1 Services

If the MDS – MAU interface is exposed it shall support at least the set of required services given in Table 44 and specified in 10.2.2.

Table 44 — Minimum services at MDS – MAU interface

Service	Abbreviation	Direction
Required:		
Transmit Signal	TxS	To MAU
Receive Signal	RxS	From MAU
Transmit Enable	TxE	To MAU
Optional:		
Loopback enable	LbE	To MAU

10.2.2 Service specifications

10.2.2.1 Transmit signal (TxS)

The Transmit Signal service (TxS) shall transfer the encoded PhPDU signal sequence across the MDS – MAU interface to the MAU, where the sequence shall be transmitted on to the medium if the Transmit Enable (TxE) is set to logic 1 (high level).

10.2.2.2 Receive signal (RxS)

The Receive Signal service (RxS) shall transfer the encoded PhPDU signal sequence or silence across the MAU – MDS interface to the MDS. The RxS shall echo the signal transmitted via TxS by simultaneously receiving the transmissions from the medium.

10.2.2.3 Transmit enable (TxE)

The Transmit Enable service (TxE) shall provide the MDS with the facility to enable the MAU to transmit. The TxE shall be set to logic 1 (high level) at the commencement of preamble transmission and then set to logic 0 (low level) after the last bit of the end delimiter has been transmitted.

If redundant media are in use and the method of implementing redundancy is to receive on all channels but transmit on only one then the channel (cable) that is currently used for transmission shall be selected by setting its TxE to logic 1 (high level). All channels that are not currently in use for transmission shall be disabled by setting the TxE to logic 0 (low level).

10.2.2.4 Loopback enable (LbE)

If the optional Loopback Enable (LbE) service shown in Table 44 is used it shall disable the final output stage of the MAU transmit circuit, connect the output of the previous stage of the MAU transmit circuit to the MAU receive circuit and disconnect the MAU receive circuit from the medium. The state of the Loopback Enable shall not change while the MAU is transmitting or receiving.

NOTE This confirmation service is of local significance only and provides a device with the facility to test the integrity and functionality of the PhL circuitry, excluding the medium.

10.2.3 Signal characteristics

Timing characteristics shall be compatible with those specified in the requirements of this standard for the relevant MDS.

If the MDS – MAU interface is exposed it shall operate with digital signal levels as shown in Table 45. Both sides of the interface shall operate with the same value of V_{DD}.

Table 45 — Signal levels for an exposed MDS – MAU interface

Symbol	Parameter	Conditions	Limits	Units	Remarks
V_{OL}	Maximum low-level output voltage	I_{out} = ±100 μA	0,1	V	See Note 1
		I_{out} = +1,6 mA	0,4	V	
V_{OH}	Min.high-level output voltage	I_{out} = ±100 μA	V_{DD} – 0,1	V	See Note 1
		I_{out} = –0,8 mA	V_{DD} – 0,8	V	See Note 2
V_{IL}	Max.low-level input voltage		0,2 V_{DD}	V	
V_{IH}	Min.high-level input voltage		0,7 V_{DD}	V	See Note 3

NOTE 1 Provides the capability to drive two typical CMOS loads.

NOTE 2 CMOS input compatibility with TTL output requires a "pull-up" resistor from signal input to V_{DD}.

NOTE 3 Compatible with CMOS output for 3,0 V ≤ V_{DD} ≤ 5,5 V. Compatibility with TTL output (4,75 V ≤ V_{DD} ≤ 5,25 V) requires a "pull-up" resistor from signal input to V_{DD}.

10.2.4 Communication mode

The communication mode at this interface shall allow simultaneous transmission and reception.

10.2.5 Timing characteristics

The MDS – MAU interface shall function correctly with a PhSDU bit rate of between 1 kbit/s and 1,1 times the highest stated MAU bit rate.

NOTE The bit rates available in an implementation are stated in the Protocol Implementation Conformance Statement (PICS).

10.3 Type 1: MDS – MAU interface: Radio signaling

When exposed, this interface should use the industry standard SPI protocol and signals, or equivalent, in which octet registers and FIFOs in the MAU are read and written by the MDS and in which the MAU can interrupt the MDS.

10.4 Type 2: MDS – MAU interface: Wire and optical media

10.4.1 MDS-MAU interface: general

10.4.1.1 Conformance

A node may include any (or more than one) PhL variant but the appropriate medium interface shall be provided for each PhL variant implemented.

The MDS-MAU interface need not be exposed in the implementation of any PhL variant. This interface may be internal to the node and may be internal to a semiconductor device. If, however, conformance to the MDS-MAU interface is claimed, the implementation shall conform to the requirements of this subclause.

10.4.1.2 Delay from medium to MDS–MAU interface

For all implementations conformant to the MDS-MAU interface, the receive delay from the medium to the MDS-MAU interface shall be less than 200 ns and the transmit delay from the MDS-MAU interface to the medium shall be less than 200 ns.

10.4.2 MDS-MAU interface: 5 Mbit/s, voltage-mode, coaxial wire

10.4.2.1 Signal definitions

This subclause lists the signals defined for the 5 Mbit/s, voltage-mode, coaxial wire medium MDS-MAU interface, as shown in Table 46.

Table 46 — MDS-MAU interface definitions: 5 Mbit/s, voltage-mode, coaxial wire

TxDataOut	TxDataBar	NetEnable	RxData	RxCarrier	Ph-symbol
x	x	0	undefined	0	No transmission MAU_FRAME_REQUEST = false
0	0	1	undefined	0	No transmission MAU_FRAME_REQUEST = false
1	0	1	1	1	H
0	1	1	0	0	L
1	1	1	-	-	Not allowed, transmitter damage may occur

10.4.2.2 TxDataOut

TXDATAOUT shall be true to represent H from the MAU, and shall be false to represent L as shown in Table 46. TXDATAOUT shall be false when no Ph-symbol data is to be transmitted (MAU_FRAME_REQUEST = false)

10.4.2.3 TxDataBar

TXDATABAR shall be true to represent L from the MAU, and shall be false to represent H as shown in Table 46. TXDATABAR shall be false when no Ph-symbol data is to be transmitted (MAU_FRAME_REQUEST = false)

10.4.2.4 NetEnable

NETENABLE shall be true to enable the MAU for transmission of TXDATAOUT and TXDATABAR Ph-symbol data on the coaxial wire medium. NETENABLE false shall prevent transmission of TXDATAOUT and TXDATABAR Ph-symbol data as shown in Table 46.

10.4.2.5 RxData

RxData shall represent the raw, distorted, unsynchronised Ph-symbols (H or L) as recovered from the coaxial wire medium. This signal shall be true or false based on the requirements shown in Table 84. After data recovery and resynchronisation to meet the MDS timing requirements (from Table 31), these Ph-symbols shall be decoded into the appropriate MDS M_symbols as shown in Table 32.

10.4.2.6 RxCarrier

RxCarrier shall be true when the signal level on the coaxial wire medium exceeds the carrier detection threshold voltage as shown in Table 85; otherwise, it shall be false. This signal shall be used to create the Ph-CARRIER indication at the DLL-PhL interface as defined in 5.3.5.

10.4.3 MDS-MAU interface 5 Mbit/s, optical medium

10.4.3.1 Signal definitions

This subclause lists the signals defined for the 5 Mbit/s, optical fiber medium MDS-MAU interface, as shown in Table 47.

Table 47 — MDS-MAU interface 5 Mbit/s, optical fiber medium

TXDATAOUT	NETENABLE	RXDATA	RXCARRIER	Ph-symbol
Don’t care	0	0	0	L or ‘light off’
1	1	1	1	H or ‘light on’
0	1	0	0	L or ‘light off’

10.4.3.2 TxDataOut

TXDATAOUT shall be true to represent H from the MAU, and shall be false to represent L as shown in Table 92. A true signal shall be represented on the fiber medium as ‘light on’. A false signal shall be represented on the fiber medium as ‘light off’. The fiber transmit level requirements that define ‘light on’ (or Coupled Power, PT on) and ‘light off’ (or Coupled Power, PT off) shall be as defined in 19.6.

10.4.3.3 NetEnable

NETENABLE shall be true to indicate the MDS sublayer has valid Ph-symbols to be transmitted onto the fiber medium. NETENABLE shall enable the MAU for transmission of TXDATAOUT light levels on the fiber medium. NETENABLE false shall prevent transmission of TXDATAOUT signals, as shown in Table 47.

10.4.3.4 RxData

RXDATA shall represent the raw, distorted, unsynchronised Ph-symbols (H or L) as recovered from the fiber medium. This signal shall be true when the light level on the medium meets the 'light on' requirements defined in 19.6, otherwise this signal shall be false. After data recovery and resynchronisation to meet the MDS timing requirements (from Table 31), these Ph-symbols shall be decoded into the appropriate PLS_DATA_INDICATION M_symbols as shown in Table 32. RXDATA shall report false if the medium is broken, missing or power is removed from the transmitting end of the fiber.

10.4.3.5 RxCarrier

RXCARRIER shall be true when the light level on the medium meets the 'light on' requirements defined in 19.6, otherwise this signal shall be false. This signal shall be used directly to create the PLS_CARRIER_INDICATION at the DLL-PhL interface. If the fiber transceiver does not support a carrier indication mechanism, this interface signal shall be connected to the RXDATA interface signal. The RXCARRIER shall report false if the medium is broken, missing or power removed from the transmitting end of the fiber.

10.4.4 MDS–MAU interface Network Access Port (NAP)

The following signals shall be required for the NAP MDS-MAU interface:

a) /TxPTC shall be false to represent H transmit data from the MAU, and shall be true to represent L;
b) /RxPTC shall be false to represent H receive data from the MDS, and shall be true to represent L. This signal shall be true if the NAP medium is removed, broken, short-circuited or the source transmitter is disabled.

10.5 Type 3: MDS – MAU interface: Wire and optical media

10.5.1 Synchronous transmission

The MDS – MAU interface specified for Type 1 shall be used (see 10.2).

10.5.2 Asynchronous transmission

Instead of the MDS – MAU interface as described in 10.2 the DL – Ph interface for asynchronous transmission shall be used (see 5.1 and 5.4.2).

10.6 Type 8: MDS – MAU interface: Wire and optical media

10.6.1 Overview of the services

The MDS-MAU interface makes services available to connect the MDS with a corresponding MAU. The services are defined as logical signals that the MAU sublayer directly converts into physical signals (see Table 48).

Table 48 — Services of the MDS-MAU interface

Service	Mnemonic	Direction
Data Out	DO	From MDS
Data In	DI	From MAU
Bus Connector	BC	From MAU
Loopback Enable	LbE	From MDS
Data Select	DS	From MDS
Medium Activity	MA	From MDS
NOTE The Bus Connector, Loopback Enable, Data Select and Medium Activity services are only supported by the MAU of an outgoing interface.		

10.6.2 Description of the services

10.6.2.1 Data-out (DO)

This service transmits the PhPDU from the MDS to the MAU.

10.6.2.2 Data-in (DI)

This service transmits the PhPDU from the MAU to the MDS.

10.6.2.3 Bus connector (BC)

This service indicates to a MDS whether the transmission medium is connected to the MAU of an outgoing interface. If the transmission medium is not connected to the MAU of an outgoing interface, the systems management shall, for this MAU, disconnect the receive circuit from the medium with the Loopback Enable (LbE) service and connect the send circuit with the receive circuit.

NOTE 1 The Bus Connector service is only supported by the MAU of an outgoing interface. It is not related to the other services of the MDS-MAU interface.

NOTE 2 This service is a local management service that indicates whether another bus device is connected to the outgoing interface of the MAU, which allows the systems management to close or open the transmission ring with the Loopback Enable service.

NOTE 3 The detection of another connected bus device is caused by a signal that is led through a bridge in the connector of the outgoing cable (see cable definition).

10.6.2.4 Loopback enable (LbE)

This service allows the systems management to decouple the receive circuit from the transmission medium for a MAU of an outgoing interface, and to connect the send circuit with the input circuit.

NOTE 1 The Loopback Enable service is only supported by the MAU of an outgoing interface and is not related to the other services of the MDS-MAU interface.

NOTE 2 This service is a local management service that allows the systems management to close the transmission ring if no other bus slave is connected to the MAU of an outgoing interface.

10.6.2.5 Medium activity (MA)

This service transmits a special status PhPDU from the MDS to the MAU if the active ring was decoupled from the medium and the send and receive circuit were connected but controlled activity is to be generated on the medium.

NOTE 1 This service is used by a slave only.

NOTE 2 The Medium Activity service is only supported by MAU of an outgoing interface and has no time relation to the other services of the MDS-MAU interface.

10.6.2.6 Data select (DS)

The systems management uses this service to transmit on the decoupled medium of an outgoing MAU either a reset PhPDU or with the Medium Activity service certain status PhPDUs.

NOTE 1 This service is used by a slave only.

NOTE 2 The Data Select service is only supported by MAU of an outgoing interface and is not related to the other services of the MDS-MAU interface.

10.6.3 Time response

The MDS shall be able to correctly decode a bit with bit jitter specified in Figure 53. The variation for the sample clock shall be within the range of ± 0,1 %.

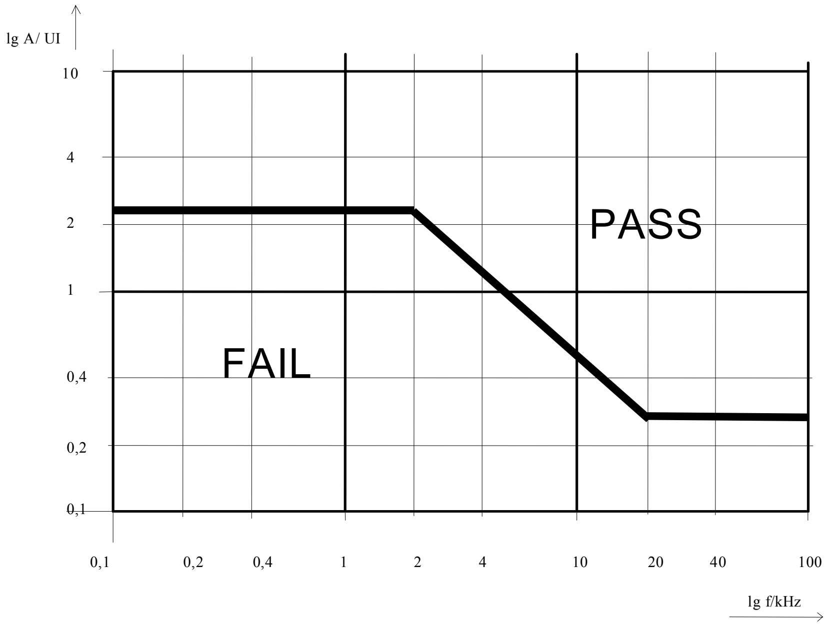


Figure 53 — Jitter tolerance

10.6.4 Transmission mode

The MDS-MAU interface shall allow a simultaneous, independent sending and receiving.

10.7 Type 18: MDS – MAU interface: Wire media

10.7.1 General

The granularity of PhPDU exchanged at the MAU interface is one bit.

10.7.2 Services

If the MAU interface is exposed it shall support at least the set of required services given in Table 49 and specified in 10.2.2.

Table 49 — Minimum services at MAU interface

Service	Abbreviation	Direction
Transmit Signal	TxS	To MAU
Receive Signal	RxS	From MAU
Transmit Enable	TxE	To MAU

10.7.3 Service specifications

10.7.3.1 Transmit Signal (TxS)

The Transmit Signal service (TxS) shall transfer the encoded PhPDU signal sequence across the interface to the MAU, where the sequence shall be transmitted on to the medium if the Transmit Enable (TxE) is set to logic one (high level).

10.7.3.2 Receive Signal (RxS)

The Receive Signal service (RxS) shall transfer the encoded PhPDU signal sequence or silence across the interface to the MDS. The RxS shall echo the signal transmitted via TxS by simultaneously receiving the transmissions from the medium.

10.7.3.3 Transmit Enable (TxE)

The Transmit Enable service (TxE) shall provide the facility to enable the MAU to transmit. The TxE shall be set to logic one (high level) at the commencement of preamble transmission and then set to logic zero (low level) after the last bit of the end delimiter has been transmitted.

10.7.4 Signal characteristics

If the MAU interface is exposed it shall operate with digital signal levels as shown in Table 50. Both sides of the interface shall operate with the same value of V_{DD}.

Table 50 — Signal levels for an exposed MAU interface

Symbol	Parameter	Conditions	Limits	Units	Remarks
V_{OL}	Maximum low-level output voltage	I_{out} = ±100 μA	0,1	V	See Note 1
		I_{out} = +1,6 mA	0,4	V	
V_{OH}	Minimum high-level output voltage	I_{out} = ±100 μA	V_{DD} – 0,1	V	See Note 1
		I_{out} = –0,8 mA	V_{DD} – 0,8	V	See Note 2
V_{IL}	Maximum low-level input voltage		0,2 V_{DD}	V	
V_{IH}	Minimum high-level input voltage		0,7 V_{DD}	V	See Note 3

NOTE 1 Provides the capability to drive two typical CMOS loads.

NOTE 2 CMOS input compatibility with TTL output requires a "pull-up" resistor from signal input to V_{DD}.

NOTE 3 Compatible with CMOS output for 3,0 V ≤ V_{DD} ≤ 5,5 V. Compatibility with TTL output (4,75 V ≤ V_{DD} ≤ 5,25 V) requires a "pull-up" resistor from signal input to V_{DD}.

10.7.5 Communication mode

The communication mode at this interface shall allow simultaneous transmission and reception.

10.7.6 Timing characteristics

The MAU shall function correctly with a PhSDU bit rate of between 1 kbit/s and 1,1 times the highest stated MAU bit rate. The clocking frequency shall be implemented accurate to within 150 ppm of the specified rate.

11 Types 1 and 7: Medium attachment unit: voltage mode, linear-bus-topology 150 Ω twisted-pair wire medium

11.1 General

These MAU requirements are not specifically intended to facilitate the options of

– power distribution via the signal conductors;

– suitability for intrinsic safety certification.

The network medium consists of shielded twisted-pair cable. Independent of topology, all attached devices, other than possibly the transmitting device, present a high impedance to prevent significant network loading. Trapezoidal waveforms are used to reduce electromagnetic emissions and signal distortion.

A linear bus topology is supported, as are some branched acylic topologies. A network contains one trunk cable, terminated at its ends.

11.2 Bit-rate-dependent quantities

Six bit rates are defined for the voltage-mode twisted-pair medium attachment unit (MAU). A given MAU shall support at least one of these bit rates.

Table 51 specifies the supported bit rates, and defines symbols for bit-rate-dependent quantities used throughout the remainder of this clause.

Table 51 — Bit-rate-dependent quantities of voltage-mode networks

Quantity		Symbol	Unit	Value					
Nominal bit rate		BR	Mbit/s	0,031 25	1	2,5	5	10	25
Maximum deviation from BR		ΔBR		0,2 %	0,01 %				
Nominal bit duration		T_{bit}	µs	32	1,0	0,4	0,2	0,1	0,04
Maximum deviation from T_{bit}		ΔT_{bit}	–	0,9 µs	0,025 %				
Signaling frequencies	Nominal for a repeated bit	f_r	MHz	0,031 25	1	2,5	5	10	25
	Nominal minimum = 0,25 f_r	f_{min}	MHz	0,007 8	0,25	0,625	1,25	2,5	6,25
	Nominal maximum = 1,25 f_r	f_{max}	MHz	0,039	1,25	3,125	6,25	12,5	31,25
Maximum number of devices		N_{max}		32				16	
Maximum inter-device distance		L_{max}	m	4 000	750	500	400	200	100
Maximum inter-device attenuation		A_{max}	dB	15	17	18			
Maximum inter-device attenuation distortion		AD_{max}	dB	8		10			
Maximum inter-device mismatching distortion		MD_{max}	dB	0,2			0,4	0,6	
Maximum signal rise or fall time		T_{rf}	ns	8 000	200	80	40	20	8
Maximum coupler spacing to form a cluster		CS_{max}	m	4		2	1	0,5	0,25
Minimum device input impedance		Din_{min}	kΩ	8			4	2	1
Maximum quiescent transmitter output		QTO_{max}	mV rms	1	5	10	20	40	80
Maximum frequency for QTO_{max} measurement		f_{QTOmax}	MHz	0,1	4 f_r				

The average bit rate shall be BR ± ΔBR, averaged over a frame having a minimum length of 16 octets. The instantaneous bit time shall be $T_{bit} \pm \Delta T_{bit}$.

11.3 Network specifications

11.3.1 Components

A voltage-mode MAU operates in a network composed of the following components:

a) twisted-pair wire cable;
b) devices (containing at least one communication element);
c) connectors;
d) couplers;
e) terminators.

11.3.2 Topologies

A wire MAU shall operate in a network with an acyclic nominally linear bus topology, consisting of a trunk, terminated at each end as specified in 11.8.5, to which communication elements are connected via couplers. Each communication element shall be connected in parallel with the trunk cable.

NOTE 1 The coupler and communication element are generally integrated in one device.

NOTE 2 Active repeaters may be used to establish branches or to extend the length of the trunk beyond that of a single segment as permitted by the network configuration rules. Branches must be considered as segments, and may make the bus non-linear. Cycles (closed loops) are never permitted.

11.3.3 Network configuration rules

An MAU that claims conformance to this clause of this standard shall meet the requirements of this clause when used in a network that complies with these rules.

Rule 1: A fieldbus shall be capable of communication between two and N_{max} devices, all operating at the same bit rate.

NOTE 1 This rule does not preclude the use of more than N_{max} devices in an installed system.

Rule 2: A fully loaded (maximum number of connected devices) fieldbus segment shall have a total cable length, including branches, between any two devices, of up to L_{max}.

NOTE 2 Support of this maximum cable length is a requirement for MAU conformance to this clause of this standard, but this does not preclude the use of longer lengths in an installed system.

Rule 3: The total number of waveform regenerations by repeaters and active couplers between any two devices is repeater implementation dependent.

NOTE 3 Prior editions of this standard limited this total number to four.

Rule 4: The maximum propagation delay between any two devices shall not exceed 40 T_{bit}.

NOTE 4 For efficiency of the network, that part of the turn-around time of any device on the network caused by a PhE between the end of a received frame and the beginning of the transmitted frame containing an associated immediate response should not exceed 30 bit times, no more than 2 bit times of which should be due to the MAU. As it is not mandatory to expose either the DLL – PhL interface or the MDS – MAU interface, that part of the turn-around time of a fieldbus device caused by the PhL or the MAU cannot be specified or conformance tested.

Rule 5: The fieldbus shall be capable of continued operation while a device is being connected or disconnected. Data errors induced during connection or disconnection shall be detected.

Rule 6: For a fieldbus that is not powered via the signal conductors, a single failure in any one communication element (including a short circuit but excluding jabber) shall not interfere with transactions between other communication elements for more than 1 ms.

Rule 7: In polarity sensitive systems, the medium wire pairs shall have distinctly marked conductors that uniquely identify individual conductors. Consistent polarization shall be maintained at all connection points.

Rule 8: The degradation of the electrical characteristics of the signal, between any two devices, due to attenuation, attenuation distortion and mismatching distortion shall be limited to the values indicated below.

a) Signal attenuation: The configuration of the bus (trunk length, number of devices, and possible matching devices) shall be such that the attenuation between any two devices at frequency f_r shall not exceed A_{max};

b) Attenuation distortion: The configuration of the bus (trunk and spur lengths and number of devices) shall be such that between any two devices:

$$0 \leq [\text{Attenuation } (f_{max}) - \text{Attenuation } (f_{min})] \leq AD_{max}$$

Attenuation shall be monotonic non-decreasing for all frequencies from f_{min} to f_{max};

c) Mismatching Distortion: Mismatching (due to any effect) on the bus shall be such that, at any point along the trunk, in the frequency band f_{min} to f_{max}:

$$|Z - Z_{fr}| / |Z + Z_{fr}| \leq MD_{max}$$

where Z_{fr} is the characteristic impedance of the trunk cable at frequency f_r and Z is the parallel combination of Z_{fr} and the load impedance at the coupler.

NOTE 5 This rule minimizes restrictions on trunk and spur length, number of devices etc. by specifying only the transmission limitations imposed by combinations of these factors. Different combinations may be used depending on the needs of the application.

NOTE 6 The usual cause of a large mismatch is the concentration of several couplers on a short length of the trunk.

If the distance between two consecutive couplers is less than CS_{max}, then the propagation delay between them is smaller than T_{rf} and the concentration appears as a single mismatched element inducing large reflections of the signal transitions.

A concentration of couplers where the distance between two consecutive couplers is less than CS_{max} is defined as a cluster. In order to comply with Rule 8c using devices with an input impedance of minimum value Din_{min} and zero-length spurs, it is recommended that a cluster not include more than 4 couplers.

Using devices with input impedance significantly higher than the minimum value Din_{min} allows clusters with more couplers. Using non-zero-length spurs could require clusters to have fewer than 4 couplers.

NOTE 7 It is possible to reduce the mismatching due to a cluster by the following means:
– using active multiport couplers,
– inserting matching devices (passive attenuators) on each side of the cluster while satisfying Rule 8.

Rule 9: The following rules shall apply to systems implemented with redundant media:

a) each channel (cable) shall comply with the network configuration rules;

b) there shall not be a non-redundant segment between two redundant segments;

c) repeaters shall also be redundant;

d) if the devices of the system are configured (by Systems management) to transmit on more than one channel simultaneously then the propagation time difference between any two devices on any two channels shall not exceed five bit times;

NOTE 8 This period may be extended, but not reduced, by Systems management as given in Table 4 (see 6.2.2.2 and 9.2.9).

e) channel numbers and association with the physical transmission media shall be maintained consistently throughout the fieldbus, i.e. channels 1, 2, 3... from Systems management shall always connect to physical channels 1, 2, 3...;

11.3.4 Power distribution rules for network configuration

The cable shield shall not be used as a power conductor.

11.4 MAU transmit circuit specification

11.4.1 Summary

Table 52 through Table 54 summarise the requirements of the MAU.

Table 52 — MAU transmit level specification summary

Transmit level characteristics, values referred to trunk (but measured using test load as shown in Figure 54)	**Limits**
Output level (peak-to-peak, see Figure 55) With test load (0,5 nominal Z_o of the trunk cable at f_r)	5,5 V to 9,0 V 75 Ω ± 1 %
Maximum positive and negative amplitude difference (signaling bias) as shown in Figure 56	± 0,45 V
Output level with one terminator removed (peak-to-peak) with test load (nominal impedance of the trunk cable at f_r)	5,5 V to 11,0 V 150 Ω ± 1 %
Maximum output level; open circuit (peak-to-peak)	5,5 V to 30,0 V
Maximum output signal distortion; i.e., overvoltage, ringing and droop (see Figure 55)	±10 %
Quiescent transmitter output; i.e. transmitter noise (measured over the frequency band 1 kHz to f_{QTOmax})	≤ QTO_{max} (r.m.s.)

Table 53 — MAU transmit timing specification summary for 31,25 kbit/s operation

Transmit timing characteristics, values referred to trunk (but measured using test load as shown in Figure 54)	**Limits**
Transmitted bit rate	BR ± ΔBR
Instantaneous bit time	$T_{bit} \pm \Delta T_{bit}$
Rise and fall times (10 % to 90 % of peak-to-peak signal, see Figure 55)	≤ 25 % T_{bit}
Slew rate (at any point from 10 % to 90 % of peak-to-peak signal)	≤ 0,2 V/µs
Maximum transmitted bit cell jitter (zero-crossing point deviation, see Figure 56)	± 2,5 % T_{bit}
Transmit enable/disable time (i.e. time during which the output waveform may not meet the transmit requirements)	≤ 2,0 T_{bit}

Table 54 — MAU transmit timing specification summary for ≥ 1 Mbit/s operation

Transmit timing characteristics, values referred to trunk (but measured using test load as shown in Figure 54)	**Limits**
Transmitted bit rate	BR ± ΔBR
Instantaneous bit time	$T_{bit} \pm \Delta T_{bit}$
Rise and fall times (10 % to 90 % of peak-to-peak signal, see Figure 55)	≤ 20 % T_{bit}
Slew rate (at any point from 10 % to 90 % of peak-to-peak signal)	≤ 100 V/µs × ($f_{r/MHz}$)
Maximum transmitted bit cell jitter (zero-crossing point deviation, see Figure 56)	± 2,5 % T_{bit}
Transmit enable/disable time (i.e. time during which the output waveform may not meet the transmit requirements)	≤ 2,0 T_{bit}

11.4.2 MAU test configuration

Figure 54 shows the configuration that shall be used for testing MAUs, as follows.

- Differential signal voltage: $V_d = V_a – V_b$
- Test load resistance R = 75 Ω (0,5 nominal impedance of the trunk cable at f_r) and C = 0,15 µF except where otherwise stated in a specific requirement.

- Data "+" terminal connected to the power "+" terminal and data "–" terminal connected to the power "–" terminal.

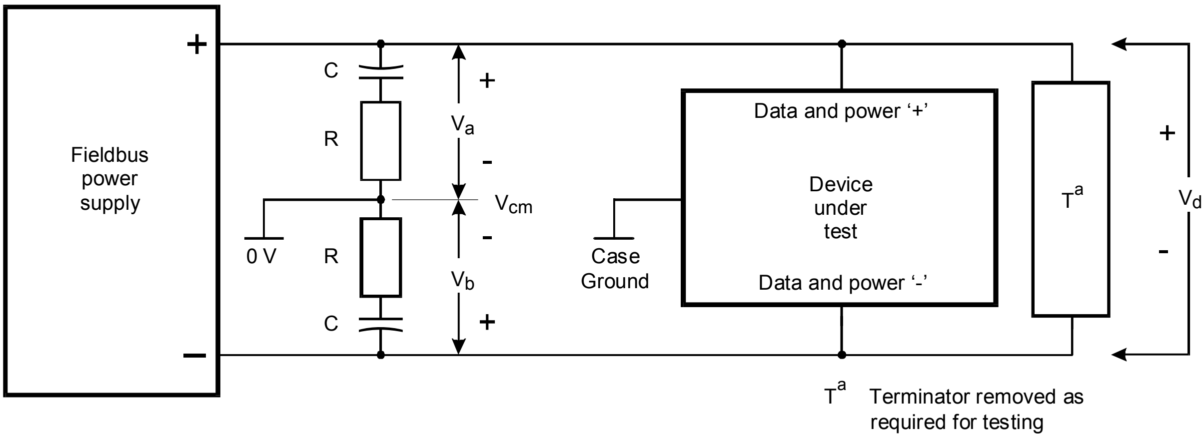


Figure 54 — Transmit circuit test configuration

11.4.3 MAU output level requirements

Figure 55 describes the output form of the signal for the twisted-pair voltage output level requirements.

NOTE Figure 55 shows an example of the a.c. component of one cycle of a fieldbus waveform, illustrating some key items from the transmit circuit specification. Only signal voltages are shown; this diagram takes no account of power supply voltages.

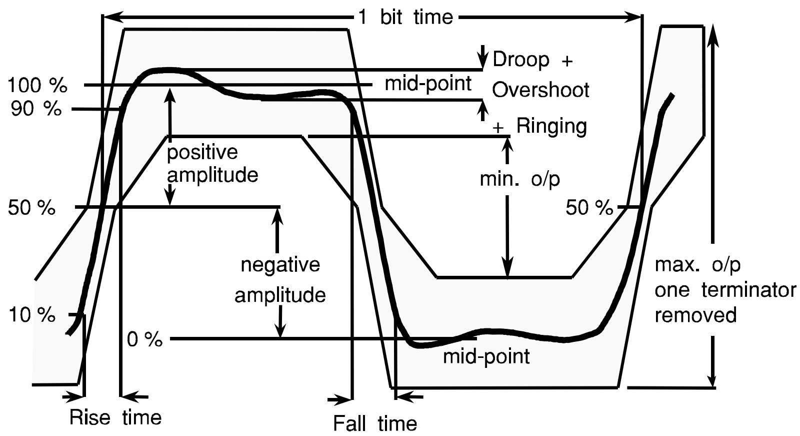


Figure 55 — Output waveform

The MAU transmit circuit shall conform to the following output level requirements, all amplitudes being measured at the estimated mid-point between any peaks or troughs in the top and bottom of the waveform ("mid-point" in Figure 55):

a) the output voltage across the test load after transformer step up/down (if applicable) shall be between 5,5 V and 9,0 V peak-to-peak with a load resistance of 75 Ω ± 1 % ("min. o/p" in Figure 55);

b) the output voltage at the trunk, or at the transmit terminals, with a load resistance of 150 Ω ± 1 % (i.e. with one trunk terminator removed) shall be between 5,5 V and 11,0 V peak-to-peak ("max. o/p one terminator removed" in Figure 55);

c) the output voltage at the trunk, or at the transmit terminals, with any load including an open circuit shall be between 5,5 V and 30,0 V peak-to-peak. For test purposes open circuit shall be defined as a load of 100 kΩ resistance in parallel with 15 pF capacitance;

d) during transmission a device shall not suffer permanent failure when a load resistance of ≤1 Ω is applied for 1 s;

e) the difference between positive amplitude and negative amplitude, measured as shown in Figure 55, shall not exceed ±0,45 V peak;

f) the output noise from an MAU which is receiving or not powered shall not exceed QTO_{max} r.m.s., measured differentially over the frequency band 1 kHz to f_{QTOmax}, referred to the trunk;

g) the differential voltage across the test load shall be such that the voltage monotonically changes between 10 % and 90 % of peak-to-peak value. Thereafter, the signal voltage shall not vary more than ±10 % of peak-to-peak value until the next transition occurs. This permitted variation shall include all forms of output signal distortion, i.e. overvoltage, ringing and droop.

11.4.4 MAU output timing requirements

11.4.4.1 Common output timing requirements for all data rates

An MAU transmit circuit shall conform to the following output timing requirements:

a) transmitted bit cell jitter shall not exceed ΔT_{bit} from the ideal zero crossing point, measured with respect to the previous zero crossing (see Figure 56);

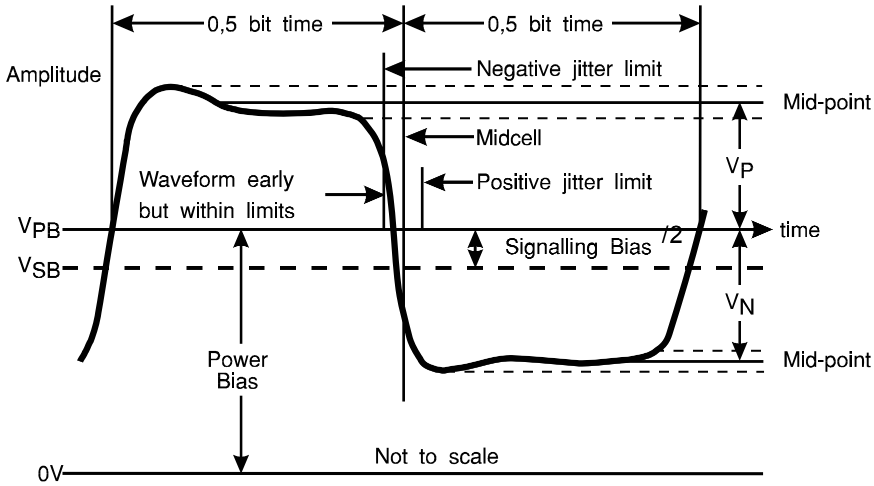


Figure 56 — Transmitted and received bit cell jitter (zero crossing point deviation)

b) the transmit circuit shall turn on, i.e. the signal shall rise from below the transmit circuit maximum output noise level as specified in 11.4.3f) to full output level, in less than 2,0 T_{bit}. The waveform corresponding to the third and later bit times shall be as specified in Figure 55;

c) the transmit circuit shall turn off, i.e. the signal shall fall from full output level to below the transmit circuit maximum output noise level as specified in 11.4.3 f), in less than 2,0 T_{bit}. The time for the transmit circuit to return to its off-state impedance shall not exceed 4,0 T_{bit}. For the purposes of testing, this requirement shall be met with the transmit circuit test configuration of Figure 54 with the equivalent capacitance of a maximum length cable across the DUT terminals.

NOTE This requirement is to ensure that the transition of the transmit circuit from active to passive leaves the line capacitance fully discharged.

11.4.4.2 Additional output timing requirements for 31,25 kbit/s operation

The MAU transmit circuit shall conform to the following additional output timing requirements:

a) rise and fall times, measured from 10 % to 90 % of the peak-to-peak signal amplitude shall not exceed 0,25 T_{bit} (see Figure 55);

b) slew rate shall not exceed 0,2 V/µs measured at any point in the range 10 % to 90 % of the peak-to-peak signal amplitude (see Figure 55).

NOTE Requirements a) and b) produce a trapezoidal waveform at the transmit circuit output. Requirement b) limits the level of interference emissions that may be coupled to adjacent circuits etc. Requirement b) is calculated from the formula:

$$\text{max. slew rate} = 2 \times \text{min. slew rate} = 2 \times 0{,}8\ V_o / 0{,}25\ T_{bit} = 6{,}4 \times V_o / T_{bit},$$

where V_o is the maximum peak-to-peak output voltage (9,0 V) with a standard load.

11.4.4.3 Additional output timing requirements for ≥ 1 Mbit/s operation

The MAU transmit circuit shall conform to the following additional output timing requirements:

a) rise and fall times, measured from 10 % to 90 % of the peak-to-peak signal amplitude shall not exceed 0,2 T_{bit} (see Figure 55);

b) slew rate shall not exceed 100 V/µs × ($f_{r/MHz}$) measured at any point in the range 10 % to 90 % of the peak-to-peak signal amplitude (see Figure 55).

NOTE Requirements a) and b) produce a trapezoidal waveform at the transmit circuit output. Requirement b) limits the level of interference emissions that may be coupled to adjacent circuits etc. Requirement b) is calculated from the formula:

$$\text{max. slew rate} = 36 \times \text{min. slew rate} = 3 \times 0{,}8\ V_o / 0{,}2\ T_{bit} = 12 \times V_o / T_{bit},$$

where V_o is the maximum peak-to-peak output voltage (9,0 V) with a standard load.

11.4.5 Signal polarity

For a bus-powered device, the data "+" terminal shall be connected to the power "+" terminal, and the data "–" terminal shall be connected to the power "–" terminal. See Figure 54.

When transmission is enabled, a high to low transition of the Manchester encoded signal shall result in a high to low transition in V_d on the bus. A low to high transition of the Manchester encoded signal shall result in a low to high transition in V_d on the bus. The signal polarity is defined in Figure 57.

During reception, a high to low transition in V_d on the bus shall result in a high to low transition of the Manchester encoded signal. A low to high transition in V_d on the bus shall result in a low to high transition of the Manchester encoded signal.

NOTE 1 Manchester encoding is defined in 9.2.2.

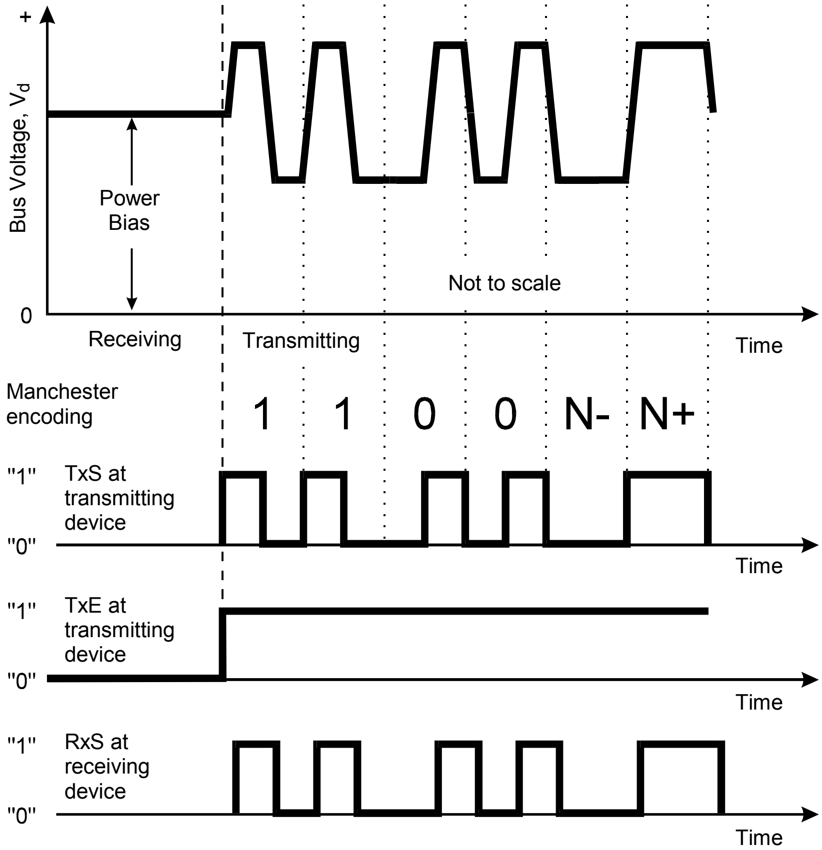


Figure 57 — Signal polarity

NOTE 2 The waveform in Figure 57 is shown to provide an example of the “1”, “0”, “N+”, and “N–” symbols. This waveform does not represent an actual PhPDU. See 9.2.2 for the encoding rules.

NOTE 3 The TxS and RxS waveforms in Figure 57 are indeterminate in the time period marked “Receiving”.

NOTE 4 The signals at the MDS-MAU interface are defined in Clause 10. The TxS, TxE, and RxS signals shown in Figure 57 are only accessible if the MDS-MAU interface is exposed.

11.5 MAU receive circuit specification

11.5.1 Summary

Table 55 summarises the specification.

Table 55 — MAU receive circuit specification summary

Receive circuit characteristics (values referred to trunk)	Limits
Input impedance, measured over the frequency range f_{min} to f_{max}	≥8 kΩ
Sensitivity; min. peak-to-peak signal required to be accepted (see Figure 58)	700 mV
Noise rejection; max. peak-to-peak noise required to be rejected (see Figure 58)	280 mV
Maximum received bit cell jitter (zero crossing-point deviation, see Figure 55)	±0,10 T_{bit}

11.5.2 Input impedance

The differential input impedance of an MAU receive circuit shall be no less than Din_{min} over the frequency range f_{min} to f_{max}. This requirement shall be met in the power-off and power-on (not transmitting) states and in transition between these states. This impedance shall be measured at the communication element terminals using a sine wave with a signal amplitude greater than the receiver sensitivity threshold and lower than 9,0 V peak-to-peak.

NOTE The requirement for $\geq Din_{min}$ input impedance during power-up and power-down may be met by automatic disabling of the transmitter during these periods.

11.5.3 Receiver sensitivity and noise rejection

An MAU receive circuit shall be capable of accepting an input signal of amplitude no less than 700 mV peak-to-peak, including overvoltage and oscillation (see "signal level" together with "positive amplitude" and "negative amplitude", all in Figure 58).

An MAU receive circuit shall not respond to an input signal with a peak-to-peak amplitude which does not exceed 280 mV (see "noise rejection" in Figure 58).

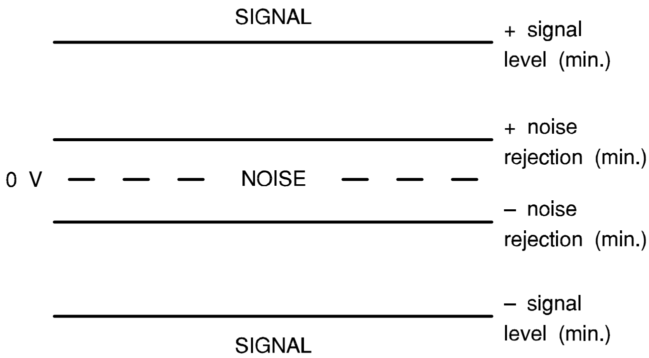


Figure 58 — Receiver sensitivity and noise rejection

11.5.4 Received bit cell jitter

The receive circuit shall accept a Manchester encoded signal transmitted in accordance with 11.2 and 11.4. In addition, the receiver shall work properly with signals with the time variation between any two adjacent signal transition points (zero crossing) of ±0,10 T_{bit} or less. See Figure 56.

NOTE 1 This specification does not preclude the use of receivers that perform better than this specification.

NOTE 2 Depending on the symbol pattern, the nominal time between zero crossings may be 0,5 T_{bit} or 1,0 T_{bit}.

NOTE 3 There is no requirement to reject a signal with a specified time variation value. The receiver reports an error when the received bit cell jitter exceeds the receiver's ability to reliably decode signaling.

11.5.5 Interference susceptibility and error rates

NOTE 1 When a fieldbus is operating in a variety of standard noise environments the probability that an Application Layer User Data Unit contains an undetected error, due to operation of the conveying Physical and DLL entities, should be less than 1 in 10^{12} (1 error in 20 years at 1 600 messages/s). A communication element is regarded as conforming to this theoretical requirement when it meets the following interference susceptibility requirements. These are specified by a detected frame error rate which is derived by using a ratio of detected to undetected errors of 10^6. This should be readily achievable with a 16 bit Frame Check Sequence at the DLL.

A communication element which includes an MAU, operating with frames containing 64 random user data bits, with maximum frame rate and with signals of 1,4 V pk-pk amplitude, shall produce no more than three detected frame errors in 3×10^6 frames during operation in the presence of common-mode voltage or Gaussian noise as follows:

a) a common-mode sinusoidal signal of any frequency from 63 Hz to 2 f_r, with an amplitude of 4 V r.m.s. and from 47 Hz to 63 Hz with an amplitude of 250 V r.m.s.;

b) a common-mode d.c. signal of ±10 V;

c) white Gaussian additive differential noise in the frequency band 1 kHz to 4 f_r, with a noise density of 30 µV/√Hz r.m.s.

NOTE 2 The common-mode voltage and Gaussian noise specifications are for receive circuit conformance testing with balanced loads and are not indicative of system installation practice.

A communication element which includes an MAU, operating with frames containing 64 random user data bits, at an average of 1 600 messages/s, with signals of 1,4 V peak-to-peak amplitude, shall produce no more than six detected frame errors in 100 000 frames during operation in the presence of electromagnetic or electrical interference environments as follows:

1) 10 V/m electromagnetic field as specified in IEC 61000-4-3 at severity level 3;
2) electrical fast transient as specified in IEC 61000-4-4 at severity level 3.

The above error rate specification shall also be satisfied after but not during operation in the following noise environments:

i) 8 kV electrostatic discharge to exposed metalwork as specified in IEC 61000-4-2 at severity level 3. If the device suffers temporary loss of function or performance as a result of this test it shall recover from any such loss without operator intervention within 3 s after the end of the test;
ii) high-frequency disturbance tests as specified in IEC 60255-22-1:1988, Test voltage class III (2,5 kV and 1 kV peak values of first half-cycle in longitudinal and transverse mode respectively). If the device suffers temporary loss of function or performance because of this test, it shall recover from any such loss without operator intervention within 3 s after the end of the test.

11.6 Jabber inhibit

The MAU shall contain a self-interrupt capability to inhibit transmitted signals from reaching the medium. Hardware within the MAU (with no external message other than the detection of output signals or leakage via the transmit function) shall provide a window of between 5 000 T_{bit} and 15 000 T_{bit} during which time a normal frame may be transmitted. If the frame length exceeds this duration, the jabber inhibit function shall inhibit further output signals from reaching the medium and shall disable echo on the RxS line (see 10.2.2.2) to indicate jabber detection to the MDS.

For a data rate of 31,25 kbit/s, the MAU shall reset the self-interrupt function after a period of 3 s ± 50 %.

NOTE 1 This inhibits bus traffic for no more than 8 % (≈ 1/12,5) of the available time.

For a data rate of 1 Mbit/s or greater, the MAU shall reset the self-interrupt function after a period of 500 000 T_{bit} ± 50 %.

NOTE 2 This inhibits bus traffic for no more than 3 % (≈ 1/32) of the available time.

11.7 Power distribution

11.7.1 Overview

Voltage mode MAUs operating at a data rate of ≤ 2,5 Mbit/s can optionally receive power via the signal conductors or be separately powered. Voltage mode MAUs operating at a data rate of > 2,5 Mbit/s are separately powered. A separately powered device can be connected to a powered fieldbus.

For ease of reference, the requirements of 11.7 for network-powered devices and network power supplies are summarized in Table 56 and Table 57, respectively.

Table 56 — Network powered device characteristics

Network powered device characteristics	Limits		
	31,25 kbit/s	1 Mbit/s	> 1 Mbit/s
Maximum rate of change of quiescent current (non-transmitting)	1 mA/μs	0,05 mA/μs	0,1 mA/μs
Operating voltage	9,0 V to 32,0 V d.c.		
Minimum withstand voltage, either polarity, for no damage	35 V		

Table 57 — Network power supply requirements

Network power supply requirements	Limits
Output voltage	≤ 32 V d.c.
Output ripple and noise	See Figure 59
Output impedance, measured over the frequency range f_{min} to f_{max}	≥ Din_{min}

11.7.2 Supply voltage

A fieldbus device claiming conformance to this clause shall be capable of operating within a voltage range of 9 V to 32 V d.c. between the two conductors including ripple. The device shall withstand a minimum voltage of ±35 V d.c. without damage.

A fieldbus device claiming conformance to this clause shall conform to the requirements of this clause of this standard when powered by a supply with the following specifications:

a) The output voltage of the power supply shall be 32 V d.c. maximum including ripple.

NOTE 1 The voltage of the power supply added to the open circuit transmitter output voltage should be less than the limit specified by the local regulatory agency for the particular implementation.

b) The output impedance of the power supply shall be ≥8 kΩ over the frequency range f_{min} to f_{max}.

c) The breakdown requirements of the isolation of the signal circuit and the power distribution circuit from ground and from each other shall be in accordance with IEC 61131-2.

NOTE 2 The equivalent test voltage is to be applied between independent isolated circuits or between isolated circuits and accessible conducting parts. For circuits with a nominal voltage ≤50 V d.c. or r.m.s., the equivalent test voltages at sea level are 444 V r.m.s., 635 V d.c. and 635 V peak impulse test. For circuits with a nominal voltage between 150 V and 300 V r.m.s., the equivalent test voltages at sea level are 2 260 V r.m.s., 3 175 V d.c. and 3 175 V peak impulse test.

d) When a power supply powers two or more segments, the isolation impedance to each segment shall be split ±10 % between the two signal conductors of the segment.

11.7.3 Powered via signal conductors

A fieldbus device claiming conformance to this clause that is powered via the signal conductors shall conform to the requirements of this clause when operating with maximum levels of power supply ripple and noise as follows:

a) 30 mV peak-to-peak over the frequency range f_{min} to f_{max};

b) 2 V peak-to-peak over the frequency range 47 Hz to 63 Hz;

c) 300 mV peak-to-peak at frequencies greater than 12,5 f_r, up to a maximum of 50 MHz;

d) levels at intermediate frequencies generally in accordance with Figure 59, which gives the level and the frequencies for power via signal conductors.

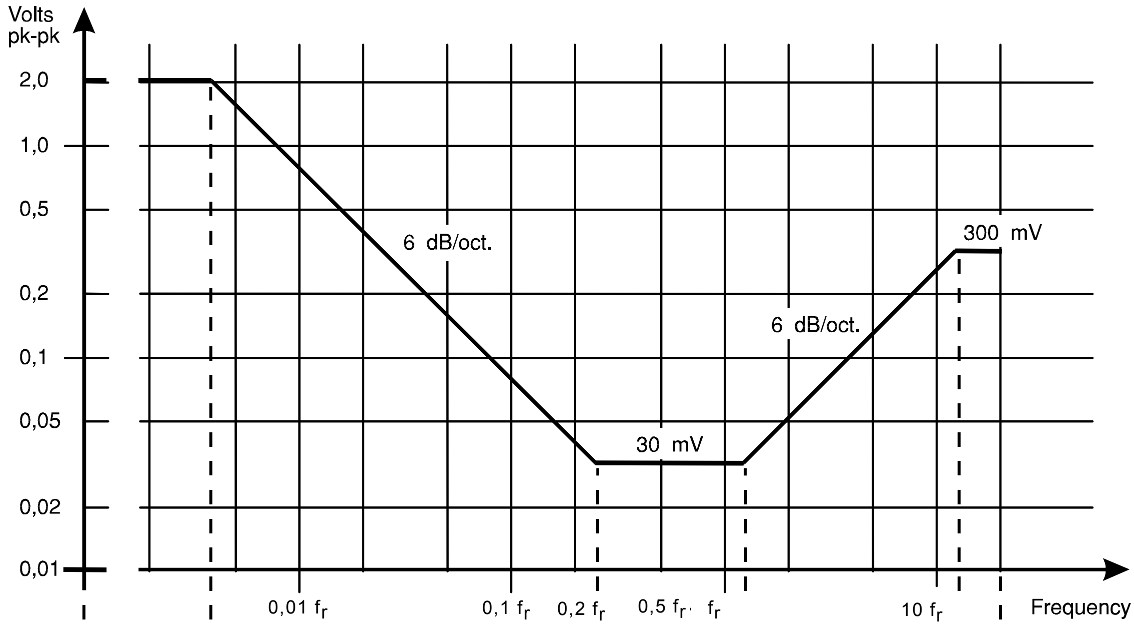


Figure 59 — Power supply ripple and noise

The device shall have a maximum rate of change of quiescent current in the non-transmitting condition of 0,1 mA/μs.

NOTE This requirement limits the effect of power transients on the signals.

11.7.4 Powered separately from signal conductors

NOTE Power distribution to non-bus-powered fieldbus devices is by separate conductors feeding local power supplies or regulators. These conductors can be in a separate cable or in the same cable as the signal conductors.

A separately powered fieldbus device claiming conformance to this clause shall draw no more than 100 μA direct current from the signal conductors, nor shall it supply more than 100 μA direct current to the signal conductors when not transmitting.

11.7.5 Electrical isolation

All fieldbus devices, whether separately powered or powered via the signal conductors, shall provide low-frequency isolation between ground and the fieldbus trunk cable.

NOTE 1 This may be by isolation of the entire device from ground or by use of a transformer, opto-coupler or some other isolating component between trunk cable and device.

A combined power supply and communication element shall not require electrical isolation.

For electrical installations providing different grounds, the isolation impedance measured between the shield of the fieldbus cable and the fieldbus device ground shall be greater than 250 kΩ at all frequencies below 63 Hz.

The isolation shall be bypassed at high frequencies by capacitance, such that the impedance measured between the shield of the fieldbus cable and the fieldbus device ground shall be less than 15 Ω between 3 MHz and 100 MHz.

NOTE 2 The capacitance between ground and trunk cable shield necessary to meet both these requirements can be any value between 3,5 nF and 10,6 nF.

For electrical installations providing a common ground in conformance with IEC 60364-4-41 and IEC 60364-5-54, the shield of the fieldbus cable and the fieldbus device ground may be directly connected.

The maximum unbalanced capacitance to ground from either input terminal of a device shall not exceed 250 pF.

The breakdown requirements of the isolation of the signal circuit and the power distribution circuit from ground and from each other shall be in accordance with IEC 61131-2.

NOTE 3 The equivalent test voltage is applied between independent isolated circuits or between isolated circuits and accessible conducting parts. For circuits which is powered from a supply with rated voltage ≤50 V d.c. or r.m.s., the equivalent test voltages at sea-level are 444 V r.m.s., 635 V d.c. and 635 V peak impulse test. For a device which is powered from a supply with rated voltage between 150 V and 300 V r.m.s., the equivalent test voltages at sea-level are 2 260 V r.m.s., 3 175 V d.c. and 3 175 V peak impulse test.

11.8 Medium specifications

11.8.1 Connector

Cable connectors, if used, shall be in accordance with this standard (see Annex A). Field termination techniques such as screw or blade terminals and permanent terminations (splices) may also be used.

11.8.2 Standard test cable

The cable used for testing fieldbus devices with a 150 Ω voltage-mode MAU for conformance to the requirements of this clause of this standard, shall be a single twisted-pair cable with overall shield meeting the following minimum requirements at 25 °C:

a) Z_O = 150 Ω ± 10 % over the range 0,25 f_r to 1,25 f_r;

b) maximum attenuation at ,25 f_r to 1,25 f_r, as specified in Table 58;

c) maximum capacitive unbalance to shield = 1,5 nF/km

d) maximum d.c. resistance (per conductor) = 57,1 Ω/km;

e) conductor cross-sectional area (wire size) = nominal 0,33 mm^2;

f) minimum resistivity between either conductor and shield = 16 GΩ km;

g) minimum shield coverage shall be 95 %.

Table 58 — Test cable attenuation limits

Bit rate	Maximum attenuation at	
	0,25 f_r	1,25 f_r
31,25 kbit/s	1,5 dB	3 dB
1 Mbit/s	6,5 dB	13 dB
2,5 Mbit/s	10 B	20 dB
5 Mbit/s	13 dB	26 dB
10 Mbit/s	17 dB	37 dB
25 Mbit/s	26 dB	60 dB

NOTE The preceding specification is for conformance testing an MAU. Other types of cable may be used in real installations (see Annex B.) Cables with improved specifications may enable increased trunk length or superior interference immunity or may be required to meet environmental or installation conditions. Conversely, cables with inferior specifications may be used subject to length limitations for both trunk and spurs, plus possible non-conformance to the RFI/EMI susceptibility requirements.

11.8.3 Coupler

The coupler, as shown in Figure 60, shall provide one or several point(s) of connection to the trunk. It is generally integrated with a fieldbus device.

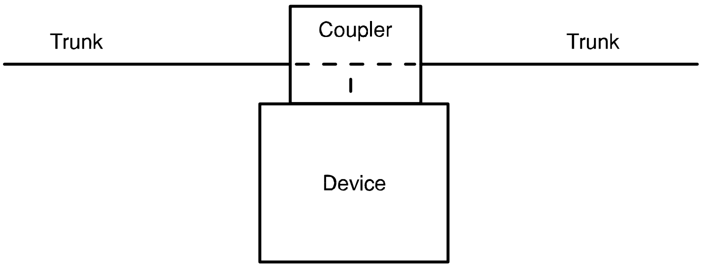


Figure 60 — Fieldbus coupler

A passive coupler may contain any or all of the optional elements as described below:

a) a transformer, to provide galvanic isolation and impedance transformation between trunk and device;
b) connectors, to provide easy connection to trunk.

Active couplers, which require external power supplies, contain components for signal amplification and re-transmission. The transmit level and timing requirements shall conform to 11.4.

11.8.4 Splices

NOTE A splice is any part of the network in which the characteristic impedance of the network cable is not preserved. This is possibly due to separation of the cable conductors, removal of the cable shield, change of wire gauge or type, attachment to terminal strips, etc. A practical definition of a splice is therefore any part of the network that is not a continuous length of the specified medium.

The continuity of all conductors of the cable shall be maintained in a splice.

11.8.5 Terminator

A terminator shall be located at both ends of the trunk cable, connected from one signal conductor to the other. No connection shall be made between terminator and cable shield.

For test purposes, using the cable specified in 11.8.2, the terminator shall have an impedance value of 150 Ω ± 2 % over the overall frequency range 625 kHz to 31,25 MHz.

NOTE In practical implementations this value would be selected to be approximately equal to the average cable characteristic impedance value at the relevant frequencies to minimize transmission line reflections.

The direct current leakage through the terminator shall not exceed 100 μA. The terminator shall be non-polarized.

11.8.6 Shielding rules

For full conformance to the noise immunity requirements of 11.5.3 it is necessary to ensure the integrity of shielding throughout the cabling, connectors and couplers by the following means:

a) the coverage of the cable shield shall be greater than 95 % of the full cable length;
b) shielding shall completely cover the electrical circuits in connectors, couplers, and splices.

NOTE Deviation from these shielding rules may degrade noise immunity

11.8.7 Grounding (earthing) rules

NOTE 1 Grounding (earthing) means permanently connected to earth through sufficiently low impedance and with sufficient current-carrying capability to prevent voltage build-up which might result in undue hazard to connected equipment or persons. Zero volts (common) lines may be connected to ground where they are galvanically isolated from the fieldbus trunk.

Fieldbus devices shall be required to function to the requirements of this clause with the mid-point of one terminator or one inductive coupler connected directly to ground.

Fieldbus devices shall not connect either conductor of the twisted pair to ground at any point in the network. Signals shall be applied and preserved differentially throughout the network.

NOTE 2 It is standard practice for the shield of the fieldbus trunk cable (if applicable) to be effectively grounded at one point along the length of the cable. For this reason fieldbus devices should allow d.c. isolation of the cable shield from ground. It is also standard practice to connect the signal conductors to ground in a balanced manner at the same point, e.g. by using the center tap of a terminator or coupling transformer. For bus-powered systems the grounding of the shield and balanced signal conductors should be close to the power supply unit. Capacitive coupling between the shield or the balanced signal conductors and device local ground for EMI control is permitted.

11.8.8 Color coding of cables

NOTE Regional practice should be considered in the choice of cable colors.

Within North America, colors of inner cable conductors and outer cable sheath (jacket) should be assigned as specified in Table 59.

Table 59 — Recommended color coding of cables in North America

Color for inner conductors	
'+' (positive voltage) inner conductor	Orange, or red/orange/brown end of the spectrum
'–' (negative voltage) inner conductor	Blue, or blue/violet end of the spectrum
Shield conductor (which may be earthed)	Bare, clear, or green
Color for outer sheath (jacket)	
General purpose construction rules	Orange
Non-incendive construction rules	Orange/blue stripe
IS construction rules	Blue or blue/orange stripe or blue/black stripe

12 Types 1 and 3: Medium attachment unit: 31,25 kbit/s, voltage-mode with low-power option, bus- and tree-topology, 100 Ω wire medium

NOTE Type 3 uses this MAU only for synchronous transmission.

12.1 General

The 31,25 kbit/s 100 Ω voltage-mode MAU simultaneously provides access to a communication network and to an optional power distribution network. Devices attached to the network communicate via the medium and may or may not be powered from it. If bus powered, power is distributed as direct voltage and current, and communication signals are superimposed on the d.c. power. In Intrinsically Safe applications, available power may limit the number of devices.

The network medium consists of a one pair cable, usually, but not always, a twisted pair. Independent of topology, all attached devices, other than possibly the transmitting device, present a high impedance to prevent significant network loading. Trapezoidal waveforms are used to reduce electromagnetic emissions.

Bus and tree topologies are supported. In either topology, a network contains one trunk cable, terminated at its ends. In the bus topology, spurs are distributed along the length of the trunk. In the tree topology, spurs are concentrated at one end of the trunk. A spur may connect more than one device to the network, with the maximum number of devices on a spur depending on spur length.

At the power frequency (d.c.), devices appear to the network as current sinks, with a limited rate of change of the supply current drawn from the medium. This prevents transient changes in load current from interfering with communication signals.

This clause specifies a low-power option that allows devices to reduce their current draw from the network when not transmitting.

To minimize oscillations and ringing on the network, the power supply impedance is specified as a function of the bus terminator impedance such that the total network reactance is minimized over the frequency range 50 Hz to 39 kHz.

12.2 Transmitted bit rate

The average bit rate, BR, shall be 31,25 kbit/s ± 0,2 %, averaged over a frame having a minimum length of 16 octets. The instantaneous bit time, T_{bit}, shall be 32 μs ± 0,9 μs.

12.3 Network specifications

12.3.1 Components

An MAU operates in a network composed of the following components:

a) wire cable;
b) devices (containing at least one communication element);
c) couplers;
d) terminators.

The network may optionally include the following components:

e) connectors;
f) power supplies;
g) devices which include power supplies;

h) intrinsic safety barriers.

12.3.2 Topologies

A wire MAU shall operate in a network with an acyclic nominally linear or tree-like bus topology, consisting of a trunk, terminated at each end as specified in 12.8.5, to which communication elements are connected via couplers and spurs. A tree topology with all the communication elements located at the ends of the trunk is regarded as a special case of a bus for the purpose of this clause. Each communication element shall be connected in parallel with the trunk cable.

The coupler and communication element may be integrated in one device (i.e. a zero length spur). Several communication elements may be connected to the trunk at one point using a multi-port coupler. An active coupler may be used to extend a spur to a length that requires termination to avoid reflections and distortions. Active repeaters may be used to extend the length of the trunk beyond that of a single segment as permitted by the network configuration rules. Branches must be considered as segments, and may make the bus non-linear. Cycles (closed loops) are never permitted.

12.3.3 Network configuration rules

An MAU that claims conformance to this clause shall meet the requirements of this clause when used in a network that complies with these rules.

Rule 1: A fieldbus shall be capable of communication between the following numbers of devices, all operating at the same bit rate:

a) for a non IS fieldbus without power supplied via the signal conductors: between two and 32 devices;
b) for a non IS fieldbus with power supplied via the signal conductors: between two and the number of devices which can be powered via the signal conductors, assuming that a minimum of 120 mA (aggregate) shall be available to devices at the remote end from the power supply, communicating with one device at the power supply end drawing 10 mA;
c) for an IS fieldbus: between two and the number of devices which can be powered via the signal conductors, assuming that a minimum of 40 mA (aggregate) shall be available to devices in the hazardous area.

NOTE 1 This rule does not preclude the use of more than the specified number of devices in an installed system. Since the device power consumption is not specified, the number of bus-powered devices cannot be specified.
Item b) assumes that the minimum power supply voltage is 20 V d.c.
Item c) assumes that the IS barrier operates with a 19 V d.c. output.

Rule 2: A fully loaded (maximum number of connected devices) fieldbus segment shall have a total cable length, including spurs, between any two devices, of up to 1 900 m.

NOTE 2 Support of this maximum cable length is a requirement for conformance to this clause, but this does not preclude the use of longer lengths in an installed system.

Rule 3: The total number of waveform regenerations by repeaters and active couplers between any two devices is repeater implementation dependent.

NOTE 3 Prior editions of this standard limited this total number to four.

Rule 4: The maximum propagation delay between any two devices shall not exceed 20 T_{bit}.

NOTE 4 For efficiency of the network, that part of the turnaround time of any device on the network caused by a PhE between the end of a received frame and the beginning of the transmitted frame containing an associated immediate response should not exceed five bit times, of which no more than two bit times should be due to the MAU. As it is not mandatory to expose the DLL – PhL interface or the MDS – MAU interface, that part of the turn-around time of a fieldbus device caused by the PhL or the MAU cannot be specified or conformance tested.

Rule 5: The fieldbus shall be capable of continued operation while a device is being connected or disconnected. Data errors induced during connection or disconnection shall be detected.

Rule 6: Failure of any communication element or spur (with the exception of a short circuit, low impedance, or jabber) shall not interfere with transactions between other communication elements for more than 1 ms.

Rule 7: In polarity sensitive systems, the medium wire pairs shall have distinctly marked conductors that uniquely identify individual conductors. Consistent polarization shall be maintained at all connection points.

Rule 8: The degradation of the electrical characteristics of the signal, between any two devices, due to attenuation, attenuation distortion and mismatching distortion shall be limited to the values indicated below.

a) Signal attenuation: The configuration of the bus (trunk and spur lengths, number of devices, IS barriers, galvanic isolators, and possible matching devices) shall be such that the attenuation between any two devices at f_r (31,25 kHz) shall not exceed 10,5 dB.

b) Attenuation distortion: The configuration of the bus (trunk and spur lengths and number of devices, IS barriers, and galvanic isolators) shall be such that between any two devices:

   $0 \leq$ [Attenuation (1,25 f_r) – Attenuation (0,25 f_r)] $\leq$ 6 dB

   Attenuation shall be monotonic non-decreasing for all frequencies from 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz).

c) Mismatching distortion: Mismatching (due to any effect, including one open circuit spur of maximum length) on the bus shall be such that, at any point along the trunk, in the frequency band 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz):

   $|Z – Zfr| / |Z + Zfr| \leq 0,2$

   where Z_{fr} is the impedance of the trunk cable at frequency f_r (31,25 kHz) and Z is the parallel combination of Z_{fr} and the load impedance at the coupler.

The concentration of couplers shall be less than 15 per 250 m.

NOTE 5 This rule minimizes restrictions on trunk and spur length, number of devices etc. by specifying only the transmission limitations imposed by combinations of these factors. Different combinations may be used depending on the needs of the application.

Rule 9: The following rules shall apply to systems implemented with redundant media:

a) each channel (cable) shall comply with the network configuration rules;
b) there shall not be a non-redundant segment between two redundant segments;
c) repeaters shall also be redundant;
d) if the devices of the system are configured (by Systems management) to transmit on more than one channel simultaneously then the propagation time difference between any two devices on any two channels shall not exceed five bit times;

NOTE 6 This period may be extended, but not reduced, by Systems management as given in Table 4 (see 6.2.2.2 and 9.2.9).

e) channel numbers and association with the physical transmission media shall be maintained consistently throughout the fieldbus, i.e. channels 1, 2, 3... from Systems management shall always connect to physical channels 1, 2, 3...;

Rule 10: For a bus-powered fieldbus segment, the voltage available to all devices, including ripple and the d.c. component of the voltage drop caused by signaling, shall be within the range of 9,0 V to 32,0 V d.c.

NOTE 7 The d.c. component of the voltage drop caused by signaling is dependent upon the configuration of the network. The d.c. component is caused by the step change in device current through the network resistance (cable resistance, IS barrier resistance, etc.).

12.3.4 Power distribution rules for network configuration

See 11.3.4.

12.4 MAU transmit circuit specification

12.4.1 Summary

For ease of reference, the requirements of 12.2 and 12.4 are summarized in Table 60 and Table 61.

Table 60 — MAU transmit level specification summary

Transmit level characteristics, values referred to trunk (but measured using test load as shown in Figure 54)	Limits
Output level (peak-to-peak, see Figure 55) With test load (0,5 nominal impedance of the trunk cable at f_r (31,25 kHz))	0,75 V to 1 V 50 Ω ± 1 %
Maximum positive and negative amplitude difference (signaling bias) as shown in Figure 56	±50 mV
Output level; with one terminator removed (peak-to-peak) with test load (nominal impedance of the trunk cable at f_r (31,25 kHz))	0,75 V to 2,0 V 100 Ω ± 1 %
Maximum output level; open circuit (peak-to-peak)	35 V
Maximum output signal distortion; i.e. overvoltage, ringing and droop (see Figure 55)	±10 %
Quiescent transmitter output; i.e. transmitter noise (measured over the frequency band 1 kHz to 100 kHz)	≤1 mV (r.m.s.)

Table 61 — MAU transmit timing specification summary

Transmit timing characteristics, values referred to trunk (but measured using test load as shown in Figure 54)	Limits for 31,25 kbit/s (bus powered and/or IS)
Transmitted bit rate	31,25 kbit/s ± 0,2 %
Instantaneous bit time	32 µs ± 0,9 µs
Rise and fall times (10 % to 90 % of peak-to-peak signal, see Figure 55)	≤ 25 % T_{bit}
Slew rate (at any point from 10 % to 90 % of peak-to-peak signal)	≤0,2 V/µs
Maximum transmitted bit cell jitter (zero-crossing point deviation, see Figure 56)	± 2,5 % T_{bit}
Transmit enable/disable time (i.e. time during which the output waveform may not meet the transmit requirements)	≤ 2,0 T_{bit}

12.4.2 MAU test configuration

Figure 54 shows the configuration that shall be used for testing MAUs.

Differential signal voltage: $V_d = V_a - V_b$.

Except where otherwise stated in a specific requirement, test load resistance R = 50 Ω (0,5 nominal impedance of the trunk cable at f_r (31,25 kHz)) and C = 2 µF (2 × the capacitance of one terminator).

Data "+" terminal connected to the power "+" terminal and data "–" terminal connected to the power "–" terminal.

NOTE See 12.7 for the power supply specification and 12.8.5 for the terminator specification.

12.4.3 MAU output level requirements

Figure 55 describes the output form of the signal for the twisted-pair voltage output level requirements.

NOTE 1 Figure 55 shows an example of the a.c. component of one cycle of a fieldbus waveform, illustrating some key items from the transmit circuit specification. Only signal voltages are shown; this diagram takes no account of power supply voltages.

The MAU transmit circuit shall conform to the following output level requirements, all amplitudes being measured at the estimated mid-point between any peaks or troughs in the top and bottom of the waveform ("mid-point" in Figure 55):

a) the output voltage across the test load after transformer step up/down (if applicable) shall be between 0,75 V and 1,0 V peak-to-peak, with a load resistance of 50 Ω ± 1 % ("min o/p" in Figure 55);
b) the output voltage at the trunk, or at the transmit terminals, with a load resistance of 100 Ω ± 1 % (i.e. with one trunk terminator removed) shall be between 0,75 V and 2,0 V peak-to-peak ("max. o/p one terminator removed" in Figure 55);
c) the output voltage at the trunk, or at the transmit terminals, with any load including an open circuit shall not exceed 35 V in either polarity. For test purposes, open circuit shall be defined as a load of 100 kΩ resistance in parallel with 15 pF capacitance;
d) during transmission a device shall not suffer permanent failure when a load resistance of ≤1 Ω is applied for 1 s;
e) the difference between positive amplitude and negative amplitude, measured as shown in Figure 55, shall not exceed ±50 mV peak;
f) the output noise from an MAU which is receiving or not powered shall not exceed 1 mV r.m.s., measured differentially over a frequency band of 1 kHz to 100 kHz, referred to the trunk;
g) the differential voltage across the test load shall be such that the voltage monotonically changes between 10 % and 90 % of peak-to-peak value. Thereafter, the signal voltage shall not vary more than ±10 % of peak-to-peak value until the next transition occurs. This permitted variation shall include all forms of output signal distortion, i.e. overvoltage, ringing and droop.

NOTE 2 During transmission, the output voltage developed at the device terminals may increase substantially over that specified in this subclause, but within the limit specified by 12.4.3 c), due to the affects of the combined series impedance of the device, the spur cable, and any bus protective device such as that described in 12.8.3 c).

12.4.4 Output timing requirements

An MAU transmit circuit shall conform to the following output timing requirements:

a) transmitted bit cell jitter shall not exceed ±0,025 T_{bit} from the ideal zero crossing point, measured with respect to the previous zero crossing (see Figure 56);
b) the transmit circuit shall turn on, i.e. the signal shall rise from below the transmit circuit maximum output noise level as specified in 12.4.3 f) to full output level, in less than 2,0 T_{bit}. The waveform corresponding to the third and later bit times shall be as specified in Figure 55;
c) the transmit circuit shall turn off, i.e. the signal shall fall from full output level to below the transmit circuit maximum output noise level as specified in 12.4.3 f), in less than 2,0 T_{bit}. The time for the transmit circuit to return to its off state impedance shall not exceed 4 T_{bit}. For the purposes of testing, this requirement shall be met with the transmit circuit test configuration of 12.4.2 with the equivalent capacitance of a maximum length cable across the DUT terminals.

NOTE 1 This requirement is to ensure that the transition of the transmit circuit from active to passive leaves the line capacitance fully discharged.

d) rise and fall times, measured from 10 % to 90 % of the peak-to-peak signal amplitude shall not exceed 0,25 T_{bit} (see Figure 55);
e) slew rate shall not exceed 0,2 V/μs measured at any point in the range 10 % to 90 % of the peak-to-peak signal amplitude (see Figure 55).

NOTE 2 Requirements d) and e) produce a trapezoidal waveform at the transmit circuit output. Requirement d) limits the level of interference emissions that may be coupled to adjacent circuits, etc. Requirement d) is calculated from the formula:

$$\text{max. slew rate} = 2 \times \text{min. slew rate} = 2 \times 0{,}8\ V_o / 0{,}25\ T_{bit} = 6{,}4 \times V_o / T_{bit},$$

where V_o is the maximum peak-to-peak output voltage (1,0 V) with a standard load.

12.4.5 Signal polarity

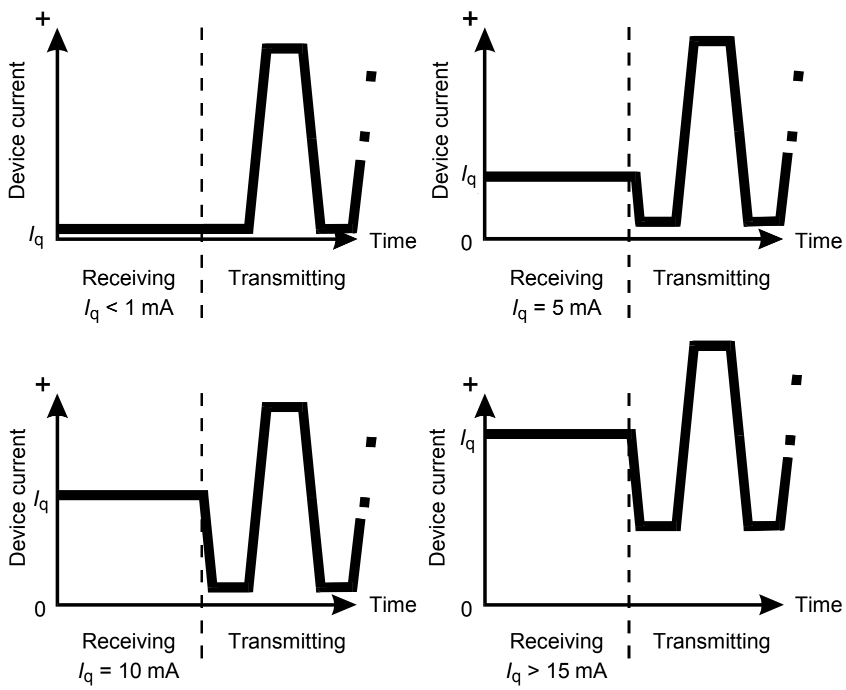
See 11.4.5.

12.4.6 Transition from receive to transmit

When a device starts to transmit, the output waveform shall immediately comply with the requirements of 12.4.3.

NOTE There is no requirement to ramp the device current from its receive value to the transmit value.

Figure 61 shows four examples of different values of device quiescent current.



NOTE This figure is included in this standard for explanatory purposes and does not imply a specific implementation.

Figure 61 — Transition from receiving to transmitting

12.5 MAU receive circuit specification

12.5.1 Summary

Table 62 summarises the specification.

Table 62 — MAU receive circuit specification summary

Receive circuit characteristics (values referred to trunk)	Limits (bus powered and/or IS)
Input impedance, measured over the frequency range 0,25 f_r to 1,25 f_r	≥ 3 kΩ
Sensitivity; min. peak-to-peak signal required to be accepted (see Figure 58)	150 mV
Noise rejection; max. peak-to-peak noise required to be rejected (see Figure 58)	75 mV
Maximum received bit cell jitter (zero crossing-point deviation, see Figure 55)	±0,10 T_{bit}

12.5.2 Input impedance

The differential input impedance of an MAU receive circuit shall be no less than 3 kΩ over the frequency range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz). This requirement shall apply after a 20 ms startup time following connection to the network or application of power to the network. Independently powered devices, and network-powered devices capable of being turned off while connected to the network, shall meet this requirement in the power-on and power-off states, and in transition between those states. This impedance shall be measured at the communication element terminals using a sine wave with a signal amplitude greater than the receiver sensitivity threshold and lower than 2,0 V peak-to-peak.

NOTE 1 The requirement for ≥3 kΩ input impedance during power-up and power-down may be met by automatic disabling of the transmitter during these periods.

NOTE 2 Devices with fault disconnection electronic circuits can have impedances less than the specified amount under fault conditions.

12.5.3 Receiver sensitivity and noise rejection

An MAU receive circuit shall be capable of accepting an input signal of amplitude no less than 150 mV peak-to-peak, including overvoltage and oscillation (see "signal level" together with "positive amplitude" and "negative amplitude", all in Figure 58).

An MAU receive circuit shall not respond to an input signal with a peak-to-peak amplitude which does not exceed 75 mV (see "noise rejection" in Figure 58).

12.5.4 Received bit cell jitter

The receive circuit shall accept a Manchester encoded signal transmitted in accordance with 12.2 and 12.4. In addition, the receiver shall work properly with signals with the time variation between any two adjacent signal transition points (zero crossing) of ±0,10 T_{bit} or less. See Figure 56.

NOTE 1 This does not preclude the use of receivers that perform better than this specification.

NOTE 2 Depending on the symbol pattern, the nominal time between zero crossings may be one-half or one bit time.

NOTE 3 There is no requirement to reject a signal with a specified time variation value. The receiver reports an error when the received bit cell jitter exceeds the receiver's ability to reliably decode signaling.

12.5.5 Interference susceptibility and error rates

NOTE 1 When a fieldbus is operating in a variety of standard noise environments, the probability that an Application Layer User Data Unit contains an undetected error, due to operation of the conveying Physical and DLL entities, should be less than 1 in 6×10^9 (1 error in 20 years at 10 messages/s). A communication element is regarded as conforming to this theoretical requirement when it meets the following interference susceptibility requirements. These are specified by a detected frame error rate which is derived by using a ratio of detected to undetected errors of 10^6. This should be readily achievable with a 16 bit Frame Check Sequence at the DLL.

A communication element which includes an MAU, operating with frames containing 32 random user data bits, with maximum frame rate and with signals of 375 mV peak-to-peak amplitude, shall produce no more than 10 detected frame errors in 60 000 frames during operation in the presence of common mode voltage or Gaussian noise as follows:

a) a common mode sinusoidal signal of any frequency from 63 Hz to 2 MHz, with an amplitude of 4 V r.m.s. and from 47 Hz to 63 Hz with an amplitude of 250 V r.m.s.;

b) a common mode d.c. signal of ±10 V;

c) white Gaussian additive differential noise in the frequency band 1 kHz to 100 kHz, with a noise density of 70 μV/√Hz r.m.s.

NOTE 2 The common mode voltage and Gaussian noise specifications are for receive circuit conformance testing with balanced loads and are not indicative of system installation practice.

A communication element which includes an MAU, operating with frames containing 32 random user data bits, at an average of 10 messages per second, with signals of 375 mV peak-to-peak amplitude, shall produce no more than 10 detected frame errors in 1 000 frames during operation in the presence of electromagnetic or electrical interference environments as follows:

1) 10 V/m electromagnetic field as specified in IEC 61000-4-3 at severity level 3;

2) electrical fast transient as specified in IEC 61000-4-4 at severity level 3.

The noise above error rate specification shall also be satisfied after but not during operation in the following noise environments:

i) 8 kV electrostatic discharge to exposed metalwork as specified in IEC 61000-4-2 at severity level 3. If the device suffers temporary loss of function or performance as a result of this test it shall recover from any such loss without operator intervention within 3 s after the end of the test;

ii) high frequency disturbance tests as specified in IEC 60255-22-1:1988, appendix E, Test voltage class III (2,5 kV and 1 kV peak values of first half-cycle in longitudinal and transverse mode respectively). If the device suffers temporary loss of function or performance because of this test, it shall recover from any such loss without operator intervention within 3 s after the end of the test.

12.6 Jabber inhibit

The MAU shall contain a self-interrupt capability to inhibit transmitted signals from reaching the medium. Hardware within the MAU (with no external message other than the detection of output signals or leakage via the transmit function) shall provide a window of between 120 ms and 240 ms during which time a normal frame may be transmitted. If the frame length exceeds this duration, the jabber inhibit function shall inhibit further output signals from reaching the medium and shall disable echo on the RxS line (see 10.2.2.2) to indicate jabber detection to the MDS.

The MAU shall reset the self-interrupt function after a period of 3,0 s ± 50 %.

NOTE This inhibits bus traffic for no more than 16 % (≈ 240 ms / 1,5 s) of the available time.

12.7 Power distribution

12.7.1 General

A device can receive power via the signal conductors or can be separately powered.

A device can be certified as Intrinsically Safe with either method of receiving power.

NOTE 1 This standard does not include requirements for IS certification but seeks to exclude conditions or situations that would prevent IS certification.

NOTE 2 A separately powered device can be connected to a powered fieldbus.

For ease of reference, the requirements of 12.7 for network-powered devices and network power supplies are summarized in Table 63 and Table 64.

Table 63 — Network powered device characteristics

Network powered device characteristics	Limits for 31,25 kbit/s
Operating voltage	9,0 V to 32,0 V d.c.
Minimum withstand voltage, either polarity, for no damage	35 V
Maximum rate of change of quiescent current (non-transmitting); this requirement does not apply within the first 20 ms after the connection of the device to an operating network or within the first 20 ms after the application of power to the network.	1,0 mA/ms
Maximum current; this requirement applies during the time interval of 500 µs to 20 ms after the connection of the device to an operating network or 500 µs to 20 ms after the application of power to the network (see note)	Rated quiescent current plus 20 mA
NOTE 1 The first 500 µs is excluded to allow for the charging of RFI filters and other capacitance in the device. The rate of change specification applies after 20 ms. NOTE 2 The maximum current during that first 500 µs should be no more than twice the maximum current specified above, to minimize affects of the current inrush on the rest of the connected fieldbus network. NOTE 3 These exclusions have the potential to cause a "brown out" at devices powered from the same power supply during the exclusion interval. NOTE 4 These exclusions can substantially increase the current requirements of the power supply during the exclusion interval which occurs immediately after power is applied to the PhL segment.	

Table 64 — Network power supply requirements

Network power supply requirements	Limits for 31,25 kbit/s
Output voltage, non-IS	≤ 32 V d.c.
Output voltage, IS	Depends on barrier rating
Output ripple and noise	See Figure 62
Output impedance	See 12.7.4
NOTE Power supply designs should take into account the current surge at device connection or power-up permitted by Table 63.	

12.7.2 Supply voltage

A fieldbus device claiming conformance to this clause shall be capable of operating within a voltage range of 9 V to 32 V d.c. between the two conductors including ripple. The device shall withstand a minimum voltage of ±35 V d.c. without damage.

12.7.3 Powered via signal conductors

A fieldbus device claiming conformance to this clause shall conform to the requirements of this clause when powered by a supply with the following specifications:

a) The output voltage of the power supply for non IS networks shall be 32 V d.c. maximum including ripple.

NOTE 1 For IS systems the operating voltage may be limited by the certification requirements. In this case, the power supply will be located in the safe area and its output voltage will be attenuated by a safety barrier or equivalent component.

b) The breakdown requirements of the isolation of the signal circuit and the power distribution circuit from ground and from each other shall be in accordance with IEC 61131-2.

NOTE 2 See 11.7.5, note 3.

c) When a power supply powers two or more segments, the isolation impedance to each segment shall be split ±10 % between the two signal conductors of the segment.

A fieldbus device claiming conformance to this clause that is powered via the signal conductors shall conform to the requirements of this clause when operating with maximum levels of power supply ripple and noise as follows:

d) 16 mV peak-to-peak over the frequency range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz);

e) 2,0 V peak-to-peak over the frequency range 47 Hz to 63 Hz for non-IS applications;

f) 0,2 V peak-to-peak over the frequency range 47 Hz to 625 Hz for IS applications;

g) 1,6 V peak-to-peak at frequencies greater than 125 f_r, up to a maximum of 25 MHz;

h) levels at intermediate frequencies generally in accordance with Figure 62.

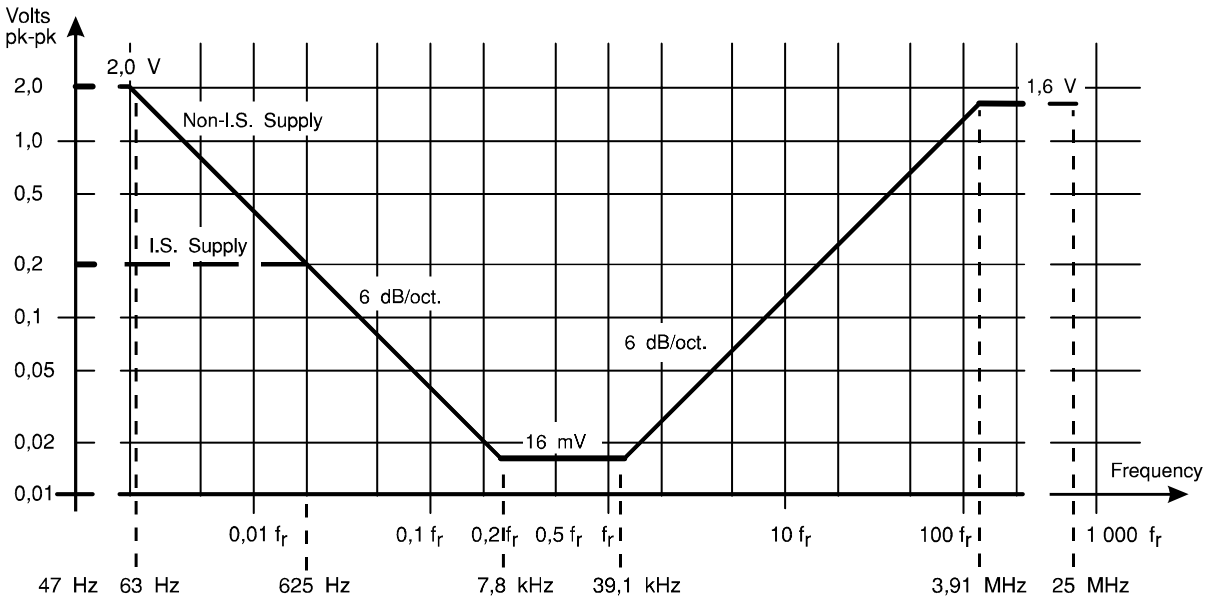


Figure 62 — Power supply ripple and noise

A fieldbus device claiming conformance to this clause which is powered via the signal conductors shall exhibit a maximum rate of change of current drawn from the network of 1 mA/ms. This requirement does not apply:

1) when transmitting,
2) within the first 20 ms after the connection of the device to an operating network,
3) within the first 20 ms after the application of power to the network, or
4) upon disconnection from the network or removal of power to the network.

A device shall be marked with its rated quiescent current. A device shall draw no more than 20 mA above its rated current from the network during the time interval of 500 µs to 20 ms after the connection of the device to an operating network or 500 µs to 20 ms after the application of power to the network.

NOTE 3 The first 500 µs are excluded to allow for the charging of RFI filters and other capacitance in the device. The rate of change specification applies after 20 ms.

NOTE 4 The maximum current during that initial 500 µs should be no more than twice the maximum current specified above, to minimize affects of the current inrush on the rest of the connected fieldbus network.

NOTE 5 These exclusions have the potential to cause a "brown out" at devices powered from the same power supply during the exclusion interval.

NOTE 6 These exclusions can substantially increase the current requirements of the power supply during the exclusion interval which occurs immediately after power is applied to the PhL segment.

12.7.4 Power supply impedance

The power supply used to provide power on the signal conductors shall comply with the impedance specification in 12.7.4.1, 12.7.4.2, or 12.7.4.3.

NOTE Power supply designs should take into account the current surge at device connection or power-up permitted by 12.7.3.

12.7.4.1 Power supply impedance for single output power supplies

For power supplies having a single output, power supply impedance shall be measured using the test circuit of Figure 63.

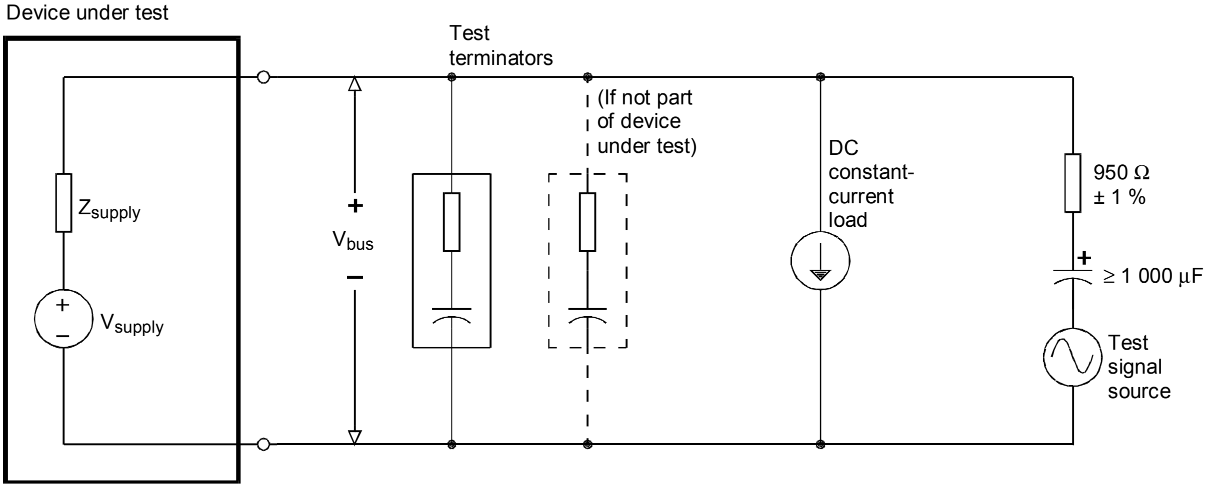


Figure 63 — Test circuit for single-output power supplies

The test terminators shown in Figure 63 shall each be 100 Ω ± 1 % in series with 1 µF ± 5 %. Two test terminators shall be used in the test circuit if the supply under test does not contain an internal terminator. If the supply under test contains an internal terminator that is always connected, only one test terminator shall be used in the test circuit. If the supply under test contains an internal terminator that can be optionally connected into the circuit, the supply shall be tested a) with the internal terminator and one test terminator and b) with two test terminators and no internal terminator.

If the power supply is intended to be used with an external impedance-determining network (for example, as might be the case with supplies designed to be used redundantly), the supply shall be tested with the external network connected.

The supply shall be tested at 20 %, 50 %, and 80 % of its rated output current (or 20 mA, whichever is greater), with the supply loaded by a d.c. constant-current load having 1 mA/V compliance or better (i.e. ≥1 kΩ impedance).

The power supply shall be tested by monitoring the a.c. bus voltage V_{BUS} while applying a 10 $V_{pk\text{-}pk}$ sine wave from a test signal source through a 950 Ω ± 1 % resistor and a coupling capacitor of at least 1 000 µF.

The measured a.c. bus voltage V_{BUS} shall conform to the following.

a) **For non-IS power supplies intended for feeding IS barriers:** V_{BUS} shall be between 0,40 $V_{pk\text{-}pk}$ and 0,60 $V_{pk\text{-}pk}$ at all frequencies from 50 Hz to 39 kHz.

b) **For IS power supplies, and for non-IS power supplies not intended for feeding IS barriers:** V_{BUS} shall be between 0,40 $V_{pk\text{-}pk}$ and 0,60 $V_{pk\text{-}pk}$ from 3 kHz to 39 kHz, and shall not increase or decrease at a rate greater than 20 dB per decade at any frequency from 50 Hz to 3 kHz.

NOTE It is acceptable for the functions of power supply and terminator to be combined as long as the combination is electrically equivalent to the independent devices meeting the requirements of this clause, and if the network configuration rules of 12.3 are followed.

Power supplies not intended for feeding IS barriers shall be marked “Not for use with IS barriers”.

12.7.4.2 Power distribution through an IS barrier

Intrinsic safety barrier output impedance shall be defined in terms of its frequency dependent characteristics when connected in the test circuit of Figure 64.

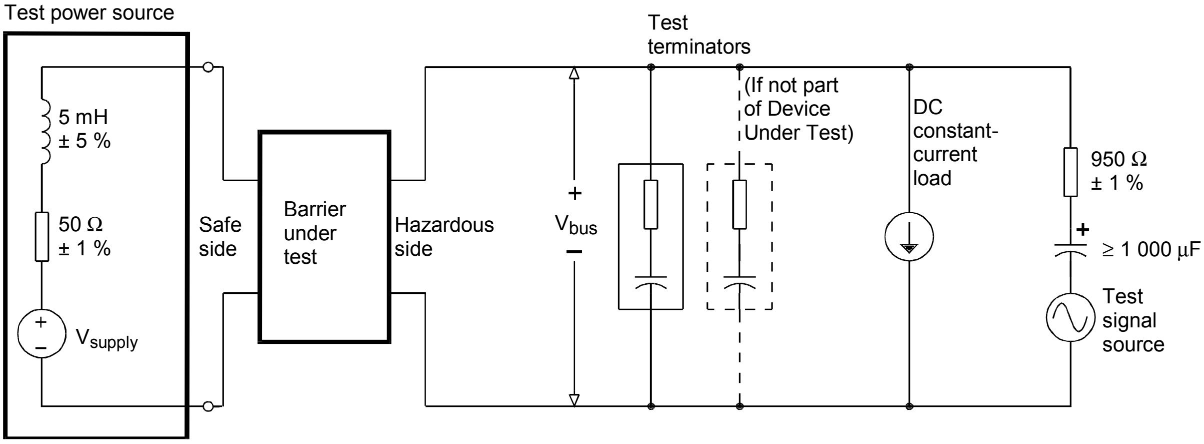


Figure 64 — Test circuit for power distribution through an IS barrier

The test power source shown in Figure 64 consists of a low-impedance d.c. voltage source in series with 5 mH ± 5 % and 50 Ω ± 1 %. The test terminators shall each be 100 Ω ± 1 % in series with 1 μF ± 5 %. If the barrier contains an internal terminator, the barrier shall be tested with one test terminator. Otherwise, the barrier shall be tested with two test terminators.

The barrier shall be tested at 20 %, 50 %, and 80 % of rated output current (or 20 mA, whichever is greater), when loaded by a d.c. constant-current load having 1 mA/V compliance or better (i.e. ≥1 kΩ impedance).

The barrier shall be tested by monitoring the bus voltage V_{BUS} while applying a 10 V_{pk-pk} sine wave from a test signal source through a 950 Ω ± 1 % resistor and a coupling capacitor of at least 1 000 μF.

The measured a.c. bus voltage V_{BUS} on the hazardous side of the barrier shall be between 0,40 V_{pk-pk} and 0,60 V_{pk-pk} from 3 kHz to 39 kHz, and shall not increase or decrease at a rate greater than 20 dB per decade at any frequency from 50 Hz to 3 kHz.

NOTE It is acceptable for the functions of power supply, IS barrier and terminator to be combined in various ways as long as the combination is electrically equivalent to the independent devices meeting the requirements of this clause, and if the network configuration rules of 12.3 are followed.

12.7.4.3 Power supply impedance for multiple-output supplies with signal coupling between outputs

NOTE 1 This subclause is applicable to galvanic isolators, active couplers, and other devices providing multiple power and signal ports.

For multiple-output power supplies with a coupling of fieldbus communication signal between outputs, power supply impedance shall be measured using the test circuit of Figure 65.

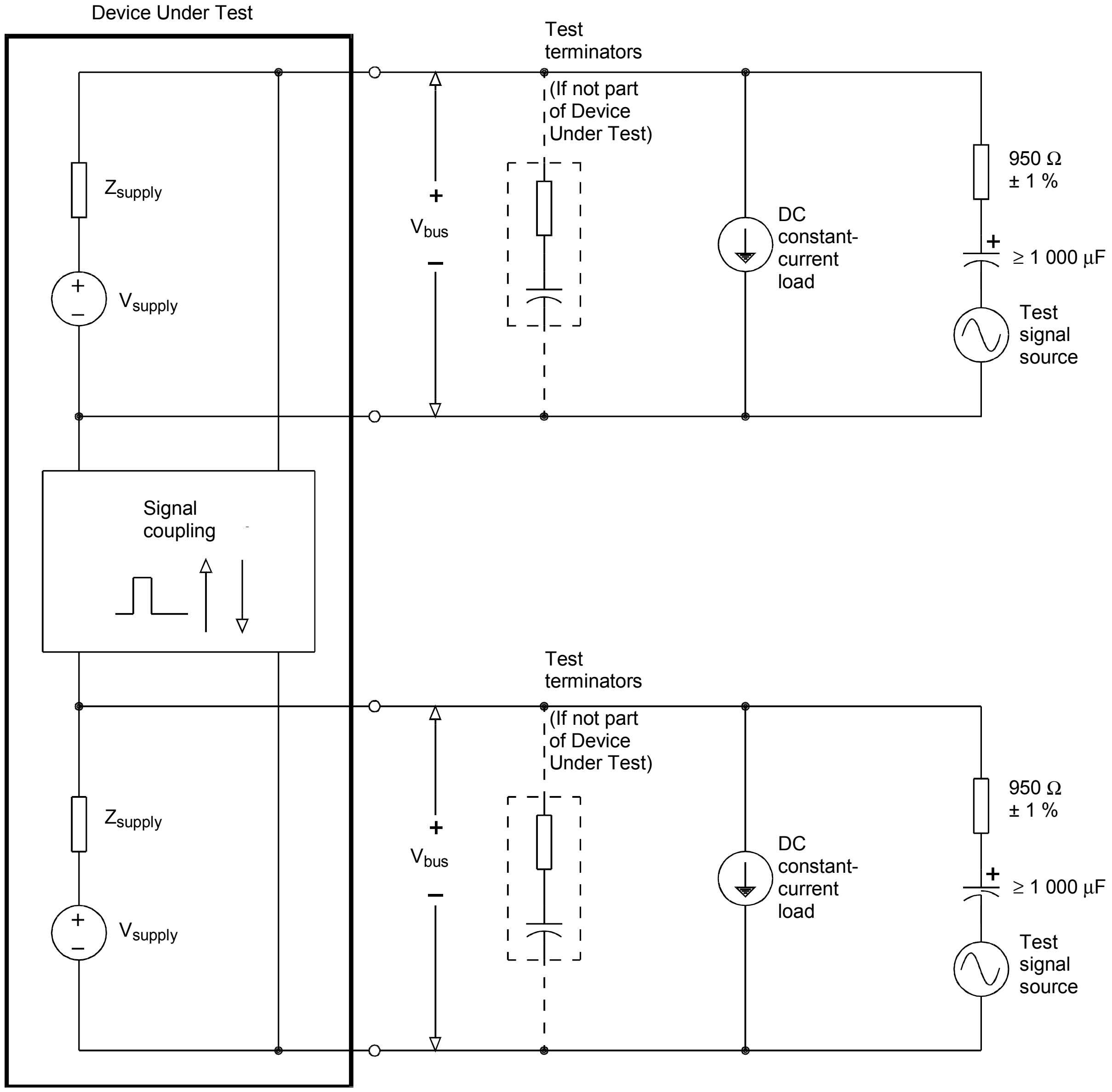


Figure 65 — Test circuit for multiple output supplies with signal coupling

The test terminators shown in Figure 65 shall each be 100 Ω ± 1 % in series with 1 µF ± 5 %. Two test terminators shall be used in the test circuit if the device under test does not contain an internal terminator. If the device under test contains an internal terminator that is always connected, only one test terminator shall be used in the test circuit. If the device under test contains an internal terminator that can be optionally connected into the circuit, the device shall be tested a) with the internal terminator and one test terminator and b) with two test terminators and no internal terminator.

If the device under test is intended to be used with an external impedance-determining network (for example, as might be the case with supplies designed to be used redundantly), the supply shall be tested with the external network connected.

The device under test shall be tested at 20 %, 50 %, and 80 % of its rated output current (or 20 mA, whichever is greater) on each output, with the device loaded by a d.c. constant-current load having 1 mA/V compliance or better (i.e. ≥1 kΩ impedance).

The measured a.c. bus voltage V_{BUS} shall be between 0,40 V_{pk-pk} and 0,60 V_{pk-pk} from 3 kHz to 39 kHz, and shall not increase or decrease at a rate greater than 20 dB per decade at any frequency from 50 Hz to 3 kHz.

NOTE 2 It is acceptable for the functions of power supply, isolator or coupler, and terminator to be combined in various ways as long as the impedance of the combination is equivalent to the parallel impedance of independent devices meeting the requirements of this clause and the network configuration rules of 12.3 are followed.

12.7.5 Powered separately from signal conductors

NOTE Power distribution to non-bus powered fieldbus devices is by separate conductors feeding local power supplies, regulators or safety barriers. IS certification may require these conductors to be in a separate cable from the signal conductors and may also impose more stringent requirements for current levels than specified.

A separately powered fieldbus device shall draw no more than 10 mA direct current from the signal conductors nor shall it supply more than 100 µA direct current to the signal conductors when not transmitting. A device shall be marked with its rated quiescent current draw from the network.

12.7.6 Electrical isolation

All fieldbus devices, whether separately powered or powered via the signal conductors, shall provide low frequency isolation between ground and the fieldbus trunk cable.

NOTE 1 This may be by isolation of the entire device from ground or by use of a transformer, opto-coupler or some other isolating component between trunk cable and device.

A combined power supply and communication element shall not require electrical isolation.

For shielded cables, the isolation impedance measured between the shield of the fieldbus cable and the fieldbus device ground shall be greater than 250 kΩ at all frequencies below 63 Hz.

The maximum unbalanced capacitance to ground from either input terminal of a device shall not exceed 250 pF.

The breakdown requirements of the isolation of the signal circuit and the power distribution circuit from ground and from each other shall be in accordance with IEC 61131-2.

NOTE 2 See 11.7.5, note 3.

12.8 Medium specifications

12.8.1 Connector

Cable connectors, if used, shall be in accordance with this standard (see Annex A for Type 1, and Annex I for Type 3 synchronous transmission). Field termination techniques such as screw or blade terminals and permanent termination may also be used.

12.8.2 Standard test cable

The cable used for testing fieldbus devices which claim conformance to this clause shall be a single twisted-pair cable with overall shield meeting the following minimum requirements at 25 °C:

a) impedance at f_r (31,25 kHz) = 100 Ω ± 20 %;
b) maximum attenuation at 1,25 f_r (39 kHz) = 3,0 dB/km;
c) maximum capacitive unbalance to shield = 4 nF/km, tested using a 30 m or longer sample;
d) maximum d.c. resistance (per conductor) = 24 Ω/km;
e) maximum propagation delay change 0,25 f_r to 1,25 f_r = 1,7 µs/km;
f) conductor cross-sectional area (wire size) = nominal 0,8 mm^2;

g) minimum shield coverage shall be 90 %.

NOTE 1 The preceding specification is for conformance testing an MAU. Other types of cable may be used in real installations. (See Annex B.) Cables with improved specifications may enable increased trunk length or superior interference immunity or may be required to meet environmental or installation conditions. Conversely, cables with inferior specifications may be used subject to length limitations for both trunk and spurs, plus possible non-conformance to the RFI/EMI susceptibility requirements.

NOTE 2 For intrinsically safe applications, the inductance/resistance ratio (L/R) should be less than the limit specified by the local regulatory agency for the particular implementation.

12.8.3 Coupler

The coupler shall provide one or several point(s) of connection to the trunk. It may be integrated in a fieldbus device, in which case there is no spur. Otherwise, it has at least three access points as shown in Figure 66: one for the spur and one for each side of the trunk.

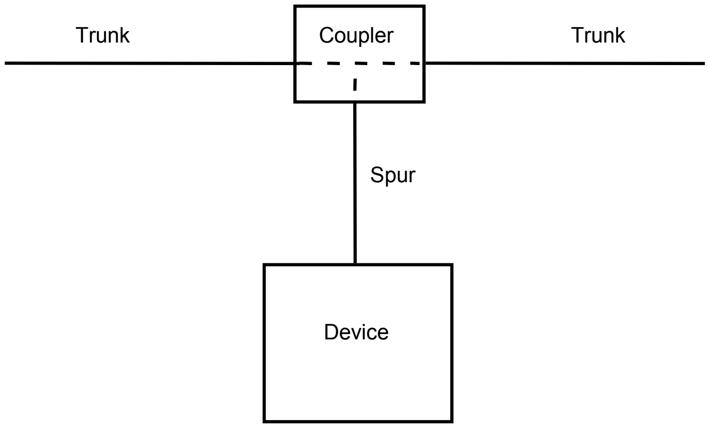


Figure 66 — Fieldbus coupler

A passive coupler may contain any or all of the optional elements as described below:

a) a transformer, to provide galvanic isolation and impedance transformation between trunk and spur;
b) connectors, to provide easy connection to spur and/or trunk;
c) protection resistors, as shown in Figure 67, to protect bus traffic between other devices from the effects of a short-circuit spur on an unpowered, non-intrinsically-safe trunk.

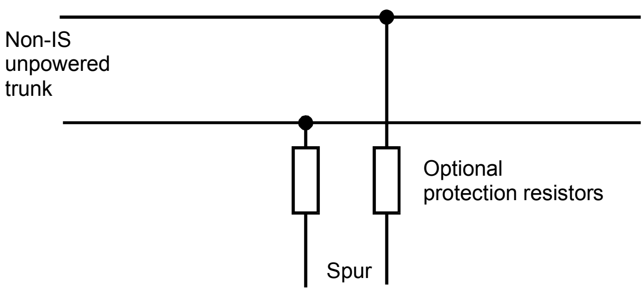


Figure 67 — Protection resistors

NOTE Such series resistors inherently increase the voltage at the device terminals when it is transmitting. This will affect the voltage at the receiving terminals of electrically “nearby” devices. See 12.4.3 for the maximum withstand voltage required of all such devices.

Active couplers, which require external power supplies, contain components for signal amplification and re-transmission. The transmit level and timing requirements shall conform to 12.3.

12.8.4 Splices

NOTE 1 A splice is any part of the network in which the characteristic impedance of the network cable is not preserved. This is possibly due to separation of the cable conductors, removal of the cable shield, change of wire gauge or type, connection to spurs, attachment to terminal strips, etc. A practical definition of a splice is therefore any part of the network that is not a continuous length of the specified medium.

For networks having a total cable length (trunk and spurs) of greater than 400 m, the sum of the lengths of all splices shall not exceed 2,0 % of the total cable length. For cable lengths of 400 m or less, the sum of the lengths of all splices shall not exceed 8 m.

NOTE 2 The motivation for this specification is to preserve transmission quality by requiring that the network be constructed almost entirely of the specified medium.

The continuity of all conductors of the cable shall be maintained in a splice.

12.8.5 Terminator

A terminator shall be located at both ends of the trunk cable, connected from one signal conductor to the other. No connection shall be made between terminator and cable shield.

The terminator impedance value shall be 100 Ω – 2 Ω/+ 6 Ω over the frequency range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz). The terminator impedance shall be equivalent to a 100 Ω resistor in series with a 1,0 µF capacitor. The maximum component tolerances shall be 100 Ω ± 2 Ω and 1,0 µF ± 0,2 µF.

NOTE 1 This impedance value is approximately the average cable characteristic impedance value for suitable cables at the relevant frequencies and is chosen to minimize transmission line reflections.

NOTE 2 The terminator components should be chosen to meet the specified values over the temperature range and operating life of the installation. It is recommended that the 25 °C rating of the components be 100 Ω ± 1 Ω and 1 µF ± 0,1 µF.

The direct current leakage through the terminator shall not exceed 100 µA. The terminator shall be non-polarized.

All terminators used for IS applications shall comply with isolation requirements (creepage and clearance) commensurate with the required IS approval. Terminators for non-IS applications shall not be required to have IS approval.

NOTE 3 It is acceptable for the functions of power supply, safety barrier, and terminator to be combined in various ways as long as the impedance of the combination is equivalent to the parallel impedance of independent devices meeting the requirements of this clause and the network configuration rules of 12.3.3 are followed.

12.8.6 Shielding rules

Where conformance to the noise immunity requirements of 12.5 is to be met by the use of shielding it is necessary to ensure the integrity of shielding throughout the cabling, connectors and couplers. The following rules can assist in meeting these requirements, but are not themselves a requirement:

a) the cable should be shielded for more than 90 % of its full length;
b) shielding should completely cover the electrical circuits in connectors, couplers, and splices.

NOTE 1 Deviation from these shielding rules may degrade noise immunity.

NOTE 2 Due to the long wavelengths involved, breaks in the shield coverage of 25 cm or so at connectors, couplers and splices, including where spurs are attached, should not usually be a problem, provided that shield continuity is maintained.

NOTE 3 Enclosure of connectors, couplers and splices in a metallic junction box can provide shielding from noise sources outside the junction box.

12.8.7 Grounding (earthing) rules

NOTE 1 Grounding (earthing) means permanently connected to earth through sufficiently low impedance and with sufficient current-carrying capability to prevent voltage build-up which might result in undue hazard to connected equipment or persons. Zero volts (common) lines may be connected to ground where they are galvanically isolated from the fieldbus trunk.

Fieldbus devices shall be required to function to the requirements of this clause with the mid-point of one terminator or one inductive coupler connected directly to ground.

Fieldbus devices shall not connect either conductor of the twisted pair to ground at any point in the network. Signals shall be applied and preserved differentially throughout the network.

NOTE 2 It is standard practice for the shield of the fieldbus trunk cable (if applicable) to be effectively grounded at one point along the length of the cable. For this reason fieldbus devices should allow d.c. isolation of the cable shield from ground. It is also standard practice to connect the signal conductors to ground in a balanced manner at the same point, e.g. by using the center tap of a terminator or coupling transformer. For bus-powered systems the grounding of the shield and balanced signal conductors should be close to the power supply unit. For IS systems the grounding should be at the safety barrier earth connection. Capacitive coupling between the shield or the balanced signal conductors and device local ground for EMI control is permitted, subject to IS requirements.

12.8.8 Color coding of cables

See 11.8.8.

Where consideration of regional practices, such as those specified in 11.8.8, does not override, the following cable colors are recommended for Type 3 systems, as shown in Table 65.

Table 65 — Type 3 cable color specification

Cable Parameter	Color
Color of sheath non-IS	Black
Color of sheath IS	Blue or blue/black stripe
Color of inner cable conductor A (PA-)	Green
Color inner cable conductor B (PA+)	Red

12.9 Intrinsic safety

12.9.1 General

This standard does not attempt to list the requirements by which an item of equipment may be certified as intrinsically safe nor does it require equipment to be intrinsically safe. Rather, it seeks to exclude conditions or situations that would prevent IS certification.

12.9.2 Intrinsic safety barrier

The barrier impedance shall be greater than 460 Ω at any frequency in the range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz). The IS barrier impedance specification shall apply to all barriers used as part of the PhL, whether installed as a separate item of network hardware or embedded in a power supply card. The barrier impedance shall be measured across the terminals on both sides of the barrier. The barrier impedance shall be measured while the network power supply is set at the rated working voltage (not safety voltage) of the barrier.

NOTE It is acceptable for the functions of power supply, safety barrier, and terminator to be combined in various ways as long as the impedance of the combination is equivalent to the parallel impedance of independent devices meeting the requirements of this clause and the network configuration rules of 12.3.3 are followed.

At the rated working voltage of the barrier, and at any frequency in the range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz), the capacitance measured from the "+" (positive) network terminal (hazardous side) to ground shall differ by no more than 250 pF from the capacitance measured from the "–" (negative) network terminal (hazardous side) to ground.

12.9.3 Barrier and terminator placement

A barrier shall be separated from the nearest terminator by no more than 100 m of cable.

12.10 Galvanic isolators

The communications characteristics of galvanic isolators used on the fieldbus shall comply with the specifications of 12.4, 12.5 and 12.9. Galvanic isolators that provide power to fieldbus devices shall also comply with the power supply specifications of 12.7.

13 Type 1: Medium attachment unit: current mode, twisted-pair wire medium

13.1 General

The 1,0 Mbit/s current-mode MAU simultaneously provides access to a communication network and to a power distribution network. Devices attached to the network communicate via the medium and may or may not be powered from it. Power is distributed as a constant a.c. current. The communications signals are superimposed on the a.c. power.

The network medium consists of shielded twisted-pair cable.

Trapezoidal waveforms are used to reduce electromagnetic emissions and signal distortion.

In Intrinsically Safe applications, available power may limit the number of devices.

The devices are connected in series on the bus whereas in the voltage-mode variants the devices are connected in parallel to the bus.

13.2 Transmitted bit rate

The average bit rate, BR ± ΔBR, shall be 1,0 Mbit/s ± 0,01 %, averaged over a frame having a minimum length of 16 octets. The instantaneous bit time, $T_{bit} \pm \Delta T_{bit}$, shall be 1,0 μs ± 0,025 μs.

13.3 Network specifications

13.3.1 Components

An MAU operates in a network composed of the following components:

a) cable;
b) terminators;
c) couplers;
d) devices (containing at least one communication element).

A wire network in current mode may additionally include the following components:

e) connectors;
f) power supplies;
g) devices which include power supplies;
h) intrinsic safety barriers.

The network medium consists of shielded twisted-pair cable. Independent of topology, all attached devices, other than possibly the transmitting device, are low impedance to prevent significant network loading.

13.3.2 Topologies

A wire MAU shall operate in a network with a linear bus topology, consisting of a trunk, terminated at each end as specified in 13.8.5, to which communication elements are connected via couplers and spurs.

The coupler and communication element may be integrated in one device (i.e. zero-length spur).

A tree topology with all the communication elements located at the ends of the trunk is regarded as a special case of a bus for the purpose of this clause.

Several communication elements may be connected to the trunk at one point using a multi-port coupler. An active coupler may be used to extend a spur to a length that requires termination to avoid reflections and distortions. Active repeaters may be used to extend the length of the trunk beyond that of a single segment as permitted by the network configuration rules.

13.3.3 Network configuration rules

An MAU that claims conformance to this clause shall meet the requirements of this clause when used in a network that complies with these rules.

Rule 1: One fieldbus shall be capable of communication between two and 32 devices, all operating at the same bit rate, both for a powered and a non-powered bus and in a hazardous area using distributed barriers.

NOTE 1 The use of a single barrier in the safe area may limit the number of devices in the hazardous area.

NOTE 2 This rule does not preclude the use of more than the specified number of devices in an installed system. The numbers of devices were calculated on the assumption that a bus-powered device draws 100 mW.

Rule 2: A fully loaded (maximum number of connected devices), current-mode fieldbus segment shall have a total cable length, between any two devices, of up to 750 m.

NOTE 3 750 m maximum cable length is the requirement for conformance to this clause but this does not preclude the use of longer lengths in an installed system.

Rule 3: The total number of waveform regenerations by repeaters and active couplers between any two devices is repeater implementation dependent.

NOTE 4 Prior editions of this standard limited this total number to four.

Rule 4: The maximum propagation delay between any two devices shall not exceed 40 T_{bit}.

NOTE 5 For efficiency of the network, that part of the turn-around time of any device on the network caused by a PhE between the end of a received frame and the beginning of the transmitted frame containing an associated immediate response should not exceed 5 bit times, no more than 2 bit times of which should be due to the MAU. As it is not mandatory to expose the DLL – PhL interface or the MDS – MAU interface, that part of the turn-around time of a fieldbus device caused by the PhL or the MAU cannot be specified or conformance tested.

Rule 5: The fieldbus shall be capable of continued operation while a device is being connected or disconnected. Data errors induced during connection or disconnection shall be detected.

Rule 6: Failure of any communication element or spur (including a short circuit or open circuit, but excluding jabber) shall not interfere with transactions between other communication elements for more than 1 ms.

Rule 7: The network shall not be polarity sensitive with or without power injected on the line.

Rule 8: The degradation of the electrical characteristics of the signal, between any two devices, due to attenuation, attenuation distortion and mismatching shall be limited to the values indicated below.

a) Signal attenuation: The signal attenuation due to each device shall not exceed 0,2 dB. The configuration of the bus (trunk and spur lengths, number of devices, IS barriers, galvanic isolators, and possible matching devices) shall be such that the attenuation between any two devices at the frequency corresponding to the bit rate shall not exceed 16 dB.

b) Attenuation distortion: The configuration of the bus (trunk and spur lengths and number of devices) shall be such that between any two devices:

[Attenuation (1,25 f_r) – Attenuation (0,25 f_r)] ≤ 6 dB

Attenuation (1,25 f_r) ≥ Attenuation (0,25 f_r)

where f_r is the frequency corresponding to the bit rate. Attenuation shall be monotonic for all frequencies from 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz).

c) Mismatching distortion: Mismatching (due to spurs or any other effect, including one open circuit spur of maximum length) on the bus shall be such that, at any point along the trunk, in the frequency band 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz):

$|Z – Zfr| / |Z + Zfr| \le 0,2$

where

Z_o is the characteristic impedance of the trunk cable;

Z is the parallel combination of Z_o and the load impedance at the coupler.

NOTE 6 This rule minimizes restrictions on trunk and spur length, number of devices etc. by specifying only the transmission limitations imposed by combinations of these factors. Different combinations may be used depending on the needs of the application.

Rule 9: The following rules shall apply to systems implemented with redundant media:

a) each channel (cable) shall comply with the network configuration rules;

b) there shall not be a non-redundant segment between two redundant segments;

c) repeaters shall also be redundant;

d) if the system is configured (by Systems management) to transmit on more than one channel simultaneously then the propagation time difference between any two devices on any two channels shall not exceed five bit times;

e) channel numbers shall be maintained throughout the fieldbus, i.e. channels 1,2,3... from Systems management shall always connect to physical channels 1,2,3...

13.3.4 Power distribution rules for network configuration

See 11.3.4.

13.4 MAU transmit circuit specification

The requirements of this subclause are summarized in Table 66 and Table 67.

Table 66 — MAU transmit level specification summary

Transmit level characteristics, values referred to trunk (but measured using test load as shown in Figure 68)	Limits (bus-powered and/or IS)
Output level (peak-to-peak, see Figure 55) With test load (>2 × nominal Z_o of trunk cable)	≥2,5 V 320 Ω ± 1 %
Maximum positive and negative amplitude difference (signaling bias) as shown in Figure 56	±0,2 V
Output level; open circuit (peak-to-peak)	≤4,0 V
Maximum output signal distortion; i.e., overvoltage, ringing and droop (see Figure 55)	±10 %
Quiescent transmitter output; i.e. transmitter noise (measured over the frequency band 1 kHz to 4 MHz)	≤1 mV (r.m.s.)

Table 67 — MAU transmit timing specification summary

Transmit timing characteristics, values referred to trunk (but measured using test load as shown in Figure 68)	Limits (bus-powered and/or IS)
Transmitted bit rate	1 Mbit/s ± 0,01 %
Instantaneous bit time	1 μs ± 0,025 μs
Rise and fall times (10 % to 90 % of pk-pk signal, see Figure 55)	≤ 20 % T_{bit}
Slew rate (at any point from 10 % to 90 % of pk-pk signal)	≤40,0 V/μs
Maximum transmitted bit cell jitter (zero crossing-point deviation, see Figure 56)	± 2,5 % T_{bit}
Transmit enable/disable time (i.e. time during which the output waveform may not meet the transmit requirements)	≤ 2,0 T_{bit}

13.4.1 Test configuration

Figure 68 shows the configuration that shall be used for testing.

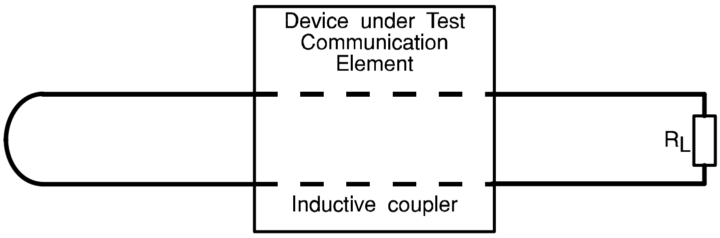


Figure 68 — Test configuration for current-mode MAU

The test configuration for this clause shall be as shown in Figure 68 except where otherwise stated in a specific requirement.

NOTE Test load resistance R = 320 Ω (twice maximum cable Z_o) as the output is loaded by a series loop of the trunk.

13.4.2 Output level requirements

NOTE Figure 55 shows an example of one cycle of a fieldbus waveform, illustrating some key items from the transmit circuit specification. Only signal voltages are shown; this diagram takes no account of power-supply voltages.

A current-mode MAU transmit circuit shall conform to the following output level requirements, all amplitudes being measured at the estimated mid-point between any peaks or troughs in the top and bottom of the waveform ("mid-point" in Figure 55):

a) the output voltage across the test load after transformer step up/down shall be no less than 2,5 V peak-to-peak with a load resistance of 320 Ω ± 1 % ("min o/p" in Figure 55);

b) the output voltage at the trunk, or at the transmit terminals, with any load including an open circuit shall not exceed 4,0 V peak-to-peak ("max. o/c at trunk" in Figure 55). For test purposes, open circuit shall be defined as a load of 100 kΩ resistance in parallel with 15 pF capacitance;

c) during transmission a device shall not suffer permanent failure when a load resistance of ≤1 Ω is applied for 1 s;

d) the difference between positive amplitude and negative amplitude, measured as shown in Figure 55, shall not exceed ±0,2 V peak;

e) the output noise from a current-mode MAU which is receiving or not powered shall not exceed 1 mV r.m.s., measured differentially over the frequency band 1 kHz to 4 MHz, referred to the trunk;

f) the differential voltage across the test load shall be such that the voltage monotonically changes between 10 % and 90 % of peak-to-peak value. Thereafter, the signal voltage shall not vary more than ±10 % of peak-to-peak value until next transition occurs. This permitted variation shall include all forms of output signal distortion, i.e. overvoltage, ringing and droop.

13.4.3 Output timing requirements

A current-mode MAU transmit circuit shall conform to the following output timing requirements:

a) rise and fall times, measured from 10 % to 90 % of the peak-to-peak signal amplitude shall not exceed 0,2 T_{bit} (see Figure 55);

b) slew rate shall not exceed 40 V/µs measured at any point in the range 10 % to 90 % of the peak-to-peak signal amplitude (see Figure 55);

NOTE 1 Requirements a) and b) produce a trapezoidal waveform at the transmit circuit output. Requirement b) limits the level of interference emissions that may be coupled to adjacent circuits etc. Requirement b) is calculated from the formul1a:

Max. slew rate = 3 × min. slew rate = $3 \times 0{,}8\ V_o / 0{,}2\ T = 12 \times V_o / T_{bit}$,
where V_o is an estimated maximum pk-pk output voltage with standard load (3,3 V).

c) transmitted bit cell jitter shall not exceed ±0,025 nominal bit time from the ideal zero crossing-point, measured with respect to previous zero crossing (see Figure 69);

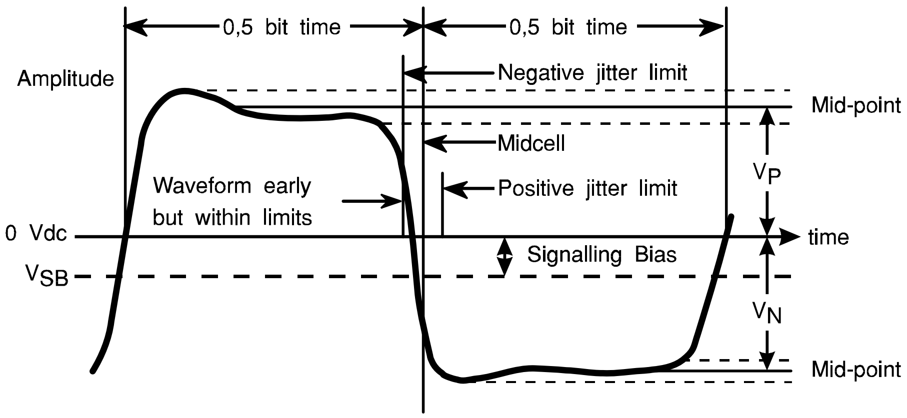


Figure 69 — Transmitted and received bit cell jitter (zero crossing point deviation)

d) the transmit circuit shall turn on, i.e. the signal shall rise from below the transmit circuit maximum output noise level as specified in 13.4.2e) to full output level, in less than 2,0 T_{bit}. The waveform corresponding to the third and later bit times shall be as specified by other subclauses of 13.4;

e) the transmit circuit shall turn off, i.e. the signal shall fall from full output level to below the transmit circuit maximum output noise level as specified in 13.4.2e), in less than 2,0 T_{bit}. The time for the transmit circuit to return to its off state impedance shall not exceed 4,0 T_{bit}. For the purposes of testing, this requirement shall be met with the transmit circuit test configuration of 13.4.1 with the equivalent capacitance of a maximum length cable across the DUT terminals.

NOTE 2 This requirement is to ensure that the transition of the transmit circuit from active to passive leaves the line capacitance fully discharged.

13.5 MAU receive circuit specification

13.5.1 General

For ease of reference the requirements of 13.4 are summarized in Table 68.

Table 68 — Receive circuit specification summary

Receive circuit characteristics (values referred to trunk)	Limits (bus-powered and/or IS)
Input impedance, measured over the frequency range 0,25 f_r to 1,25 f_r	≤2,5 Ω
Sensitivity; min. peak-to-peak signal required to be accepted (see Figure 58)	1,3 mA
Noise rejection; max. peak-to-peak noise required to be rejected (see Figure 58)	0,8 mA
Maximum received bit cell jitter (zero crossing-point deviation, see Figure 69)	±0,10 T_{bit}

13.5.2 Input impedance

The differential input impedance of a current-mode MAU receive circuit shall not exceed 2,5 Ω in series with the line over the frequency range 0,25 f_r to 1,25 f_r. (250 kHz to 1,25 MHz) This requirement shall be met in the power-off and power-on (not transmitting) states and in transition between these states. This impedance shall be measured at the inductive coupler using a sinusoidal current waveform with an amplitude greater than the receiver sensitivity threshold and lower than 20 mA peak-to-peak.

NOTE The requirement for ≤2,5 Ω input impedance during power-up and power-down may be met by automatic disabling of the transmitter during these periods.

13.5.3 Receiver sensitivity and noise rejection

An MAU receive circuit shall be capable of accepting an input signal from 1,3 mA peak-to-peak to 20,0 mA peak-to-peak, including overvoltage and oscillation (see "signal level" together with "positive amplitude" and "negative amplitude", all in Figure 55).

An MAU receive circuit shall not respond to an input signal with a peak-to-peak line current amplitude which does not exceed 0,8 mA (see "noise rejection" in Figure 58).

13.5.4 Received bit cell jitter

The receive circuit shall accept a Manchester encoded signal transmitted in accordance with 13.2 and 13.4. In addition, the receiver shall work properly with signals with the time variation between any two adjacent signal transition points (zero crossing) of ±0,10 T_{bit} or less. See Figure 69.

NOTE 1 This does not preclude the use of receivers that perform better than this specification.

NOTE 2 Depending on the symbol pattern, the nominal time between zero crossings may be one-half or one bit time.

NOTE 3 There is no requirement to reject a signal with a specified time variation value. The receiver reports an error when the received bit cell jitter exceeds the receiver's ability to reliably decode signaling.

13.5.5 Interference susceptibility and error rates

NOTE 1 When the fieldbus is operating in a variety of standard noise environments the probability that an Application Layer User Data Unit contains an undetected error, due to operation of the conveying Physical and DLL entities, should be less than 1 in 10^{12} (1 error in 20 years at 1 600 messages/s). A communication element is regarded as conforming to this theoretical requirement when it meets the following interference susceptibility requirements. These are specified by a detected frame error rate which is derived by using a ratio of detected to undetected errors of 10^6. This should be readily achievable with a 16 bit Frame Check Sequence at the DLL.

A communication element which includes a current-mode MAU, operating with frames containing 64 random user data bits, with maximum frame rate and with signals of 4,0 mA peak-to-peak amplitude, shall produce no more than 3 detected frame errors in 3×10^6 frames during operation in the presence of common mode voltage or Gaussian noise as follows:

a) a common-mode sinusoidal signal of any frequency from 63 Hz to 2 MHz, with an amplitude of 4 V r.m.s. and from 47 Hz to 63 Hz with an amplitude of 250 V r.m.s.;

b) a common-mode d.c. signal of ±10 V;

c) white Gaussian additive differential noise in the frequency band 1 kHz to 4 MHz, with a noise density of 0,09 µA/√Hz r.m.s. using the test circuit of Figure 70.

NOTE 2 The common mode voltage and Gaussian noise specifications are for receive circuit conformance testing with balanced loads and are not indicative of system installation practice.

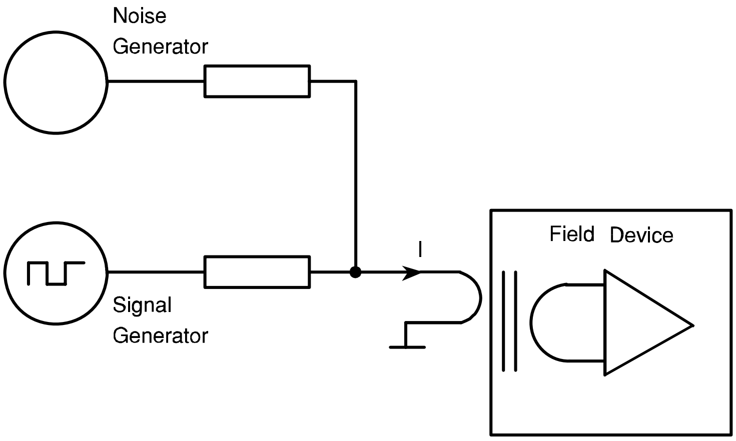


Figure 70 — Noise test circuit for current-mode MAU

A communication element which includes a current-mode MAU, operating with frames containing 64 random user data bits, at an average of 1 600 messages/s, with signals of 4,0 mA peak-to-peak amplitude, shall produce no more than six detected frame errors in 100 000 frames during operation in the presence of electromagnetic or electrical interference environments as follows:

1) 10 V/m electromagnetic field as specified in IEC 61000-4-3 at severity level 3;
2) electrical fast transient as specified in IEC 61000-4-4 at severity level 3.

The above error-rate specification shall also be satisfied after but not during operation in the following noise environments:

i) 8 kV electrostatic discharge to exposed metalwork as specified in IEC 61000-4-2 at severity level 3. If the device suffers temporary loss of function or performance as a result of this test it shall recover from any such loss without operator intervention within 3 s after the end of the test;
ii) high-frequency disturbance tests as specified in IEC 60255-22-1:1988, Test voltage class III (2,5 kV and 1 kV peak values of first half-cycle in longitudinal and transverse mode respectively). If the device suffers temporary loss of function or performance because of this test it shall recover from any such loss without operator intervention within 3 s after the end of the test.

13.6 Jabber inhibit

The MAU shall contain a self-interrupt capability to inhibit transmitted signals from reaching the medium. Hardware within the MAU (with no external message other than the detection of output signals or leakage via the transmit function) shall provide a window of between 5 ms and 15 ms during which time a normal frame may be transmitted. If the frame length exceeds this duration, the jabber inhibit function shall inhibit further output signals from reaching the medium and shall disable echo on the RxS line (see 10.2.2.2) to indicate jabber detection to the MDS.

The MAU shall reset the self-interrupt function after a period of 500 ms ± 50 %.

NOTE This inhibits bus traffic for no more than 6 % (= 15/250) of the available time.

13.7 Power distribution

13.7.1 General

A device can optionally receive power via the signal conductors or be separately powered.

A device can be certified as Intrinsically safe with either method of receiving power.

This standard does not include requirements for IS certification but seeks to exclude conditions or situations that would prevent IS certification.

A separately powered device can be connected to a powered fieldbus.

For ease of reference, the requirements of 13.7 are summarized in Table 69.

Table 69 — Network power supply requirements

Network power supply requirements	Limits
Output current	50 mA to 200 mA r.m.s.
Output frequency	16 kHz ± 0,5 %
Maximum output voltage, IS	Depends on barrier rating
Harmonic distortion of supply current	≤ 0,2 %
Output impedance, measured over the frequency range 0,25 f_r to 1,25 f_r	≤ 5 Ω

13.7.2 Powered via signal conductors

A device shall operate over a range of constant current, from 50 mA to 200 mA.

NOTE The output voltage from the supply is a function of cable loss and power consumed per device. A fieldbus device may be designed to consume one or more standard loads. A standard load is 100 mW.

The power-supply open-circuit output voltage shall be less than the limit specified by the local regulatory agency for the particular implementation. The output impedance of the power supply shall be ≤5 Ω over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz).

The voltage drop in the signal coupler shall be less than 0,1 V at 16 kHz.

The voltage drop in the terminations shall be less than 0,3 V at 16 kHz.

The power waveform shall be a clean sinusoid of frequency 16 kHz ± 0,5 % and maximum harmonic distortion of 0,2 %.

The device shall not introduce harmonic components of the power frequency larger than 1,0 mV peak-to-peak line to line in the main trunk.

13.7.3 Powered separately from signal

NOTE Power distribution to non-bus powered fieldbus devices is by separate conductors feeding local power supplies, regulators or safety barriers. IS certification may require these conductors to be in a separate cable from the signal conductors and may also impose more stringent requirements for current levels than specified.

A separately powered fieldbus device which claims conformance to this clause shall drop no more than 1 mV r.m.s. at the power frequency on the signal conductors nor shall it supply a current of more than 100 µA r.m.s. to the signal conductors when not transmitting.

13.7.4 Electrical isolation

All fieldbus devices, whether separately powered or powered via the signal conductors, shall provide low-frequency isolation between ground and the fieldbus trunk cable.

NOTE 1 This may be by use of an inductive coupler with sufficient isolation, by isolation of the entire device from ground or by use of a transformer, opto-coupler or some other isolating component between trunk cable and device.

A combined power supply and communication element shall not require electrical isolation.

The isolation impedance measured between the shield of the fieldbus cable and the fieldbus device ground shall be greater than 250 kΩ at all frequencies below 63 Hz.

The isolation shall be bypassed at high frequencies by capacitance, so that the impedance measured between the shield of the fieldbus cable and the fieldbus device ground shall be less than 15 Ω between 3 MHz and 30 MHz.

NOTE 2 The capacitance between ground and trunk cable shield necessary to meet both these requirements can be any value between 3,5 nF and 10,6 nF.

The maximum unbalanced capacitance to ground from either input terminal of a device shall not exceed 250 pF.

The breakdown requirements of the isolation of the signal circuit and the power distribution circuit from ground and from each other shall be in accordance with IEC 61131-2.

NOTE 3 The equivalent test voltage is to be applied between independent isolated circuits or between isolated circuits and accessible conducting parts. For circuits with a nominal voltage ≤ 50 V d.c. or r.m.s., the equivalent test voltages at sea level are 444 V r.m.s., 635 V d.c. and 635 V peak impulse test. For circuits with a nominal voltage between 150 V and 300 V r.m.s., the equivalent test voltages at sea level are 2 260 V r.m.s., 3 175 V d.c. and 3 175 V peak impulse test.

13.8 Medium specifications

13.8.1 Connector

Cable connectors, if used, shall be to the IEC fieldbus standard (see Annex A). Field termination techniques such as screw or blade terminals and permanent termination may also be used.

13.8.2 Standard test cable

The cable used for testing fieldbus devices with a current-mode MAU for conformance to the requirements of this clause shall be a single twisted pair cable with overall shield meeting the following minimum requirements at 25 °C:

a) Z_o at 0,25 f_r (250 kHz) = 150 Ω ± 10 %;

b) Z_o at 1,25 f_r (1,25 MHz) = 150 Ω ± 10 %;

c) maximum attenuation at 0,25 f_r (250 kHz) = 6,5 dB/km;

d) maximum attenuation at 1,25 f_r (1,25 MHz) = 13 dB/km;

e) maximum capacitive unbalance to shield = 1,5 nF/km

f) maximum d.c. resistance (per conductor) = 57,1 Ω/km;

g) conductor cross-sectional area (wire size) = nominal 0,33 mm^2;

h) minimum resistivity between either conductor and shield = 16 GΩ/km;

i) minimum shield coverage shall be 95 %.

NOTE 1 The preceding specification is for conformance testing an MAU. Other types of cable may be used in real installations. (See Annex B.) Cables with improved specifications may enable increased trunk length and/or superior interference immunity. Conversely, cables with inferior specifications may be used subject to length limitations for both trunk and spurs plus possible non-conformance to the RFI/EMI susceptibility requirements.

NOTE 2 For intrinsically safe applications the inductance/resistance ratio (L/R) should be less than the limit specified by the local Regulatory Agency for the particular implementation.

13.8.3 Coupler

An inductive coupler connects one device or spur to the trunk. It transfers data signals to and from the device and may transfer power to the device. The trunk cable operates as a single primary turn in the inductive coupler transformer. The following options are permitted:

a) the coupling may be performed without violation of the cable insulation;

b) the inductive coupler may be used as a connector;

c) an IS barrier element may be included as an integral part of the inductive coupler.

The coupler shall be an integral part of the MAU if the device is connected in the trunk. The input impedance of the coupler shall be a maximum of 2,5 Ω in series with the line.

13.8.4 Splices

NOTE A splice is any part of the network in which the characteristic impedance of the network cable is not preserved. This is possibly due to separation of the cable conductors, removal of the cable shield, change of wire gauge or type, connection to spurs, etc. A practical definition of a splice is therefore any part of the network that is not a continuous length of the specified medium.

The continuity of all conductors of the cable shall be maintained in a splice.

13.8.5 Terminator

A terminator shall be located at both ends of the trunk cable, connected from one signal conductor to the other. No connection shall be made between terminator and cable shield.

For test purposes, using the cable specified in 13.8.2, the terminator shall have an impedance value of 120 Ω ± 2 % over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz).

NOTE 1 The terminator resistance value was selected to be lower than the test cable characteristic impedance value because the current-mode devices add impedances in series with the terminator. The value was chosen to reduce transmission line reflections for a fieldbus with 2 to 32 devices.

NOTE 2 In practical implementations with power supplied via the signal conductors the terminator would be by-passed at power frequencies to minimize power losses.

The direct current leakage through the terminator shall not exceed 100 μA. The terminator shall be non-polarized.

All terminators used for IS applications shall comply with isolation requirements (creepage and clearance) commensurate with the required IS approval. Terminators for non-IS applications shall not be required to have IS approval.

13.8.6 Shielding rules

For full conformance to the noise immunity requirements of 13.5 it is necessary to ensure the integrity of shielding throughout the cabling, connectors and couplers by the following means:

a) the coverage of the cable shield shall be greater than 95 % of the full cable length;

b) shielding shall completely cover the electrical circuits in connectors, couplers, and splices.

NOTE Deviation from these shielding rules may degrade noise immunity.

13.8.7 Grounding rules

NOTE 1 Grounding means permanently connected to earth through a sufficiently low impedance and with sufficient current-carrying capability to prevent voltage build-up which might result in undue hazard to connected equipment or persons. Zero volts (common) lines may be connected to ground where they are galvanically isolated from the fieldbus trunk.

Fieldbus devices shall be required to function to the requirements of this clause with the mid-point of one terminator or one inductive coupler connected directly to ground.

Fieldbus devices shall not connect either conductor of the twisted pair to ground at any point in the network. Signals shall be applied and preserved differentially throughout the network.

NOTE 2 It is standard practice for the shield of the fieldbus trunk cable (if applicable) to be effectively grounded at one point along the length of the cable. For this reason fieldbus devices should allow d.c. isolation of the cable shield from ground. For bus-powered systems the grounding of the shield and balanced signal conductors should be close to the power supply unit. For IS systems the grounding should be at the safety barrier earth connection. Capacitive coupling between the shield or the balanced signal conductors and device local ground for EMI control is permitted subject to IS requirements.

13.8.8 Color coding of cables

See 11.8.8.

14 Type 1: Medium attachment unit: current mode (1 A), twisted-pair wire medium

14.1 General

A 1,0 Mbit/s current-mode MAU simultaneously provides access to a communication network, and to a power distribution network with extended power capacity. Devices attached to the network communicate via the medium, and may or may not be powered from it. Power is distributed as a constant a.c. current with a frequency far below the signal frequency. The communication signals are superimposed on the a.c. power.

The network medium consists of shielded twisted-pair cable.

In hazardous area applications, a non-IS bus may have IS barriers incorporated in connected devices thereby increasing the number of devices permissible in the hazardous area over a single barrier arrangement.

The devices are connected in series on the bus, whereas in the voltage-mode variants the devices are connected in parallel to the bus.

14.2 Transmitted bit rate

See 13.2.

14.3 Network specifications

14.3.1 Components

An MAU operates in a network composed of the following components:

a) cable;
b) terminators;
c) couplers;
d) coupler mounts;
e) devices (containing at least one communication element).

A wire network in current mode may additionally include the following components:

f) connectors;
g) power supplies;
h) devices which include power supplies;
i) intrinsic safety (IS) barriers.

The network medium consists of shielded twisted-pair cable. Independent of topology, all attached devices, other than possibly the transmitting device, are low impedance to prevent significant network loading.

A coupler mount is a network element that allows a coupler to be connected to the network medium. It may be considered as a primary winding in a transformer (inductive coupler) and has, as such, electrical characteristics that affect the network.

14.3.2 Topologies

A wire MAU shall operate in a network with a linear bus topology, consisting of a trunk, terminated at each end as specified in 14.8.5, to which communication elements are connected via couplers.

The coupler and communication element may be integrated in one device (such as zero-length spur).

Several communication elements may be connected to the trunk at one point, using a multiport coupler. An active coupler may be used to extend a spur to a length that requires termination to avoid reflections and distortions. Active repeaters may be used to extend the length of the trunk beyond that of a single segment, as permitted by the network configuration rules.

14.3.3 Network configuration rules

An MAU that claims conformance to this clause shall meet the requirements of this clause when used in a network that complies with these rules.

Rule 1: One fieldbus shall be capable of communication between two and 30 devices, all operating at the same bit rate, for both a powered and a non-powered bus, and in a hazardous area using distributed barriers.

NOTE 1 This rule does not preclude the use of more than the specified number of devices in an installed system. The numbers of devices were calculated on the assumption that a bus-powered device draws 1,0 W.

Rule 2: A fully loaded (maximum number of connected devices), current-mode fieldbus segment shall have a total cable length, between any two devices, of up to 400 m.

NOTE 2 400 m maximum cable length is the requirement for conformance to this clause, but this does not preclude the use of longer lengths in an installed system.

Rule 3: The total number of waveform regenerations by repeaters and active couplers between any two devices is repeater implementation dependent.

NOTE 3 Prior editions of this standard limited this total number to five.

Rule 4: The maximum propagation delay between any two devices shall not exceed 40 Tbit.

NOTE 4 For efficiency of the network, that part of the turnaround time of any device on the network caused by a PhE between the end of a received frame and the beginning of the transmitted frame containing an associated immediate response should not exceed five bit times, no more than two bit times of which should be due to the MAU. As it is not mandatory to expose the DLL-PhL interface, or the MDS-MAU interface, that part of the turnaround time of a fieldbus device caused by the PhL or the MAU cannot be specified, or conformance tested.

Rule 5: The fieldbus shall be capable of continued operation while a device is being connected or disconnected. Data errors induced during connection or disconnection shall be detected.

Rule 6: Failure of any communication element or spur (including a short circuit or open circuit, but excluding jabber) shall not interfere with transactions between other communication elements for more than 1 ms.

Rule 7: The network shall not be polarity sensitive with or without power injected on the line.

Rule 8: The degradation of the electrical characteristics of the signal, between any two devices, due to attenuation, attenuation distortion and mismatching shall be limited to the values indicated below.

a) Signal attenuation: the signal attenuation due to each device shall not exceed 0,35 dB. The signal attenuation due to each full or empty coupler mount shall not exceed 0,6 dB. The configuration of the bus (trunk and spur lengths, number of devices, IS barriers, galvanic isolators, and possible matching devices) shall be such that the attenuation between any two devices at the frequency corresponding to the bit rate shall not exceed 10 dB.

NOTE 5 The signal attenuation due to a device is with a cable of 80 Ω characteristic impedance. If a lower impedance cable is used, then the attenuation per device will increase.

NOTE 6 It will be required that the devices be connected to the bus using a mount to reach the maximum number of connected devices.

b) Attenuation distortion: the configuration of the bus (trunk and spur lengths and number of devices) shall be such that between any two devices:

   [Attenuation (1,25 f_r) – Attenuation (0,25 f_r)] ≤ 6 dB

   Attenuation (1,25 f_r) ≥ Attenuation (0,25 f_r)

   where f_r is the frequency corresponding to the bit rate. Attenuation shall be monotonic for all frequencies from 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz).

c) Mismatching distortion: mismatching (due to spurs or any other effect, including one open-circuit spur of maximum length) on the bus shall be such that, at any point along the trunk, in the frequency band 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz):

   $$|Z - Z_{fr}| / |Z + Z_{fr}| \leq 0,2$$

   where

   Z_o is the characteristic impedance of the trunk cable;

   Z is the series combination of Z_o and the load impedance at the coupler.

NOTE 7 This rule minimizes restrictions on trunk and spur length, number of devices etc., by specifying only the transmission limitations imposed by combinations of these factors. Different combinations may be used, depending on the needs of the application.

Rule 9: The following rules shall apply to systems implemented with redundant media:

a) each channel (cable) shall comply with the network configuration rules;
b) there shall not be a non-redundant segment between two redundant segments;
c) repeaters shall also be redundant;
d) if the system is configured (by systems management) to transmit on more than one channel simultaneously, then the propagation time difference between any two devices on any two channels shall not exceed five bit times;

NOTE 8 This delay is equal to the default value of the inter-channel signal skew (see 9.2.9). The propagation delay difference can be larger, if the inter-channel signal skew parameter is set to match this difference.

e) channel numbers shall be maintained throughout the fieldbus, that is channels 1,2,3… from systems management shall always connect to physical channels 1,2,3…

14.3.4 Power distribution rules for network configuration

See 11.3.4.

14.4 MAU transmit circuit specification

The requirements of this subclause are summarized in Table 70 and Table 71.

Table 70 — Transmit level specification summary for current-mode MAU

Transmit level characteristics, values referred to trunk (but measured using test load as shown in Figure 68)	Limits (bus powered and/or IS)
Output level (peak-to-peak, see Figure 55) With test load (>2 × nominal Z_o of trunk cable)	≥2,25 V 160 Ω ± 1 %
Maximum output signal distortion; this is overvoltage, ringing and droop (see Figure 55)	±10 %
Quiescent transmitter output; that is transmitter noise (measured over the frequency band 1 kHz to 4 MHz)	≤1 mV (r.m.s.)

Table 71 — Transmit timing specification summary for current-mode MAU

Transmit level characteristics, values referred to trunk (but measured using test load as shown in Figure 68)	Limits (bus powered and/or IS)
Transmitted bit rate	1 Mbit/s ± 0,01 %
Instantaneous bit time	1 µs ± 0,025 µs
Rise and fall times (10 % to 90 % of peak-to-peak signal, see Figure 55)	≤ 20 % T_{bit}
Slew rate (at any point from 10 % to 90 % of peak-to-peak signal)	≤200,0 V/µs
Maximum transmitted bit cell jitter (zero-crossing point deviation, see Figure 71)	± 2,5 % T_{bit}
Transmit enable/disable time (that is, time during which the output waveform may not meet the transmit requirements)	≤ 2,0 T_{bit}

14.4.1 Configuration

Figure 68 shows the configuration which shall be used for testing.

The test configuration for this clause shall be as shown in Figure 68 except where otherwise stated in a specific requirement.

NOTE Test load resistance R_L = 160 Ω ± 1 % as the output is loaded by a series loop of the trunk.

14.4.2 Output level requirements

NOTE Figure 55 shows an example of one cycle of a fieldbus waveform, illustrating some key items from the transmit circuit specification. Only signal voltages are shown; this diagram takes no account of power supply voltages.

A current-mode MAU transmit circuit shall conform to the following output level requirements, all amplitudes being measured at the estimated mid-point between any peaks or troughs in the top and bottom of the waveform ("Mid-point" in Figure 55):

a) the output voltage across the test load after transformer step up/down shall be no less than 2,25 V peak-to-peak, with a load resistance of 160 Ω ± 1 % ("min. o/p" in Figure 55);

b) during transmission, a device shall not suffer permanent failure when a load resistance of ≤1 Ω is applied for 1 s;

c) the output noise from a current-mode MAU which is receiving or not powered shall not exceed 1 mV (r.m.s.), measured differentially over the frequency band 100 kHz to 4 MHz, referred to the trunk;

d) the differential voltage across the test load shall be such that the voltage monotonically changes between 10 % and 90 % of peak-to-peak value. Thereafter, the signal voltage shall not vary more than ±10 % of peak-to-peak value until next transition occurs. This permitted variation shall include all forms of output signal distortion, such as overvoltage, ringing and droop.

14.4.3 Output timing requirements

An MAU transmit circuit shall conform to the following output timing requirements:

a) rise and fall times, measured from 10 % to 90 % of the peak-to-peak signal amplitude shall not exceed 0,2 (see Figure 55);

b) slew rate shall not exceed 200,0 V/µs measured at any point in the range 10 % to 90 % of the peak-to-peak signal amplitude (see Figure 55);

transmitted bit cell jitter shall not exceed ±0,025 Tbit from the ideal zero crossing point, measured with respect to previous zero crossing (see Figure 71);

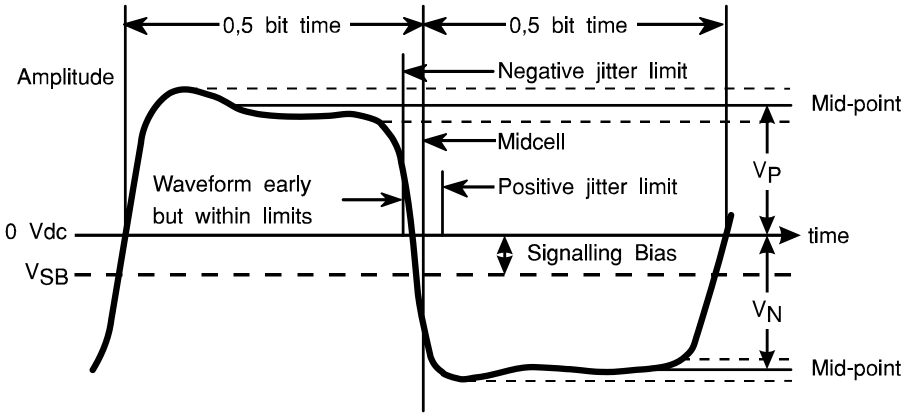


Figure 71 — Transmitted and received bit cell jitter (zero crossing point deviation)

d) the transmit circuit shall turn on, that is the signal shall rise from below the transmit circuit maximum output noise level as specified in 14.4.2 c) to full output level, in less than 2,0 Tbit. The waveform corresponding to the third and later bit times shall be as specified by other subclauses of 14.4;

e) the transmit circuit shall turn off, that is the signal shall fall from full output level to below the transmit circuit maximum output noise level as specified in 14.4.2 c), in less than 2,0 Tbit. The time for the transmit circuit to return to its off-state impedance shall not exceed 4,0 Tbit. For the purposes of testing, this requirement shall be met with the transmit circuit test configuration of 14.4.1.

NOTE This requirement is to ensure that the transition of the transmit circuit from active to passive leaves the line capacitance fully discharged.

14.5 MAU receive circuit specification

14.5.1 General

The requirements of this subclause are summarized in Table 72.

The input impedance of the receive circuit is allowed to be inductive. To prevent that the resistive part of the impedance becomes too high, both the maximum total input impedance and the maximum input resistance are specified in Table 72.

Table 72 — Receive circuit specification summary for current-mode MAU

Receive circuit characteristics (values referred to trunk)	Limits for current mode (bus powered and/or IS)
Input resistance, measured over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz)	≤0,5 Ω
Sensitivity; min. peak-to-peak signal required to be accepted (see Figure 58)	4,0 mA
Noise rejection; max. peak-to-peak noise required to be rejected (see Figure 58)	2,0 mA
Maximum received bit cell jitter (zero crossing-point deviation, see Figure 69)	±0,10 T_{bit}
Input impedance, measured over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz)	≤4,0 Ω

14.5.2 Input impedance

The differential input resistance of a current-mode MAU receive circuit shall not exceed 0,5 Ω, and the differential input impedance of a current-mode MAU receive circuit shall not exceed 4,0 Ω in series with the line over the frequency 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz).This requirement shall be met in the power-off and power-on (not transmitting) states, and in transition between these states. This impedance shall be measured at the inductive coupler, using a sinusoidal current waveform with an amplitude greater than the receiver sensitivity threshold, and lower than 20 mA peak-to-peak.

14.5.3 Receiver sensitivity and noise rejection

An MAU receive circuit shall be capable of accepting an input signal from 4,0 mA peak-to-peak to 20,0 mA peak-to-peak, including overvoltage and oscillation (see “signal level” together with “positive amplitude” and “negative amplitude”, all in Figure 55).

An MAU receive circuit shall not respond to an input signal with a peak-to-peak line current amplitude which does not exceed 2,0 mA (see “noise rejection” in Figure 58).

14.5.4 Received bit cell jitter

The receive circuit shall accept a Manchester encoded signal transmitted in accordance with 14.2 and 14.4. In addition, the receiver shall work properly with signals with the time variation between any two adjacent signal transition points (zero crossing) of ±0,10 Tbit or less. See Figure 71.

NOTE 1 This does not preclude the use of receivers that perform better than this specification.

NOTE 2 Depending on the symbol pattern, the nominal time between zero crossings may be one-half or one bit time.

NOTE 3 There is no requirement to reject a signal with a specified time variation value. The receiver reports an error when the received bit cell jitter exceeds the receiver’s ability to reliably decode signaling.

14.5.5 Interference susceptibility and error rates

See 13.5.5.

14.6 Jabber inhibit

See 13.6.

14.7 Power distribution

14.7.1 General

NOTE 1 A device can optionally receive power via the signal conductors, or be separately powered.

NOTE 2 A device can be certified as intrinsically safe with either method of receiving power.

NOTE 3 This standard does not include requirements for intrinsic safety certification, but seeks to exclude conditions or situations that would prevent intrinsic safety certification.

NOTE 4 A separately powered device can be connected to a powered fieldbus.

NOTE 5 For ease of reference, the requirements of 14.7 are summarized in Table 73.

Table 73 — Network power supply requirements

Network power supply requirements	Limits
Output current	1,0 A r.m.s. ± 5 %
Output frequency	16 kHz ± 0,5 %
Harmonic distortion and noise of supply current	See Figure 72
Output impedance, measured over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz)	≤5 Ω

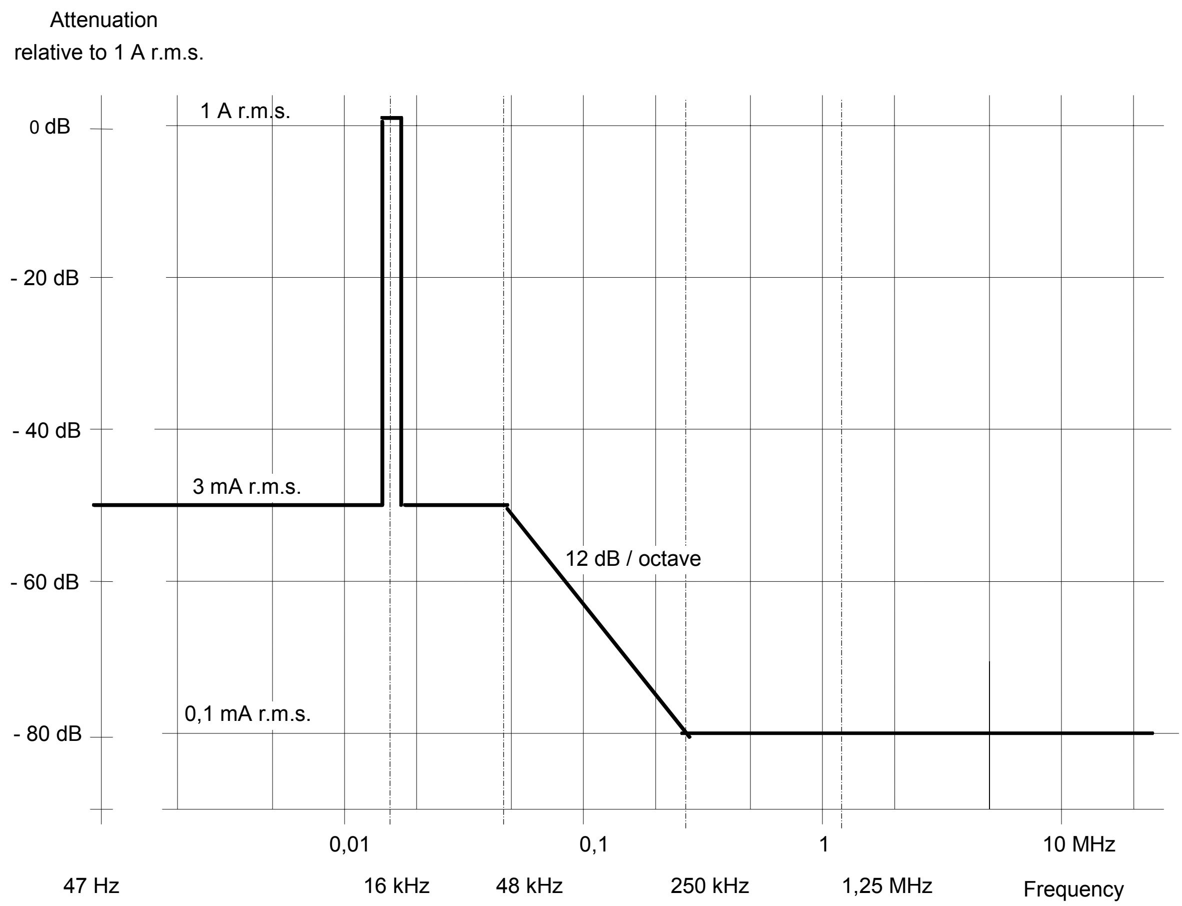


Figure 72 — Power supply harmonic distortion and noise

14.7.2 Powered via signal conductors

A fieldbus device claiming conformance to this clause that is powered via the signal conductors shall conform to the requirements of this clause when powered by a supply with the following specifications.

a) The output current of the power supply shall be a current of 1,0 A r.m.s. ± 5 %.

NOTE 1 The output voltage from the supply is a function of cable loss and power consumed per device. A fieldbus device may be designed to consume one or more standard loads. A standard load is 1,0 W.

NOTE 2 The power supply open-circuit output voltage will be less than the limit specified by the local regulatory agency for the particular implementation.

b) The output impedance of the power supply shall be ≤5 Ω over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz).

c) The power waveform shall be a sinusoid of frequency and maximum harmonic distortion and noise as follows:

   1) 0,1 mA r.m.s. over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz);

   2) 3,0 mA r.m.s. over the frequency range 47 Hz to 48 kHz, with the exception of 16 kHz ± 0,5 %;

   3) levels at other frequencies in accordance with Figure 72.

The device shall not introduce harmonic components of the power frequency larger than 15 µA r.m.s. in the main trunk.

14.7.3 Powered separately from signal

NOTE Power distribution to non-bus powered fieldbus devices is by separate conductors feeding local power supplies, regulators or safety barriers. IS certification may require these conductors to be in a separate cable from the signal conductors, and may also impose more stringent requirements for current levels than specified.

A separately powered fieldbus device claiming conformance to this clause shall drop no more than 200 mV r.m.s. at the power frequency on the signal conductors, nor shall it supply a current of more than 100 µA r.m.s. to the signal conductors when not transmitting.

14.7.4 Electrical isolation

See 13.7.4.

14.8 Medium specifications

14.8.1 Connector

See 13.8.1.

14.8.2 Standard test cable

The cable used for testing fieldbus devices with a current-mode MAU for conformance to the requirements of this clause shall be a single twisted-pair cable with overall shield meeting the following minimum requirements at 25 °C:

a) Z_o at 0,25 f_r (250 kHz) = 80 Ω ± 10 %;

b) Z_o at 1,25 f_r (1,25 MHz) = 80 Ω ± 10 %;

c) maximum attenuation at 0,25 f_r (250 kHz) = 11,0 dB/km;

d) maximum attenuation at 1,25 f_r (1,25 MHz) = 20,0 dB/km;

e) maximum d.c. resistance (per conductor) = 15,0 Ω/km;

f) conductor cross-sectional area (wire size) = nominal 1,5 mm^2.

NOTE The preceding specification is for conformance testing an MAU. Other types of cable may be used in real installations. (See Annex B.) Cables with improved specifications may enable increased trunk length and/or superior interference immunity. Conversely, cables with inferior specifications may be used, subject to length limitations for both trunk and spurs, plus possible non-conformance to the RFI/EMI susceptibility requirements.

14.8.3 Coupler

See 13.8.3.

14.8.4 Splices

See 13.8.4.

14.8.5 Terminator

A terminator shall be located at both ends of the trunk cable, connected from one signal conductor to the other. No connection shall be made between terminator and cable shield.

For test purposes, using the cable specified in 14.8.2, the terminator shall have an impedance value of 80 Ω ± 2 % over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz).

The voltage drop in the terminations shall be less than 0,3 V at 16 kHz.

NOTE In practical implementations with power supplied via the signal conductors, the terminator would be bypassed at power frequencies to minimize power losses.

The terminator shall be non-polarized.

All terminators used for potentially explosive atmospheres shall comply with requirements commensurate with the required approval documents.

14.8.6 Shielding rules

For full conformance to the noise immunity requirements of 14.5, it is necessary to ensure the integrity of shielding throughout the cabling, connectors and couplers by the following means:

a) the coverage of the cable shield shall be greater than 95 % of the full cable length;

b) shielding shall completely cover the electrical circuits in connectors, couplers, and splices.

NOTE Deviation from these shielding rules may degrade noise immunity.

14.8.7 Grounding rules

See 13.8.7.

14.8.8 Color coding of cables

See 11.8.8.

15 Types 1 and 7: Medium attachment unit: dual-fiber optical media

15.1 General

The network medium consists of a pair of fiber optic waveguides providing bidirectionality by use of a separate fiber for each direction of signal propagation. These are known collectively as an elementary optical path.

In all networks involving more than two devices, the fiber optic waveguides conveying signals from the devices are combined by a passive or active star coupler, then rebroadcast on all the waveguides conveying signals to the devices. A point-to-point link between a pair of devices using a single elementary optical path is also possible.

These dual fibers connect to the CPIC of a fieldbus device. The fiber optic transmission system is itself intrinsically safe.

15.2 Bit-rate-dependent quantities

Six bit rates are defined for a medium attachment unit (MAU) for dual-fiber optical media, where the network medium consists of a pair of unidirectional optical waveguides. A given MAU shall support at least one of these bit rates. Table 74 specifies the supported bit rates, and defines symbols for bit-rate-dependent quantities used throughout the remainder of this subclause:

Table 74 — Bit-rate-dependent quantities of high-speed (≥1 Mbit/s) dual-fiber networks

Quantity	Symbol	Unit	Value					
Nominal bit rate	BR	Mbit/s	0,031 25	1	2,5	5	10	25
Maximum deviation from BR	ΔBR		0,2 %	0,01 %				
Nominal bit duration	T_{bit}	µs	32,0	1,0	0,4	0,2	0,1	0,04
Maximum deviation from T_{bit}	ΔT_{bit}	–	0,025 %	0,015 %				
Maximum propagation delay	PD_{max}	T_{bit}	20	40				

The average bit rate shall be BR ± ΔBR, averaged over a frame having a minimum length of 16 octets. The instantaneous bit time shall be Tbit ± ΔTbit.

15.3 Network specifications

15.3.1 Components

An optical MAU operates in a network composed of the following components:

a) optical cable;
b) devices (containing at least one communication element);
c) connectors;
d) optical passive stars;
e) optical active stars.

15.3.2 Topologies

An optical MAU shall operate in a network with a star topology, or in a point-to-point network. Devices are connected to the optical stars or peer devices by elementary optical paths. Optical stars are interconnected by elementary optical paths.

15.3.3 Network configuration rules

An MAU that claims conformance to this clause shall meet the requirements of this clause when used in a network that complies with these rules.

Rule 1: All network devices operate at the same bit rate.

Rule 2: The total number of optical active stars between any two devices shall not exceed four.

Rule 3: The maximum propagation delay between any two devices shall not exceed that specified in Table 74.

NOTE For network efficiency, the part of the turn-around time of any device on the network caused by a PhE between the end of a received frame and the beginning of the transmitted frame containing an associated immediate response should not exceed five bit times, no more than two bit times of which should be due to the MAU. As it is not mandatory to expose either the DLL-PhL interface or the MDS-MAU interface, that part of the turn-around time of a fieldbus device caused by the PhL or the MAU cannot be specified or conformance tested.

Rule 4: The fieldbus shall be capable of continuing operation while a device is being connected or disconnected. Data errors induced during connection or disconnection shall be detected.

Rule 5: The network shall be acyclic, with a single path between any two devices.

Rule 6: The following rules shall apply to systems implemented with redundant media:

a) each channel shall comply with the network configuration rules;
b) there shall not be a non-redundant segment or equipment between two redundant segments;
c) if the devices of the system are configured (by systems management) to transmit on more than one channel simultaneously then the propagation time difference between any two devices on any two channels shall not exceed five bit times;
d) channel numbers and association with the physical transmission media shall be maintained consistently throughout the fieldbus, i.e. channels 1,2,3,... from systems management shall always connect to physical channels 1,2,3,...

15.4 MAU transmit circuit specifications

NOTE For ease of reference, the requirements of 15.4 are summarized in Table 75 and Table 76.

15.4.1 Test configuration

The output level, spectral and timing specifications are measured at the end of a 1 m standard test fiber connected to the CPIC.

15.4.2 Output level specification

An optical MAU transmit circuit shall conform to the following output level and spectral requirements. Level and spectral characteristics are measured at a temperature of 25 °C. Output level is the effective launch power of a Hi level. Output level specification is shown in Table 75.

Table 75 — Transmit level and spectral specification summary

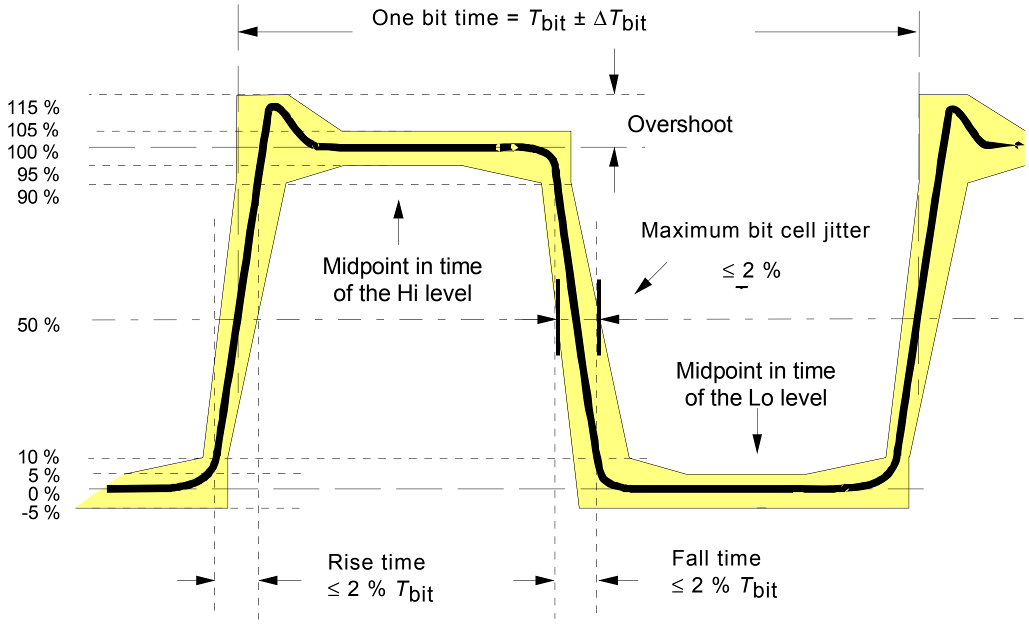
Transmit level and spectral characteristics (values referred to the CPIC with standard test fiber)	Limits, using 62,5/125 μm fiber
Peak emission wavelength (λp)	(850 ± 30) nm
Typical half-intensity wavelength (Δλ)	≤50 nm
Effective launch power Hi level	(–11,5 ± 1,5) dBm
Overshoot of transitions	≤15 % effective power
Extinction ratio	≥20:1

15.4.3 Output timing specification

An optical MAU transmit circuit shall conform to the following output timing requirements (see Figure 73). Timing characteristics are measured at a temperature of 25 °C. The output timing specification is shown in Table 76.

Table 76 — Transmit timing specification summary

Transmit timing characteristics (values referred to the CPIC with standard test fiber)	Limits
Transmitted bit rate	BR ± ΔBR
Instantaneous bit time	$T_{bit} \pm \Delta T_{bit}$
Rise and fall times (10 % to 90 % of peak-peak signal)	$\leq$ 2,0 % T_{bit}
Difference between rise and fall times	$\leq$ 0,5 % T_{bit}
Maximum transmitted bit cell jitter	± 2,0 % T_{bit}



NOTE 0 % effective power is the Lo level state power level.

100 % effective power is the Hi level state power level.

Figure 73 — Optical wave shape template

15.5 MAU receive circuit specifications

15.5.1 General

The requirements of this subclause are summarized in Table 77.

Table 77 — Receive circuit specification summary

Receive circuit characteristics (values referred to the CPIC with standard test fiber)	Limits	
	Low sensitivity system	High sensitivity system
Receiver operating range	–30,0 dBm to –10,0 dBm	–40,0 dBm to –20,0 dBm
Maximum received bit cell jitter	±14 % Tbit	

15.5.2 Receiver operating range

The specified receiver sensitivity range is

a) –30,0 dBm to –10,0 dBm effective power for low sensitivity;

b) –40,0 dBm to –20,0 dBm effective power for high sensitivity.

15.5.3 Maximum received bit cell jitter

The receive circuit shall accept a Manchester encoded signal transmitted in accordance with 15.4. In addition, the receiver shall accept signals with time variation between two adjacent signal transition points (50 % crossing) of ±14,0 % Tbit or less.

NOTE 1 This does not preclude the use of receivers that perform better than this specification but in accordance with the tolerance of the received bit cell jitter of the MDS (see 9.2.6).

NOTE 2 Depending on the symbol pattern, the nominal time between 50 % crossings may be either 1,0 Tbit or 0,5 Tbit.

15.5.4 Interference susceptibility and error rates

15.5.4.1 Low-speed (31,25 kbit/s)

NOTE When the fieldbus is operating in a variety of standard noise environments, the probability that an Application Layer User Data Unit contains an undetected error, due to operation of the conveying Physical and DLL entities, should be less than 1 in 6×10^9 (one error in 20 years at 10 messages/s). A communication element is regarded as conforming to this theoretical requirement when it meets the following interference susceptibility requirements. These are specified by a detected frame error rate which is derived by using a ratio of detected to undetected errors of 10^6.

A communication element which includes an optical MAU operating at 31,25 kbit/s with frames containing 32 random user data bits, at an average of 10 messages per second, with signals of –25 dBm, shall produce no more than 10 detected frame errors in 60 000 frames during operation in the presence of electromagnetic or electrical interference environments as follows:

a) 10 V/m electromagnetic field as specified in IEC 61000-4-3 at severity level 3;
b) electrical fast transient as specified in IEC 61000-4-4 at severity level 3.

15.5.4.2 High-speed (≥1 Mbit/s)

NOTE When the fieldbus is operating in a variety of standard noise environments, the probability that an Application Layer User Data Unit contains an undetected error, due to operation of the conveying Physical and DLL entities, should be less than 1 in 10^{12} (one error in 20 years at 1 600 messages/s). A communication element is regarded as conforming to this theoretical requirement when it meets the following interference susceptibility requirements. These are specified by a detected frame error rate which is derived by using a ratio of detected to undetected errors of 10^6.

A communication element which includes an optical MAU operating at ≥1 Mbit/s with frames containing 64 random user data bits, at an average of 1 600 messages/s, with signals of -25 dBm, shall produce no more than 6 detected frame errors in 100 000 frames during operation in the presence of electromagnetic or electrical interference environments as follows:

a) 10 V/m electromagnetic field as specified in IEC 61000-4-3 at severity level 3;
b) electrical fast transient as specified in IEC 61000-4-4 at severity level 3.

15.5.4.3 Common

The error rate specifications shall also be satisfied after, but not during, operation in the following noise environments:

a) 8 kV electrical discharge to exposed metalwork as specified in IEC 61000-4-2 at severity level 3. If the device suffers temporary loss of function or performance as a result of this test, it shall recover from any such loss without operator intervention within 3 s after the end of the test;
b) high frequency disturbance tests as specified in IEC 60255-22-1:1988, 3.1 (test voltage class III, 2,5 kV and 1 kV peak values of first half-cycle in longitudinal and transverse mode respectively). If the device suffers temporary loss of function or performance because of this test it shall recover from any such loss without operator intervention within 3 s after the end of the test.

15.6 Jabber inhibit

The MAU shall contain a self-interrupt capability to inhibit transmitted signals from reaching the medium. Hardware within the MAU (with no external message other than the detection of output signals or leakage via the transmit function) shall provide a window of between 3 750 and 7 500 Tbit, during which time a normal frame may be transmitted. If the frame length exceeds this duration, the jabber inhibit function shall inhibit further output signals from reaching the medium and shall disable echo on the RxS line (see 10.2.2.2) to indicate jabber detection to the MDS.

For a data rate of 31,25 kbit/s, the MAU shall reset the self-interrupt function after a period of 3 s ± 50 %.

NOTE 1 This inhibits bus traffic for no more than 8 % (≈ 1/12,5) of the available time.

For a data rate of 1 Mbit/s or greater, the MAU shall reset the self-interrupt function after a period of 500 000 Tbit ± 50 %.

NOTE 2 This inhibits bus traffic for no more than 3 % (≈ 1/32) of the available time.

15.7 Medium specifications

15.7.1 Connector

Cable connectors, if used, shall be in accordance with this standard (see Annex A). Permanent terminations (splices) may also be used.

15.7.2 Standard test fiber

The cable used for testing fieldbus devices or optical active stars with an optical MAU, for conformance to the requirements of this clause, shall be a 1 m fiber optic cable with two silica fiber optic waveguides. The characteristics of those waveguides shall be compatible with IEC 60793 [fiber type: A1b (62,5/125 µm)] as follows:

- core diameter (µm): 62,5 ± 3
- cladding diameter (µm): 125 ± 3
- core/cladding concentricity (%): ≤6
- no circularity core (%): ≤6
- no circularity cladding (%): ≤2
- external primary coating diameter (µm): 250 ± 15
- numerical aperture: 0,275 ± 0,015
- attenuation for 850 nm (dB/km): ≤3,0
- bandwidth for 850 nm (MHz x km): ≥200

NOTE Alternate test fibers are allowed. Operation using a 50 µm or 100 µm alternate test fiber is described in Annex E.

15.7.3 Optical passive star

NOTE For more information, see Annex C.

15.7.4 Optical active star

15.7.4.1 Definition

An opto-electronic device or module in an optical communication system, that receives a signal, amplifies it and retransmits it (retiming is optional).

15.7.4.2 Operating

Three types of link shall be considered.

a) Link between two optical active stars

Any frame coming directly from an optical active star and reaching an optical access of another optical active star is retransmitted without feedback (the access which receives the frame does not retransmit that frame).

b) Link between an optical active star and a fieldbus device

Any frame coming from an optical active star and reaching a fieldbus device is received and not retransmitted. Any frame coming from a fieldbus device and reaching an optical active star is retransmitted without feedback.

c) Link between an optical passive star and an optical active star

Any frame coming from an optical passive star and reaching an optical active star is retransmitted without feedback. A passive star reflects all frames by design. An optical active star shall not retransmit the feedback signs of an optical passive star.

Regenerative functions

An optical active star restores signals to standard transmit power levels. The timing characteristics (jitter) can be regenerated or not; that function is optional.

15.7.4.3 Transmit and receive characteristics

The following characteristics are given ...

a) Level characteristics

Transmit and receive level specifications are the same as those of an optical MAU (15.4.2 and 15.5.2). Level and spectral characteristics are measured at a temperature of 25 °C. These specifications are summarized in Table 78.

Table 78 — Transmit and receive level and spectral specifications for an optical active star

Transmit level and spectral characteristics (values referred to the CPIC with standard test fiber)	Limits, with 62,5/125 µm fiber	
Peak emission wavelength (λp)	(850 ± 30) nm	
Typical half-intensity wavelength (Δλ)	≤50 nm	
Extinction ratio	≥20:1	
Effective launch power Hi level	(–11,5 ± 1,5) dBm	
Receiver operating range (effective power)	Low sensitivity system	High sensitivity system
	–30,0 dBm to –10,0 dBm	–40,0 dBm to –20,0 dBm

b) Timing characteristics

Transmit and receive timing specifications of an optical active star concern (see Table 79):

– rise and fall times of the transmitted signal;

– temporal deformation of signals due to an optical active star.

Timing characteristics are measured at a temperature of 25 °C. For optical active stars that have a timing regenerative function, the timing characteristics are the same as those of an optical MAU.

Table 79 — Timing characteristics of an optical active star

Timing characteristics (values referred to the CPIC)	Limits
Rise and fall times of transmitted signals (10 % to 90 % of peak-peak signal)	≤2 % Tbit
Maximum temporal deformation between optical input ports and optical output ports (see Note 1)	±3 % Tbit
Propagation time of a data bit between an optical input port and any output ports for an active star with timing regenerative function (see NOTE 2)	≤2 Tbit
Maximum transmitted bit cell jitter for an optical active star with timing regenerative function (see Note 2)	±2,0 % Tbit
NOTE 1 The temporal deformation due to an optical active star is the temporal difference of width of a same physical bit, bit pattern, waveform, or other appropriate term. NOTE 2 Only for optical active stars with timing regenerative function.	

16 Type 1: Medium attachment unit: 31,25 kbit/s, single-fiber optical medium

16.1 General

The network medium consists of a set of bidirectional single-fiber optic waveguides, each known as an elementary optical path.

In all networks involving more than two devices, the fiber optic waveguides conveying signals from the devices are combined by a reflective passive star coupler, where the received signals are retransmitted on all the fiber optic waveguides to the devices. A point-to-point link between a pair of devices using a single elementary optical path is also possible.

These bidirectional single fibers connect to the CPIC of a fieldbus device. The fiber optic transmission system is itself intrinsically safe.

16.2 Transmitted bit rate

The transmitted bit rate, BR ± ΔBR, shall be 31,25 kbit/s ± 0,2 %, averaged over a frame having a minimum length of 16 octets. The instantaneous bit time, Tbit ± ΔTbit, shall be 32 μs ± 0,025 %.

16.3 Network specifications

16.3.1 Components

See 15.3.1.

16.3.2 Topologies

See 15.3.2.

16.3.3 Network configuration rules

An MAU that claims conformance to this clause shall meet the requirements of this clause when used in a network that complies with these rules.

The rules are the same as 15.3.3, except as follows.

16.4 MAU transmit circuit specifications

NOTE For ease of reference, the requirements of 16.4 are summarized in Table 80 and Table 76.

16.4.1 Test configuration

See 15.4.1.

16.4.2 Output level specification

An optical MAU transmit circuit shall conform to the following output level and spectral requirements. Level and spectral characteristics are measured at a temperature of 25 °C. Output level is the effective launch power of a Hi level. Output level specification is shown in Table 80.

Table 80 — Transmit level and spectral specification summary

Transmit level and spectral characteristics (values referred to the CPIC with standard test fiber)	Limits for 31,25 kbit/s (100/140 μm fiber)
Peak emission wavelength (λp)	(850 ± 30) nm
Typical half-intensity wavelength (Δλ)	≤50 nm
Effective launch power Hi level	(–13,5 ± 1,0) dBm
Overshoot of transitions	≤15 % effective power
Extinction ratio	≥20:1

16.4.3 Output timing specification

An optical MAU transmit circuit shall conform to the following output timing requirements (see Figure 73). Timing characteristics are measured at a temperature of 25 °C. The output timing specification is shown in Table 76.

16.5 MAU receive circuit specifications

16.5.1 General

The requirements of 16.5 are summarized in Table 77, but relative to the standard 100/140 µm test fiber of this clause.

16.5.2 Receiver operating range

The specified receiver sensitivity range is

a) –30,0 dBm to –12,5 dBm effective power for low sensitivity;

b) –40,0 dBm to –20,0 dBm effective power for high sensitivity.

16.5.3 Maximum received bit cell jitter

See 15.5.3.

16.5.4 Interference susceptibility and error rates

See 15.5.4.1 and 15.5.4.3 .

16.6 Jabber inhibit

The requirement is the same as 15.6, except as follows:

The MAU shall reset the self-interrupt function after a period of 3 s ± 50 %.

NOTE This inhibits bus traffic for no more than 8 % (≈ 1/12,5) of the available time.

16.7 Medium specifications

16.7.1 Connector

See 15.7.1

16.7.2 Standard test fiber

Silica fiber optic waveguide whose nominal characteristics are compatible with IEC 60793 [fiber type: A1d (100/140 µm)].

The cable used for testing fieldbus devices or optical active stars with an optical MAU, for conformance to the requirements of this clause, shall be a 1 m fiber optic cable with one fiber optic waveguides, whose characteristics are as follows:

- core diameter (µm): 100 ± 5
- cladding diameter (µm): 140 ± 4
- core/cladding concentricity (%): ≤6
- no circularity core (%): ≤6
- no circularity cladding (%): ≤4
- numerical aperture: 0,26 ± 0,03
- attenuation for 850 nm (dB/km): ≤4,0
- bandwidth for 850 nm (MHz x km): ≥100

NOTE Alternate test fibers are allowed. Operation using a 50 µm or 62,5 µm alternate test fibers is described in annex E.

16.7.3 Optical passive star

NOTE For more information, see Annex C.

16.7.4 Optical active star

16.7.4.1 Definition

Subclause 15.7.4.1 applies.

16.7.4.2 Operating

Subclause 15.7.4.2 applies.

16.7.4.3 Transmit and receive characteristics

16.7.4.3.1 Level characteristics

Transmit and receive level specifications are the same as those of an optical MAU (see 16.4.2 and 16.5.2). Level and spectral characteristics are measured at a temperature of 25 °C. These specifications, summarized in Table 81.

Table 81 — Transmit and receive level and spectral specifications for an optical active star

Transmit level and spectral characteristics (values referred to the CPIC with standard test fiber)	Limits, with 100/140 μm fiber	
Peak emission wavelength (λp)	(850 ± 30) nm	
Typical half intensity wavelength (Δλ)	≤50 nm	
Extinction ratio	≥20:1	
Effective launch power Hi level	(–13,5 ± 1,0) dBm	
Receiver operating range (effective power)	Low sensitivity system	High sensitivity system
	–30,0 dBm to –12,5 dBm	–40,0 dBm to –20,0 dBm

16.7.4.3.2 Timing characteristics

The timing characteristics of 15.7.4.3 apply.

17 Type 1: Medium attachment unit: radio signaling

17.1 General

The conceptual radio MAU corresponds approximately to the analog and RF portions of a real radio, including aspects related to carrier and intermediate frequencies, types of modulation, modulation indices, transmit signal filtering and shaping, receive signal filtering, signal strength assessment, signal quality assessment, and recovery of clock and data from received signaling. It also includes all digital aspects related to the configuration of these analog-world aspects. It does not include strictly digital data aspects of a radio such as coding that require binary interpretation of the signaling, even though the clock and data recovery functions of the MAU may use expected aspects of that coding (e.g., expected Manchester or 8b/10b code transitions and DC balance) in the recovery process.

The radio environment is space- and time-varying, rendering long-term prediction of properties almost impossible. Real protocols that coordinate transmission and reception may adapt to this variance in real time by changing operating modes dynamically (but in a coordinated manner) to achieve their communications objectives. Therefore this specification provides minimum requirements in a form suitable to that adaptation.

17.2 Transmit signaling rate

The radio MAU shall be capable of transmitting at a signaling (i.e., Ph-symbol) rate that is within 1 % of any configured nominal signaling rate within its design range, with an actual variance in that symbol timing of no more than 0,1 % between any arbitrarily-selected two symbols of a transmission, measured over any transmission but not including the first or last four symbols of the transmission.

The relationship between signaling (baud) rate and maximum bit rate of the radio may vary transmission to transmission as the employing protocol entities adapt to the radio environment and the criticality, urgency or other QoS aspects of the information to be communicated, and of the needs of those protocol entities. The actual bit rate may vary within the message, as occurs in the ETSI DECT standards, where the initial part of the message uses only the 1 bit/bd signaling constellation while the latter part of the message may use a richer constellation, based on data in the message header.

Common ratios of bit rate to baud rate in modems, which determine the required signaling constellation, are

- 1 bit/bd, also known as 2-ary signaling, which is historically the most common
- 2 bit/bd, also known as 4-ary signaling (e.g., QPSK, quadrature phase shift keying)
- 3 bit/bd, also known as 8-ary signaling (e.g., 8PSK)
- 4 bit/bd, also known as 16-ary signaling (e.g, QAM, quadrature amplitude modulation)

Precoding of the digital information before transmission, e.g., for forward error correction or in Manchester or biphase or 8bit/10bd coding, can lower the effective bit rate of the Ph-entity, but does not itself affect the signaling constellation of the radio.

17.3 Modulation

17.3.1 General

The radio MAU shall support at least one of the following types of modulation:

a) FSK (frequency shift keying);
b) GFSK (FSK with Gaussian shaping to reduce spectral content of the signal);
c) MSK (minimum phase shift keying);
d) GMSK (MSK with Gaussian shaping to reduce spectral content of the signal).

The radio MAU also may support other types of modulation, including:

e) OOK (on-off keying, a form of amplitude modulation).

17.3.2 Gaussian shaping (filtering)

Many modulation methods use a Gaussian low-pass filter prior to transmission to smooth the abrupt transitions between different signaling states, thereby reducing the energy in the higher-frequency components of the modulation spectrum, improving its spectral content in exchange for limited inter-symbol interference.

The untruncated impulse response ***h***(*t*) of a Gaussian filter is

$$h(t) = \frac{1}{\sqrt{2\pi \times \delta \times T}} e^{\frac{-t^2}{2\times\delta^2\times T^2}} ,$$

where

$\delta = \frac{\sqrt{\ln(2)}}{2\pi \times B \times T}$;

B is the 3 dB bandwidth of the filter;

T is the symbol duration;

giving ***BT*** as the normalized bandwidth of the filter (in Hz·s).

Pulses such as that produced by a Gaussian low-pass filter have infinite duration (albeit at infinitesimal energy for most of that duration). To make communications with such pulses practical, they are convolved with a rectangular filter that truncates their extent:

$$g(t) = \mathrm{rect}(\frac{t}{T}) \otimes h(t)$$

where $\mathrm{rect}(\frac{t}{T}) = \begin{cases} \frac{1}{T} & \text{for } |t| < \frac{T}{2} \\ 0 & \text{otherwise} \end{cases}$

and $\otimes$ denotes convolution.

17.3.3 FSK

In frequency shift keying, a nominal carrier 'center' frequency $f_{carrier}$ is modulated before transmission by subtracting or adding a deviation frequency (Δf) that is a specified fraction of the signaling rate. The maximum deviation, limit to limit (i.e., $2 \times \max \Delta f$), when divided by the signaling rate, is known as the *modulation index*, h.

A radio MAU that supports FSK shall support 2-ary modulation with a modulation index of

- $h = \frac{2 \times \Delta f}{SR} = 1{,}0 \pm 10\%$. Other greater or lesser modulation indices also may be supported.

  Modulation with more bits per baud, such as 4-ary and 8-ary FSK, also may be supported.

NOTE 1 This modulation index corresponds to the conventional estimate of channel capaicty as 1 bit/s/Hz.

For 2-ary FSK modulation, a '0' MDS-MAU symbol shall be represented by the frequency ($f_{carrier} - \Delta f$) and a '1' MDS-MAU symbol shall be represented by the frequency ($f_{carrier} + \Delta f$), where $\Delta f = h/2$.

NOTE 2 If other parts of the Ph-layer provide transparent coding, so that data bits at the DL-Ph interface are unchanged at the DCE-MAU interface, this results in a '1' data bit being represented as a greater frequency than a '0' data bit.

17.3.4 GFSK

In Gaussian frequency shift keying, the FSK modulation of 17.3.3 is shaped by the Gaussian filter of 17.3.2 prior to transmission to reduce its spectral content (that is, to narrow the part of the spectrum where most of the information is conveyed). Typical BT values for the Gaussian filter are:

- $BT = 0{,}5 \pm 10\%$, and
- $BT = 1{,}0 \pm 10\%$

A radio MAU that supports FSK shall support at least one of these two BT values. Other normalized bandwidths also may be supported.

17.3.5 PSK

In phase shift keying, a nominal carrier of frequency $f_{carrier}$ is phase-modulated before transmission by advancing a phase deviation ($\Delta\phi$) that is a specified fraction of the signaling rate and the symbol to be transmitted. The maximum deviation (i.e., $\max \Delta\phi$), is known as the *modulation index*, h.

A radio MAU that supports PSK shall support 2-ary modulation with modulation indices of

- $h = \max \Delta\phi = \pi$ radians

where a one is signaled by the maximum phase advance and a zero by half that phase advance. Other greater or lesser extents of maximum phase advance also may be supported. Modulation with more bits per baud, such as 4-ary and 8-ary PSK, also may be supported.

For 2-ary PSK modulation, a '0' DCE-MAU symbol shall be represented by the frequency ($\Phi_{carrier} + \min \Delta\phi$) and a '1' DCE-MAU symbol shall be represented by the frequency $\Phi_{carrier} + \max \Delta\phi$).

NOTE If other parts of the Ph-layer provide transparent coding, so that data bits at the DL-Ph interface are unchanged at the DCE-MAU interface, this results in a '1' data bit being represented as a greater phase advance than a '0' data bit.

17.3.6 GMSK

In Gaussian minimal (phase-) shift keying, the PSK modulation of 17.3.5 is shaped by the Gaussian filter of 17.3.2 prior to transmission to reduce its spectral content (that is, to narrow the part of the spectrum where most of the information is conveyed).

Typical BT values for the Gaussian filter are:

- $BT = 0{,}3 \pm 10\%$,
- $BT = 0{,}5 \pm 10\%$, and
- $BT = 1{,}0 \pm 10\%$

A radio MAU that supports GMSK shall support at least one of these three BT values. Other normalized bandwidths also may be supported.

17.4 Network specification

17.4.1 Components

A radio MAU operates in a network composed of the following components:

a) devices (containing at least one communication element);

b) antennas and any connecting cables.

NOTE An antenna may be integrated into a device.

17.4.2 Topologies

The concept of connection topology does not apply to the space-time fabric through which electromagnetic waves propagate. Therefore there are no MAU-induced constraints on patterns of MAU communications other than those induced by nature and sometimes codified as "the laws of physics". Chief among these are attenuation and reflections (multi-path), as well as proximity-induced affects of other nearby radios.

17.4.3 Network configuration rules

A low speed radio MAU shall be required to conform to the requirements of this clause when used in a network that complies with these rules.

Rule 1: All communicating elements on one fieldbus using a radio medium shall be capable of operating at a common baud rate and shall use the same physical or logical radio channel.

Rule 2: More than one independent radio medium fieldbus may operate in the same physical location, but then each separate network shall operate on a different physical or logical radio channel.

Rule 3: A specific radio medium fieldbus radio channel shall define a geographical area (or "CELL") over which that network will operate and no other network using the same radio channel shall operate in that cell. Networks in adjacent cells shall use different radio channels and it shall be possible to implement networks in non-adjacent cells using the same frequency. Non-adjacent cells using class 1 receivers whose geographic centers are less than 40 m apart should use different radio channels. Non-adjacent cells using class 2 receivers whose geographic centers are less than 400 m apart should use different radio channels. Non-adjacent cells using class 3 receivers whose geographic centers are less than 4 000 m apart should use different radio channels.

NOTE 1 See Figure 74 for the cellular structure using radio medium fieldbus networks covering a large industrial site. Examples of the topologies are given in Figure 75 and Figure 76. These three figures are included for explanatory purposes and do not imply a particular implementation.

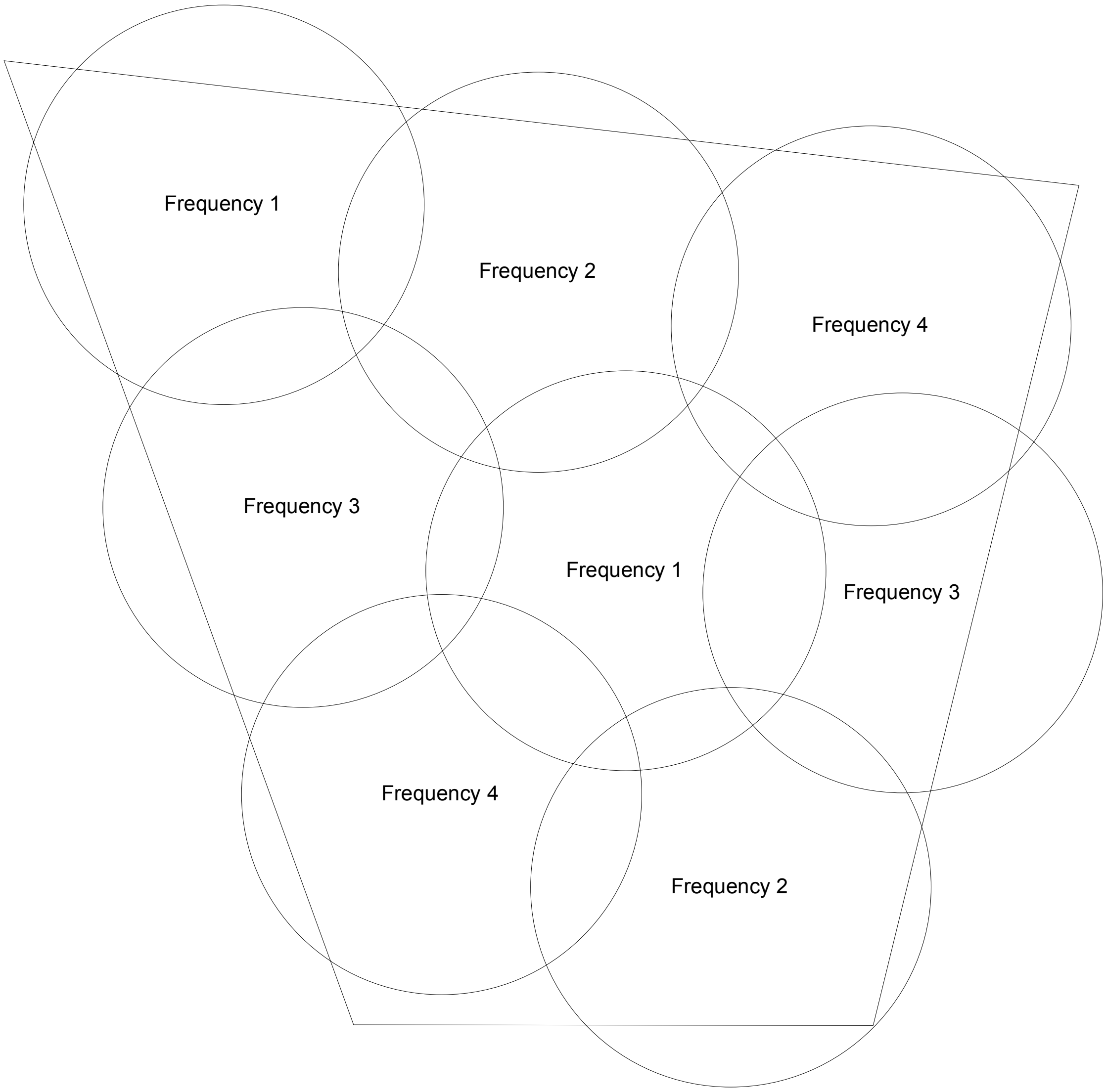


Figure 74 — Cellular radio topology and reuse of frequencies

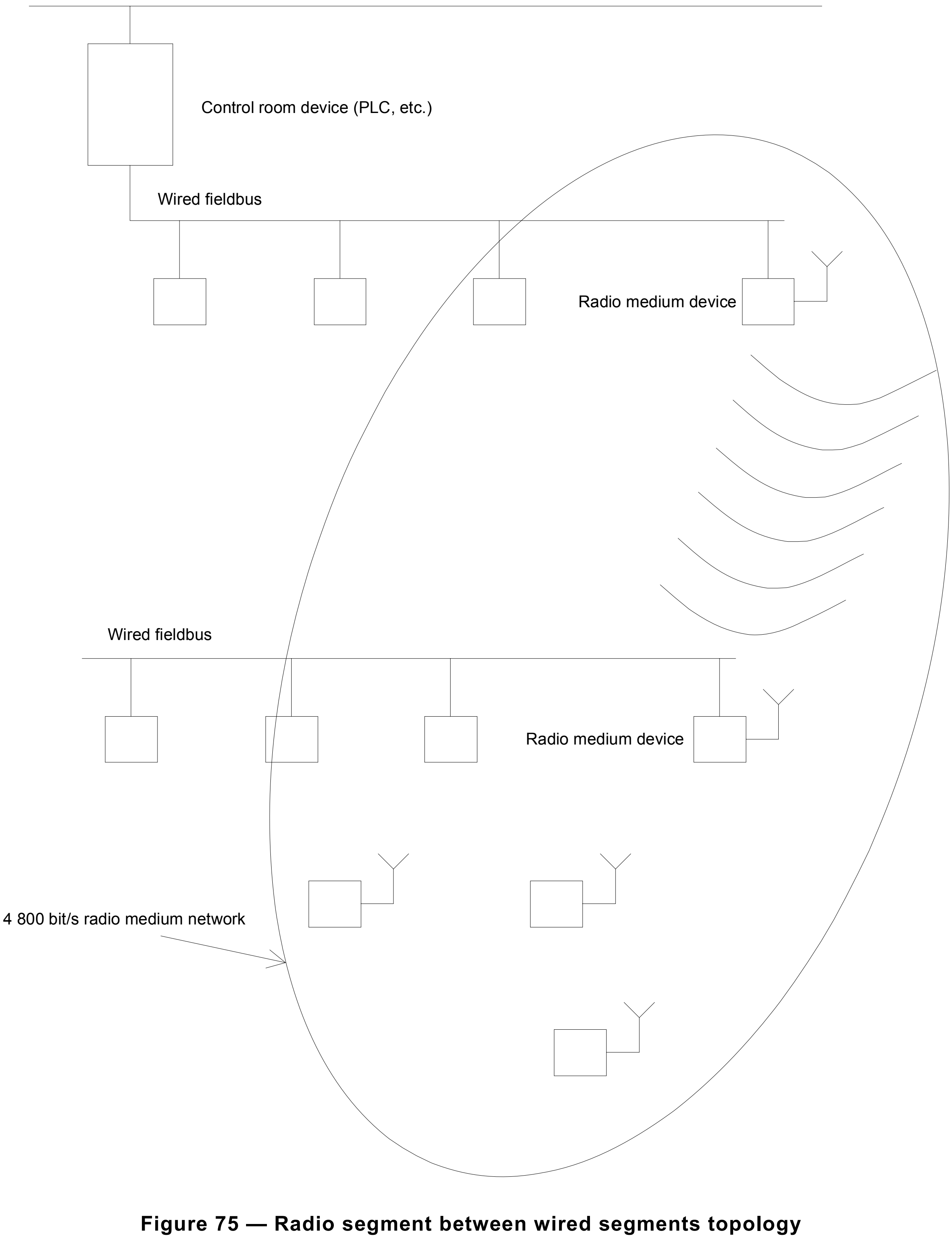


Figure 75 — Radio segment between wired segments topology

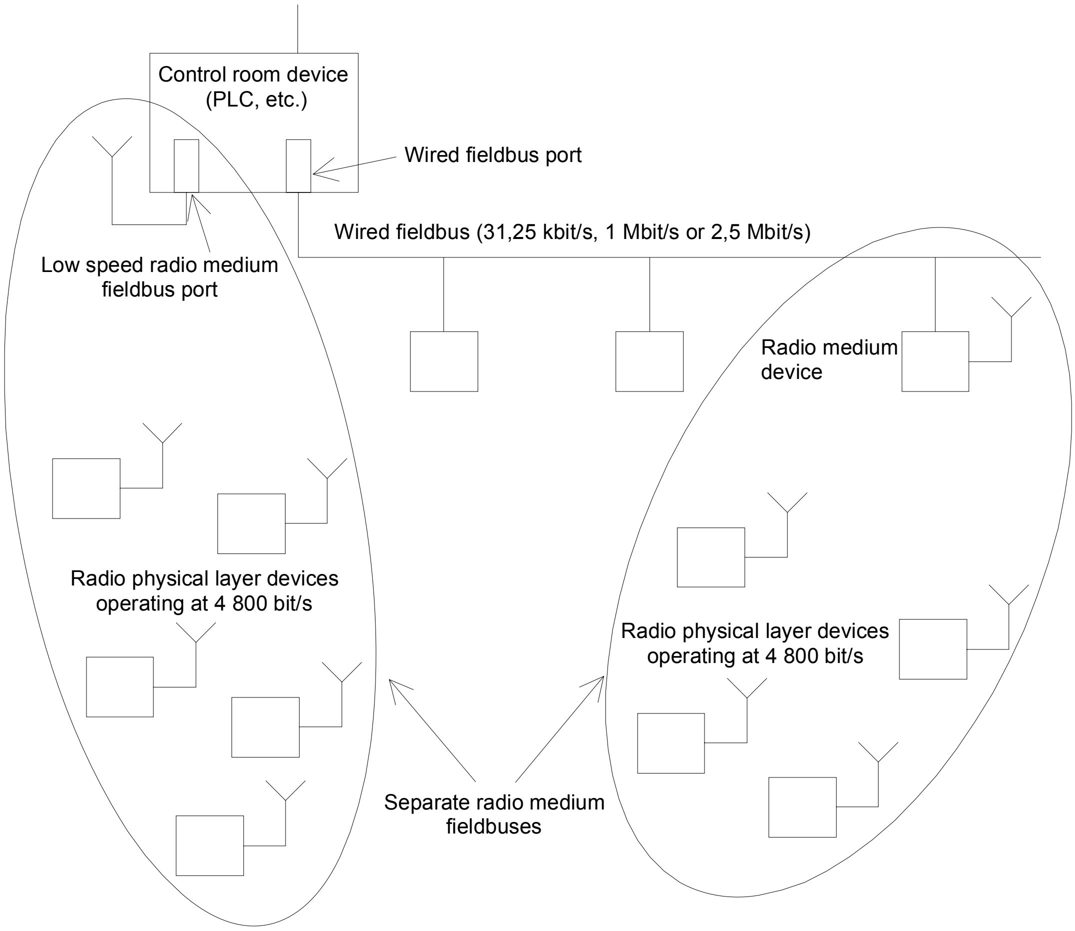


Figure 76 — Mixed wired and radio medium fieldbus topology

NOTE 2 The number and frequencies of channels available depend on the frequency allocations in each country and within that country the use of the radio spectrum in the locality of the specific installation. Due to historic use of radio spectrum it will not be possible to harmonise international frequencies for fieldbus use for some time, especially at the lower frequencies needed for technical reasons in the process industries; therefore, it is not possible to specify the radio channels in this standard. Implementers should contact their local radio regulatory body for a copy of the relevant documentation covering channel availability and specifications for the use of those channels.

NOTE 3 This standard does not define how the carrier is generated, changed or communicated, as this will be application-specific, depending on range, power supply requirements and local regulations.

NOTE 4 Network design should take into account the different speed at which the low speed radio medium fieldbus devices and other medium fieldbus devices are operating in a particular implementation.

Rule 4: It shall be possible to use radio repeaters to extend the range of a specific installation. These repeaters may use different physical or logical radio channels, or may use store-and-forward functionality to repeat on the same channel after complete reception of the message to be repeated.

17.5 Antennas

The radio medium fieldbus MAU shall be suitable for use with a single combined antenna connection for both the receiver and transmitter.

NOTE Any type of antenna can be used subject to the local radio regulations in force at any one installation. This includes directional antennas, remote, mast mounted antennas. The local regulations may set an upper limit to the Effective Radiated Power (ERP) in any one direction that may be violated if directional antennas are used. An antenna may be shared by more than one device or service providing it will handle all required frequencies adequately.

17.6 Jabber inhibit

The MAU shall contain a self-interrupt capability to inhibit transmitted signals from reaching the medium. Hardware within the MAU (with no external message other than the detection of output signals or leakage via the transmit function) shall provide a window of at least the duration of 4 000 bd during which time a normal frame may be transmitted. If the frame length exceeds this duration, the jabber inhibit function shall inhibit further output signals from reaching the medium and shall indicate jabber detection to the MDS or DTE.

The MAU shall reset the self-interrupt function after a period of 400 kbd ± 50 %.

NOTE This inhibits bus traffic for no more than 1 % of the available time.

17.7 Common air interface

17.7.1 Channel frequencies

Channel carrier frequencies to be used for the radio medium fieldbus shall be defined by the regulations and type approval documents of the country of final end use of specific implementations and are therefore not part of this standard, but could be added as a separate technical report summarising the requirements for specific countries. Where frequency hopping spread spectrum techniques are used, they shall conform to those same regulations and type approval documents.

Channel frequency accuracy will be as specified by the local radio regulations or giving a delta of less than or equal to ±0,002 % of the nominal center frequency between this frequency and the actual center frequency over the supply voltage and temperature ranges of the implementation, whichever is the greater accuracy. Automatic frequency control may be used at the receiver.

17.7.2 Transmitter characteristics

These shall depend on the local regulations and type approval specifications in force in the country of end use. It shall be possible to limit the effective radiated power from the antenna to the maximum allowable under the local regulations.

NOTE This is required to ensure that a nearby radio device, whether similar or not but operating under the local radio frequency regulations on a nearby frequency at maximum power allowed, does not swamp a lower power signal from a fieldbus device.

17.7.3 Receiver performance

NOTE 1 The receiver sensitivity requirement will depend on the local radio regulations for any one installation; however, this specification contains the minimum requirement.

A receiver in a device adhering to this standard shall conform to one of the following classes of receiver performance.

NOTE 2 These classes ensure that vendors give the users a clear indication of the applicability of a particular device or set of devices to a specific application.

NOTE 3 This subclause covers performance of the radio receiver subsystem only in the face of typical radio interference imposed via the receiver input stage. It does not cover EMC related performance of the complete fieldbus device.

Class 1

A test set-up shall be used consisting of a 40 m line of site range from transmitter to receiver. The Effective Radiated Power (ERP) from the transmitter antenna shall be set at the maximum allowed in the local regulations, for the channel in use and a 20 dB loss total shall be set in the receiving antenna to the receiver's antenna connector.

a) With this set-up, a communication element operating with frames containing 80 random user data bits with maximum frame rate, shall produce no more than 10 detected errors in 1 000 frames after any forward error correction, under the following noise environments imposed on the channel.
   1) 10 V/m electromagnetic field as specified in IEC 61000-4-3 at severity level 3, but not with a frequency that is within 25 kHz of the center channel frequency of the radio medium fieldbus network under test.
   2) Electrical fast transients as specified in IEC 61000-4-4 at severity level 3.

The above error rate specification shall also be satisfied after, but not during the following noise environments:

i) 8 kV electrostatic discharge to exposed metalwork as specified in IEC 61000-4-2 at severity level 3. If the device suffers temporary loss of function as a result of this test it shall recover from any such loss without operator intervention within 3 s after the end of the test;

ii) high frequency disturbance test as specified in IEC 60255-22-1:1988, test voltage class III (2,5 kV and 1 kV peak values of first half cycle in longitude and traverse mode respectively).

b) With the same test set-up, a communication element operating with frames containing 80 random user data bits with maximum frame rate, shall produce no more than 10 detected errors in 60 000 frames under the following condition: after any forward error correction, when an unmodulated, or asynchronously modulated, interfering carrier wave signal at any frequencies within the ranges and at the corresponding field strengths as shown in Table 82 is applied.

Class 2

A test set-up shall be used consisting of a 400 m line of site range from transmitter to receiver. The Effective Radiated Power (ERP) from the transmitter antenna shall be set at the maximum allowed in the local regulations, for the channel in use and a 20 dB loss total shall be set in the receiving antenna to the receivers antenna connector.

a) With this set-up, a communication element operating with frames containing 80 random user data bits with maximum frame rate, shall produce no more than 10 detected errors in 1 000 frames after any forward error correction, under the following noise environments imposed on the channel.

1) 10 V/m electromagnetic field as specified in IEC 61000-4-3 at severity level 3, but not with a frequency that is within 25 kHz of the center channel frequency of the radio medium fieldbus network under test.

2) Electrical fast transients as specified in IEC 61000-4-4 at severity level 3.

The above error rate specification shall also be satisfied after, but not during the following noise environments:

i) 8 kV electrostatic discharge to exposed metalwork as specified in IEC 61000-4-2 at severity level 3. If the device suffers temporary loss of function as a result of this test it shall recover from any such loss without operator intervention within 3 s after the end of the test;

ii) high frequency disturbance test as specified in IEC 60255-22-1:1988, test voltage class III (2,5 kV and 1 kV peak values of first half cycle in longitude and traverse mode respectively).

b) With the same test set-up, a communication element operating with frames containing 80 random user data bits with maximum frame rate, shall produce no more than 10 detected errors in 60 000 frames under the following condition: after any forward error correctio, when an unmodulated, or asynchronously modulated, interfering carrier wave signal at any frequencies within the ranges and at the corresponding field strengths as shown in Table 82 is applied.

Class 3

A test set-up shall be used consisting of a 4 km line of site range from transmitter to receiver. The Effective Radiated Power (ERP) from the transmitter antenna shall be set at the maximum allowed in the local regulations, for the channel in use and a 20 dB total loss shall be set in the receiving antenna to the receiver's antenna connector.

a) With this set up, a communication element operating with frames containing 32 random user data bits with maximum frame rate, shall produce no more than 10 detected errors in 1 000 frames after any forward error correction, under the following noise environments imposed on the channel.

1) 10 V/m electromagnetic field as specified in IEC 61000-4-3 at severity level 3, but not with a frequency that is within 25 kHz of the center channel frequency of the radio medium fieldbus network under test.
2) Electrical fast transients as specified in IEC 61000-4-4 at severity level 3.

The above error rate specification shall also be satisfied after, but not during the following noise environments:

i) 8 kV electrostatic discharge to exposed metalwork as specified in IEC 61000-4-2 at severity level 3. If the device suffers temporary loss of function as a result of this test it shall recover from any such loss without operator intervention within 3 s after the end of the test;
ii) high frequency disturbance test as specified in IEC 60255-22-1:1988, test voltage class III (2,5 kV and 1 kV peak values of first half cycle in longitude and traverse mode respectively).

b) With the same test set-up, a communication element operating with frames containing 32 random user data bits with maximum frame rate, shall produce no more than 10 detected errors in 60 000 frames under the following condition: after any forward error correctio, when an unmodulated, or asynchronously modulated, interfering carrier wave signal at any frequencies within the ranges and at the corresponding field strengths as shown in Table 82 is applied.

Table 82 — Interfering frequencies for testing receiver performance

Frequency range in MHz	Field strength in dB (µV/m)
25 to 800	120
800 to 4 000	110
Except where within following band around the center frequency	Where the interfering field strength shall be
±60	100
±0,3	80
±0,2	75
±0,1	65
< ±0,1	20
NOTE The values quoted in this table are considered sufficient to ensure operation in the presence of known broadcast transmissions from high power sources such as for television transmission, however, even greater levels can be experienced in close proximity to some transmitters. The signal from the radio medium fieldbus MAU transmitting element and the interfering carrier are assumed to have the same polarisation.	

17.7.4 Post processing

NOTE Receiver performance can be improved by post processing, and, in order to decrease the bit error rate of PhPDUs passed to the radio medium fieldbus MDS layer, the radio medium fieldbus MAU receiver implementations may include post processing algorithms that use the knowledge and structure of the raw radio wave forms imposed by this standard, so long as this post processing function can be shown in the worst case not to cause any timing violations.

Post processing if implemented shall not violate any timing constraints imposed by this standard.

17.7.5 Transmit receive turnaround time

The transmit to receive and the receive to transmit turnaround times shall be no more than 10 ms.

17.7.6 Random data rejection and carrier detect circuit

The radio medium fieldbus MAU shall not allow the reception of random data when no carrier is present.

NOTE This can be provided by a carrier detect circuit or by redundant bit detection methods.

18 Type 2: Medium attachment unit: 5 Mbit/s, voltage-mode, coaxial wire medium

18.1 General

Only one attachment method is specified for the 5 Mbit/s, voltage-mode, coaxial wire medium. Other methods may be used but they shall conform to the same signaling and performance characteristics. If the specified coaxial wire medium attachment method is used, then it shall incorporate transformer coupling at the node and it shall use a Passive Tap for attachment to the medium. The tap shall include a 1 m spur.

The 5 Mbit/s, voltage-mode, coaxial wire PhL variant shall connect to coaxial wire medium with network segments up to 1 km long with up to 48 nodes (see 18.5).

NOTE The physical layer can be implemented to allow certification for operation in explosive atmospheres, without sacrificing distance or reducing the number of nodes. This standard does not include requirements for intrinsic safety certification, but seeks to exclude conditions or situations that would prevent intrinsic safety certification.

The MAU shall consist of a transceiver, transformer, and connector as shown in Figure 77. The transceiver shall use the signals defined in the MDS-MAU interface to generate those necessary to drive the transformer. Attachment to the medium shall be via BNC or TNC connectors as specified in Annex F. Ground isolation shall be provided via the transformer as specified in 18.3.

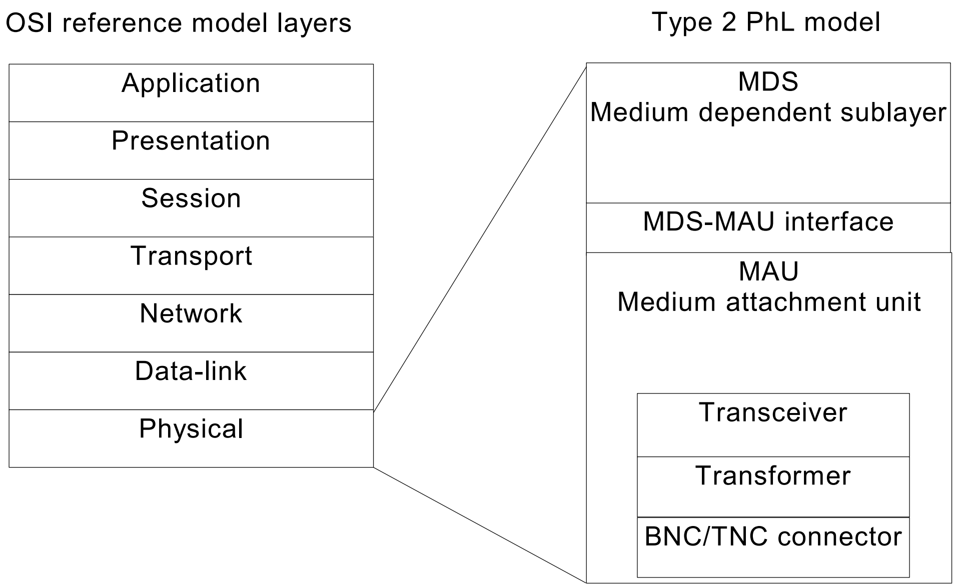


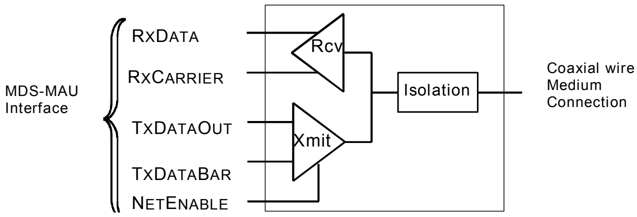
Figure 77 — Components of 5 Mbit/s, voltage-mode, coaxial wire PhL variant

18.2 Transceiver: 5 Mbit/s, voltage-mode, coaxial wire

When using a 5 Mbit/s, voltage-mode, coaxial wire medium, a coaxial wire transceiver shall be used to transmit and receive the L and H signals. The transmitter portion of the transceiver shall obtain transmit signals from the MDS-MAU interface, representing H and L symbols. It shall transmit a single-ended, ground-isolated signal onto the cable via the isolation transformer. The complement of this function shall be performed in the receiver that shall provide RXDATA and RXCARRIER indications to the MDS-MAU interface.

A functional block diagram depicting the MAU sublayer components is shown in Figure 78.

NOTE **1** Figure H.3 shows an example of a redundant transceiver and Figure H.4 shows an example of a single channel transceiver.



NOTE The blocks labeled Xmit and Isolation combine to represent the transmitter.

Figure 78 — Coaxial wire MAU block diagram

Figure 79 shows a simplified functional diagram of the transmitter.

NOTE 2 Refer to the example schematics found in Figure H.3 and Figure H.4 for more detail.

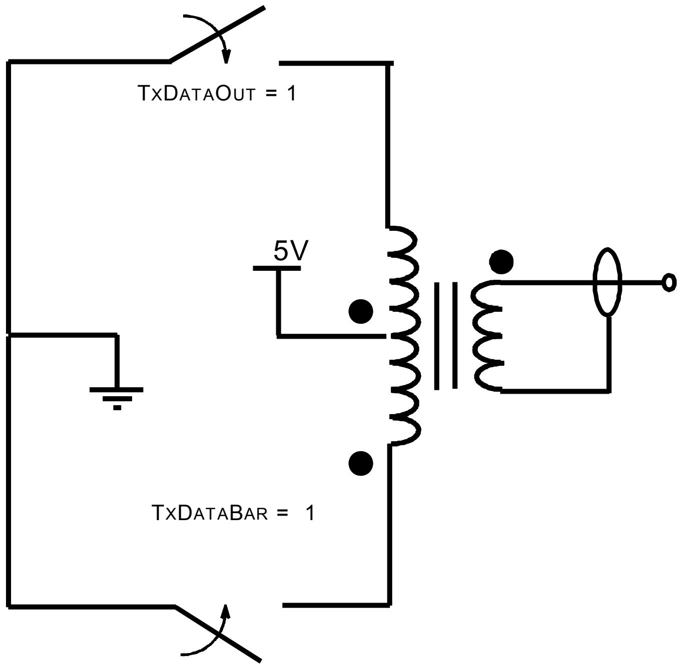
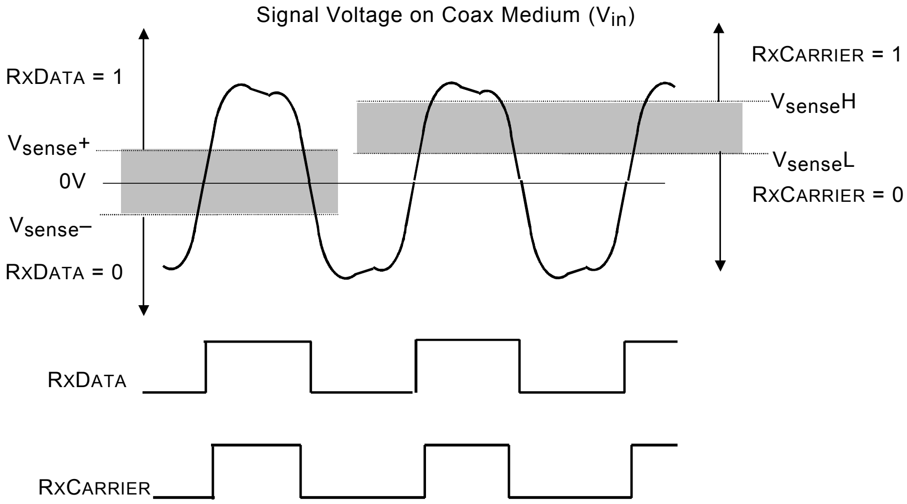


Figure 79 — Coaxial wire MAU transmitter

Three signals shall be available at the MDS-MAU interface for controlling transmission onto the medium, TXDATAOUT, TXDATABAR, and NETENABLE. These three transmit signals, when connected to the transceiver, shall define the physical symbols on the wire. The relationship between these transceiver request lines and the signals on the medium shall be as specified in Table 83.

Table 83 — Transmit control line definitions 5 Mbit/s, voltage-mode, coaxial wire

TxDataOut	TxDataBar	NetEnable	Physical symbol	Signal on medium
don't care(x)	don't care(x)	false(0)	none	Transmitter off, see Table 86.
false(0)	false(0)	true(1)	none	Transmitter off, see Table 86.
true(1)	false(0)	true(1)	H	+ voltage (positive), see Table 86.
false(0)	true(1)	true(1)	L	- voltage (negative), see Table 86.
true(1)	true(1)	true(1)	not allowed (see note)	Not allowed (see note)
NOTE This state can result in damage to the transmitter circuitry.				



NOTE The shaded areas shown above are not defined.

Figure 80 — Coaxial wire MAU receiver operation

Two indication signals shall be provided at the MDS-MAU interface from the MAU with RxDATA and RxCARRIER as shown in Table 83. The relationship between the signal voltage on the wire and these two signals for nominal thresholds shall be as shown in Table 84 and Table 85. The values referenced in Table 84 and Table 85 are defined in Table 87. The input level (V_{in}) as shown in Figure 80 shall be defined as the voltage as measured between the coaxial cable center conductor and the coaxial shield. All polarities shall be defined in terms of the voltage on the coaxial cable center conductor (V_{in}+ or V_{in}–) as referenced to the coaxial shield.

Table 84 — Receiver data output definitions: 5 Mbit/s, voltage-mode, coaxial wire

Input level at medium	RxDATA	Comments
V_{in} more positive than positive data sensitivity limit (V_{sense}+)	true (1)	See Table 87
V_{in} more negative than negative data sensitivity limit (V_{sense}–)	false (0)	See Table 87
V_{in} between positive and negative data sensitive limits	undefined	Allows for hysteresis and tolerance

Table 85 — Receiver carrier output definitions: 5 Mbit/s, voltage-mode, coaxial wire

Input level at medium	RxCARRIER	Comments
V_{in} more positive than high carrier sensitivity limit ($V_{sense}H$)	true (1)	See Table 87
V_{in} lower than low carrier sensitivity limit (or negative) ($V_{sense}L$)	false (0)	See Table 87
V_{in} between low and high carrier sensitivity limits	undefined	Allows for hysteresis and tolerance

The medium interface shall conform to the requirements shown in Table 86, Table 87 and Table 88.

Table 86 — Coaxial wire medium interface – transmit specifications

Specification	Limits / characteristics	Comments
Transmit level (Tx level) peak-to-peak	8,2 V ± 1,3 V [a, b, c]	See Figure 81
Transmit level asymmetry (between 0 and 1)	< 450 mV max [b, d]	
Transmit signal distortion (over voltage, droop, ring)	± 10 % [a, e]	See Figure 81
Total transmit jitter (Tx Jitter)	< 5 ns	See Figure 81
Transmitter output impedance	20 Ω max	
Maximum transmitter off noise level	5 mV max [a]	
Time from NETENABLE false to transmitter off noise level	400 ns [a]	
Slew limit	1 V/ns max [a]	See Figure 81
Rise / fall limit (10 % to 90 % of peak-to-peak)	30 ns max [a]	See Figure 81

[a] This shall be a peak-to-peak voltage as measured into a 37,5 Ω load from 0 MHz to 20 MHz.

[b] The transmit level shall be measured at the estimated mid-point between any peaks or troughs in both top and bottom of the waveform.

[c] This level shall be 0,5 V lower when measured as inside of eye pattern when driving a tap for a minimum signal of 6,4 V (peak-to-peak).

[d] This shall be measured as the absolute difference between the absolute value of Transmit level for 1 (+ voltage) and the absolute value of transmit level for 0 (– voltage) as measured into a 37,5 Ω load from 0 MHz to 20 MHz.

[e] Levels shall be a function of the actual measured transmit voltage.

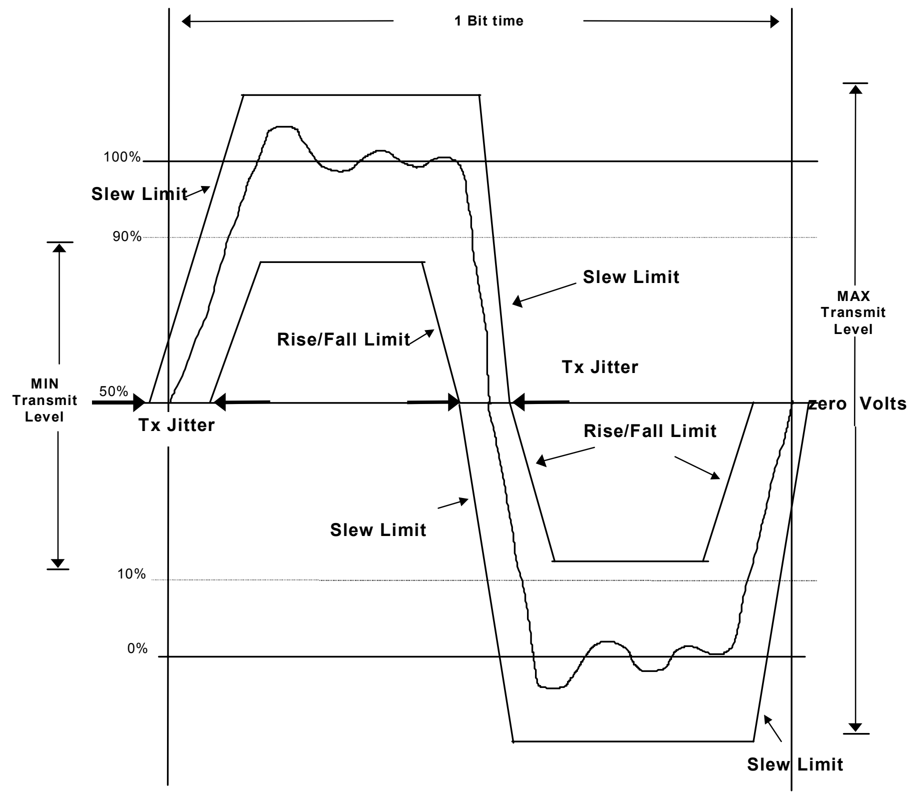


Figure 81 — Coaxial wire MAU transmit mask

Table 87 — Coaxial wire medium interface – receive

Specification	Limits / characteristics	Comments
Minimum receive signal level (peak-to-peak)	510 mV	Inside of eye pattern as shown in Figure 82
Data threshold voltage	zero V	Negative and positive sensitivity limits allow for hysteresis and tolerance
Negative data sensitivity limits (V_{sense}–)	- 140 mV	Allows for hysteresis and tolerance
Positive data sensitivity limits (V_{sense}+)	+140 mV	Allows for hysteresis and tolerance
Low carrier sensitivity limit (V_{sense}L)	+ 23 mV	Allows for hysteresis and tolerance
High carrier sensitivity limit (V_{sense}H)	+ 255 mV	Allows for hysteresis and tolerance
`RxData` pattern jitter (peak-to-peak) for V_{in} > 510 mV	< 40 ns	Inside of eye pattern as shown in Figure 82 shall be true when V_{in} > minimum receive signal level

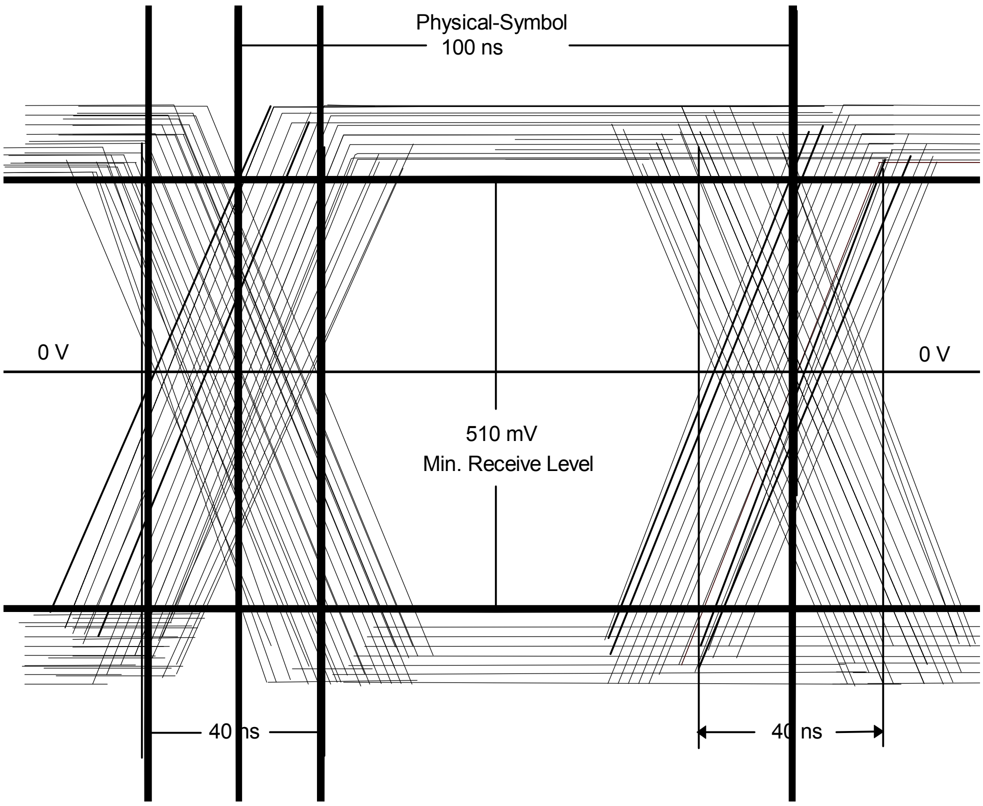


Figure 82 — Coaxial wire MAU receive mask

Table 88 — Coaxial wire medium interface – general

Specification	Limits / characteristics	Comments
Coupling	Transformer coupled	Ground isolated
Isolation at 0 Hz	500 kΩ min [a]	Shield shall be R/C coupled to local earth
Input impedance (Tx Off)	0,2 dB tap loss	(See Figure 86) Alternative to impedance model
Impedance model (Tx Off)		Alternative to input impedance
Series inductance	0,56 μH ± 20 % [b]	Power on
Parallel inductance	425 μH ± 20 % [b]	Power on
Parallel capacitance	50 pF max [b] 55 pF max [b]	Power on Power off
Parallel resistance	3,9 kΩ ± 20 % [b] 3,4 kΩ ± 20 % [b]	Power on Power off
Connector	BNC or TNC	See Annex F for more details

[a] Capacitor value shall be 0,01 μF/500 V minimum. This requirement applies to all medium interfaces connected to the network.

[b] All impedance specifications shall be met with the transmitter off and with power applied or removed as shown. All impedance specifications shall be met over the entire receiver dynamic range from minimum receive level to maximum transmit level.

NOTE 3 A reference design example for a 5 Mbit/s, voltage mode, coaxial wire MAU transceiver is shown in Annex H.1.1.

18.3 Transformer 5 Mbit/s, voltage-mode, coaxial wire

NOTE 1 The Transformer couples the transmit and receive signals to and from the medium. An important feature of the transformer is that it provides galvanic isolation or ground isolation between nodes. This prevents large common-mode voltages due to ground voltage differences between nodes. Also prevented are large ground loops, which can be susceptible to low frequency magnetic coupling.

Figure 83 shows the schematic symbol for the transformer.

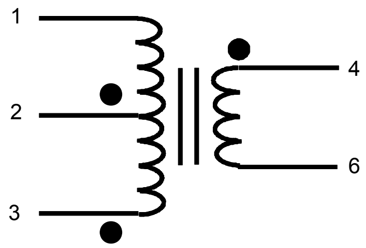


Figure 83 — Transformer symbol

Coupling transformers shall conform to the requirements specified in Table 89.

Table 89 — 5 Mbit/s, voltage-mode, coaxial wire transformer electrical specifications

Specification	Min.	Typical	Max.
Inductance (measured at 40 kHz and 100 mV)	350 µH	750 µH	
Winding capacitance (measured at 10 MHz)	16,0 pF	24,8 pF	29,5 pF
Parallel resistance (core loss)	8,0 kΩ	9,1 kΩ	11,2 kΩ
Leakage inductance	255 nH	441 nH	625 nH
Galvanic isolation (at 47-63 Hz, less than 1,0 mA)	500 V_{rms} for 60 s 600 V_{rms} for 1 s		
Resonant frequency	1,0 MHz	1,4 MHz	1,8 MHz

Leakage inductance shall be measured between pins 1 and 2 with pins 4 and 6 connected together. Galvanic isolation shall be measured with pins 1, 2 and 3 tied together and with pins 4 and 6 tied together. The galvanic isolation requirement shall be met from pin 1 to pin 4, from pin 1 to core, and from pin 4 to core. All other measurements shall be made between pins 4 and 6 with pin 2 connected to instrument ground.

NOTE 2 A reference design example for a 5 Mbit/s, voltage mode, coaxial wire MAU transformer is shown in Annex H.1.2.

18.4 Connector 5 Mbit/s, voltage-mode, coaxial wire medium

The connector used on a node shall be a BNC or TNC jack, in accordance with the requirements of this standard (see Annex F).

18.5 Topology 5 Mbit/s, voltage-mode, coaxial wire medium

A segment shall comprise a trunk–spur architecture. The trunk shall consist of coaxial cable and shall be terminated at both ends by a resistor equal to 75 Ω ± 5 %.

NOTE 1 This limits the reflections from transmitted signals on the trunk reflecting at the ends of the cable.

Nodes shall be attached to the network via drop cables. The drop cables shall attach to the trunk using the specified taps. These taps shall contain passive circuitry that allows trunk attachment while minimizing reflections due to attachment loading.

Nodes connected to the deterministic control network shall not terminate the drop cable shield directly to ground. Termination of the shield shall be in accordance with Table 88. To properly terminate each drop cable's shield, a resistor in parallel with a 0,01 µF capacitor shall be used. The parallel R/C shall be connected from shield to ground.

Figure 84 shows a topology example.

NOTE 2 In this example, two segments are connected by a repeater to form a seven node link.

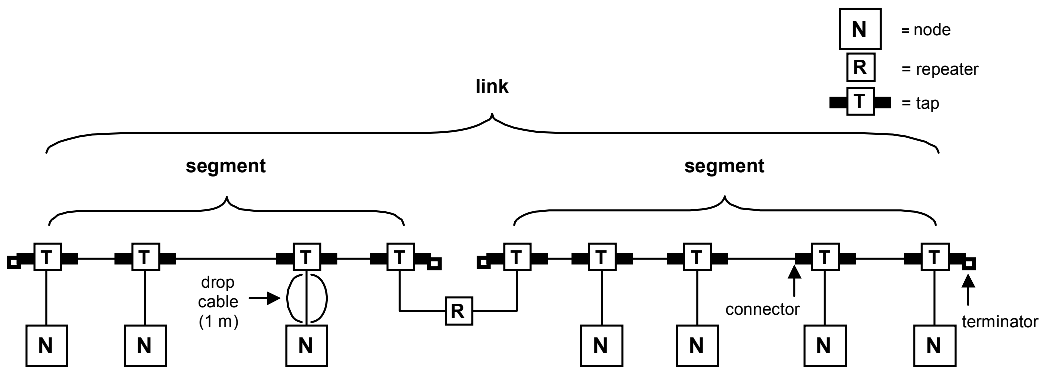


Figure 84 — 5 Mbit/s, voltage-mode, coaxial wire topology example

Topology limits are shown in Figure 85. Up to 48 nodes can be connected to a segment of length up to 1 km as shown in Figure 85. The trade-off between distance and number of nodes is shown in Figure 85. If a combination of nodes and distance is required that exceeds the segment limits, then a PhL repeater device shall be used (see Annex G). With respect to the medium, a PhL repeater device shall appear, electrically and mechanically, to be the same as a node. The PhL repeater device shall require a tap for each segment to which it is connected, and therefore, can be attached anywhere on each segment. The repeaters shall not be placed in a manner that causes more than one connection between segments.

Any topology that supports a single path between any two PhL entities shall be supported. Multiple paths between PhL entities shall not be allowed by an implementation that claims conformance to this clause.

This PhL variant may be combined with other PhL variants within the same node, or in different nodes, by using the RM (repeater machine) and/or PhL repeater devices (see Annex G).

NOTE 3 See Annex G for more information on repeaters.

NOTE 4 These limits are based upon the cable specifications in 18.7.1.

Figure 85 shall apply when using taps as specified in 18.6 and trunk coaxial cable as specified in Table 91. Cables with attenuation characteristics other than those shown in Table 91 may be used if an appropriate segment length multiplier is applied to Figure 85.

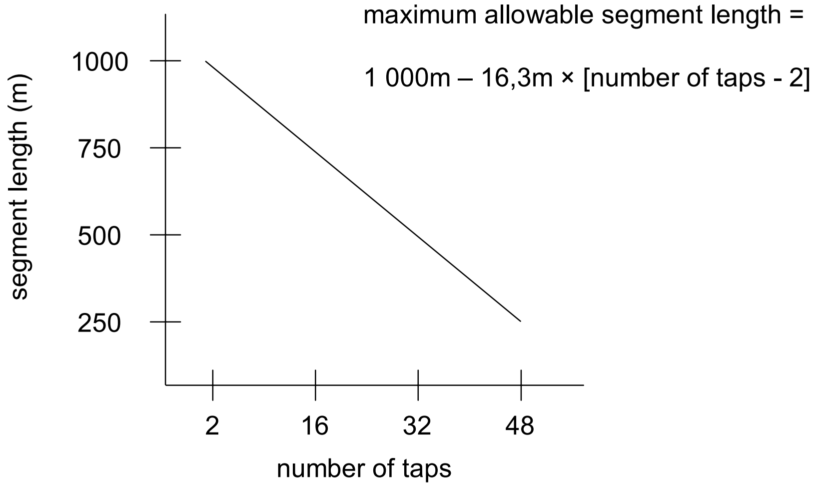


Figure 85 — Coaxial wire medium topology limits

18.6 Taps 5 Mbit/s, voltage-mode, coaxial wire medium

18.6.1 Description

The tap shall contain passive circuitry that compensates for the added loading of the attached node.

NOTE 1 In this way, a small amount of transmission loss is experienced rather than an impedance discontinuity, and therefore a reflection, on the trunk for every node.

A tap shall be used for all nodes that conform to the specified coaxial wire medium attachment method.

NOTE 2 A reference design example for a 5 Mbit/s, voltage mode, coaxial wire MAU Tap is shown in Annex H.1.3.

18.6.2 Requirements

The standard tap variant shall provide BNC jack connections at the trunk and a BNC plug at the node, the IP67 sealed tap variant shall provide TNC jack connections at the trunk and a TNC or BNC plug at the node, in accordance with the requirements of this standard (see Annex F). A 1 m length of spur cable of the specified type shall be used in the tap if proper compensation for the spur cable is to be achieved.

NOTE 1 The electrical requirements of the tap are defined by the transmitted and reflected characteristics as seen by the trunk when the tap port is properly connected by the required spur and a node equivalent load. Although the tap has three ports, it can be viewed as a two port device when it is configured this way. The term, node equivalent load, means a load that represents the nominal impedance of a node. A node equivalent load may be constructed from discrete components so long as the equivalent load meets all requirements in this clause.

The transmission and reflection requirements shall be as shown in Figure 86. Scattering parameters (S11, S22, S12, and S21) shall be used to define the tap electrical requirements. S11 and S22 shall be used to define the reflection characteristics of the trunk connector of a tap while the spur is terminated by a node equivalent load and the other trunk connector is terminated with a trunk terminator (75 Ω ± 5 %). S12 and S21 shall be used to define the transmission characteristics of the tap from one trunk connector to the other with the drop cable terminated by a node equivalent load. The transmission and reflection characteristics of all taps shall fall in the pass region defined in Figure 86.

NOTE 2 The tap is a reciprocal device (S11=S22, S12=S21) so trunk port orientation is arbitrary.

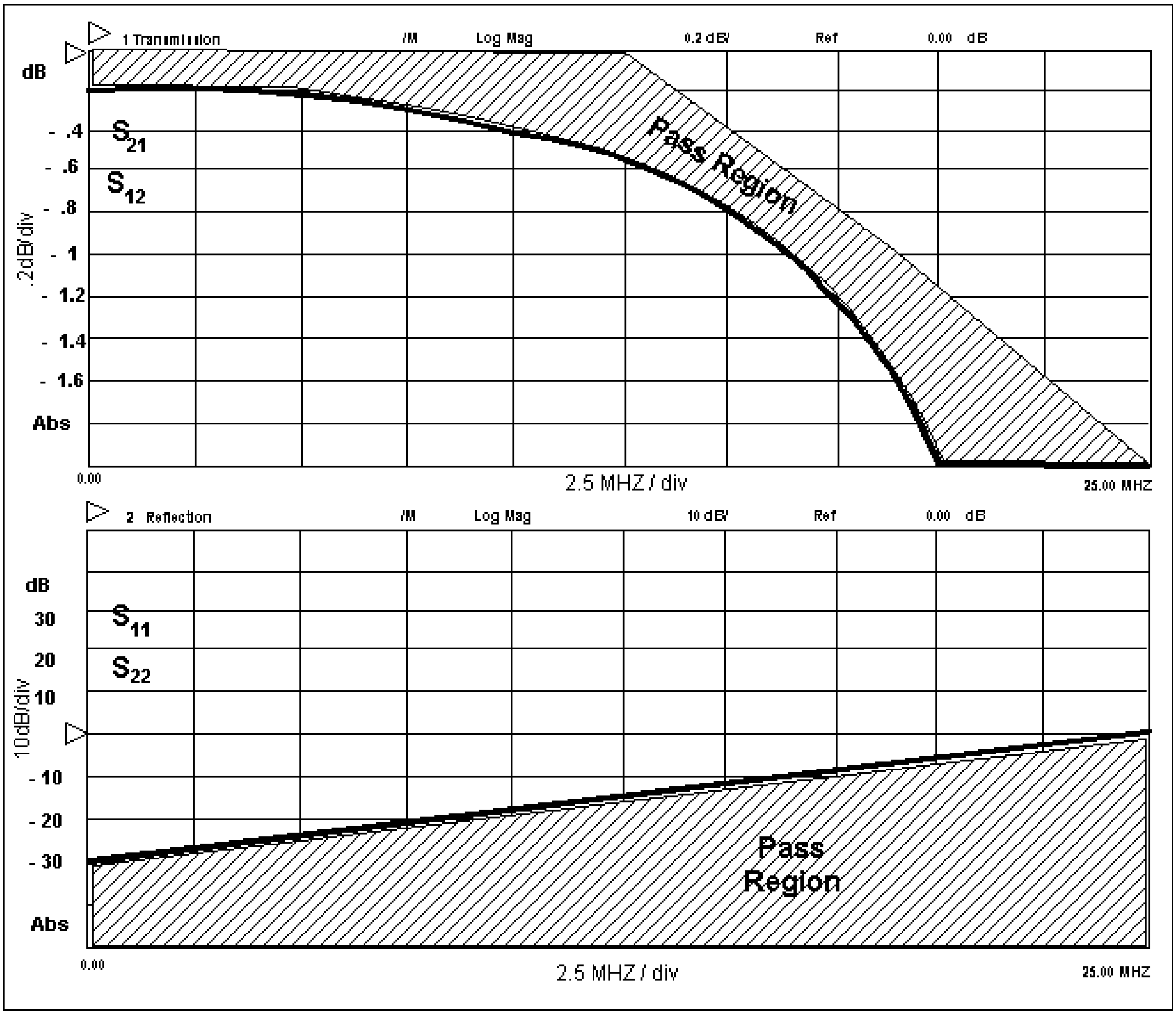


Figure 86 — Coaxial wire medium tap electrical characteristics

18.6.3 Spur

The spur cable shall conform to the limits and characteristics shown in Table 90.

Table 90 — Coaxial spur cable specifications

Specification	Limits / characteristics
Shielding	Dual braided shield, each braid is 95 % coverage
Impedance	75 Ω ± 3 Ω
Delay	4,1 ns/m ± 0,1 ns/m
Attenuation (dB/100 m) at	
1 MHz	1,25
5 MHz	3,01
10 MHz	4,33
25 MHz	6,89
50 MHz	10,1
Structural return loss	23 dB minimum from 5 MHz to 50 MHz
Conductor DC resistance	92 Ω/km nominal
Shield DC resistance	10,5 Ω/km nominal
Nominal capacitance	54,13 pF/m

18.7 Trunk 5 Mbit/s, voltage-mode, coaxial wire medium

18.7.1 Trunk Cable

The trunk cable shall meet the specification given in Table 91.

Table 91 — Coaxial trunk cable specifications

Specification	Limits / characteristics
Shielding	Quad shield
Impedance	75 Ω ± 3 Ω
Delay	4,1 ns/m ± 0,1 ns/m
Attenuation (dB/100 m) at	
1 MHz	1,15
2 MHz	1,25
5 MHz	1,48
10 MHz	1,94
20 MHz	2,82
50 MHz	4,49
Structural return loss	23 dB minimum from 5 MHz to 50 MHz
Conductor DC resistance	92 Ω/km nominal
Shield DC resistance	24 Ω/km nominal
Nominal capacitance	53,15 pF/m

Spur cable as specified in Table 90 may also be used for trunk cable in limited lengths (up to 10 m per segment).

18.7.2 Connectors

The trunk connection shall use a BNC or TNC plug, in accordance with the requirements of this standard (see Annex F).

19 Type 2: Medium attachment unit: 5 Mbit/s, optical medium

19.1 General

NOTE 1 This subclause specifies the optical medium and PhL variant. Information important to designing the PhL connection is captured here.

NOTE 2 The fiber medium attachment method defines three fiber media and PhL variants. The first variant covers fiber media and PhL requirements for a short-range system for distances of up to 300 m (nominal), the second variant covers fiber media and PhL requirements for a medium-range system for distances of up to 7 km (nominal), and the last variant covers fiber media and PhL requirements for a long-range system for distances of up to 20 km (nominal).

The fiber medium attachment method shall incorporate a full duplex point to point or ring topology using a transmitter and receiver at each end of a pair of fibers.

For all variants, the fiber medium attachment methods shall be defined either as a point to point link or as a ring topology. The point to point link shall connect between end nodes, end nodes and PhL repeater devices, or PhL repeater and PhL repeater. The ring topology shall connect between any two or more nodes or devices that implement the ring repeater machine (RRM), which is described in Annex G. Switching between media or topologies shall require the use of a PhL repeater device. This shall be implemented as an active hub, active star or active ring. An active hub or active star shall consist of a minimum of two ports.

NOTE 3 The physical layer can be implemented to allow certification for operation in explosive atmospheres, without sacrificing distance or reducing the number of nodes. This standard does not include requirements for intrinsic safety certification, but seeks to exclude conditions or situations that would prevent intrinsic safety certification.

The fiber medium MAU shall consist of the fiber transceiver and fiber connector. The transceiver shall use the signals defined in the MDS-MAU interface to generate those necessary to drive the transceiver. Attachment to the medium shall be via fiber connectors.

19.2 Transceiver 5 Mbit/s, optical medium

To support a fiber medium, a fiber transceiver shall transmit and receive the L and H signals from the MDS. The transmitter portion of the transceiver shall obtain transmit signals from the MDS-MAU interface, representing H and L symbols, and transmits either ‘light on’ (for H) or ‘light off’ (for L) using a direct coupled transceiver. This means that the transceiver shall be capable of transmitting and receiving PhL signaling at frequencies from zero (no Ph-symbol transitions) to 10 MHz minimum.

NOTE Direct coupled transceivers are required because the MDS and MAU sublayers, as specified, do not provide for the insertion and deletion of an idle sequence when there is no L or H data to be sent, i.e. during periods of no Ph-symbol activity.

The complement of this function shall be performed in the receiver, which shall provide RxData and RxCarrier indications to the MDS-MAU interface as shown in Figure 87, a functional block diagram depicting the MAU components.

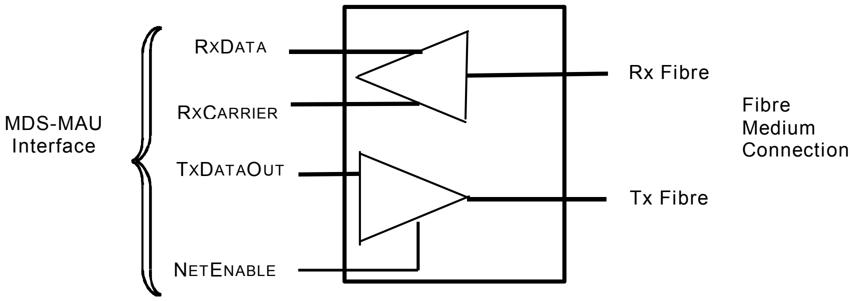


Figure 87 — MAU block diagram 5 Mbit/s, optical fiber medium

The transmit signals shall be as shown in Table 92.

Table 92 — Transmit control line definitions 5 Mbit/s, optical fiber medium

TXDATAOUT	NETENABLE	Physical symbol	Signal on fiber medium
don't care(x)	false(0)	don't care (x)	light off
false(0)	true(1)	L	light off
true(1)	true(1)	H	light on

The fiber interface transmit and receive limits shall be as shown in Table 93.

Table 93 — Fiber medium interface 5,0 Mbit/s, optical

Specification	Limits / Characteristics	Comments
Input pattern jitter	40 ns peak-to-peak max.	Measured on RXDATA
Total transmit jitter	< 5 ns peak-to-peak	

19.3 Topology 5 Mbit/s, optical medium

The media topology defined for a fiber medium attachment variant shall be a point to point link or a ring topology. The point to point topology shall be between any two PhL entities that meet the requirements of this clause and that do not implement the RRM. The ring topology shall be between any two PhL entities that meet the requirements of this clause and that implement the RRM (see Annex G). Switching between these two topologies shall require the use of a PhL repeater or of any device implementing the RRM function and repeater PhL. In either case, nodes and repeaters shall be cascadable as long as each link meets the requirements specified in this clause. The total signal propagation delay shall be used in the calculation of the slot time value as described in IEC 61158-4-2.

Any topology that supports a single path between any two PhL entities shall be supported. Multiple paths between PhL entities shall not be allowed by an implementation that claims conformance to this clause.

This PhL variant may be combined with other PhL variants within the same node, or in different nodes, by using the RM (repeater machine) and/or PhL repeater devices (see Annex G).

19.4 Trunk fiber 5 Mbit/s, optical medium

The trunk fiber shall meet the requirements specified in 19.6 for the appropriate fiber PhL variant.

19.5 Trunk connectors 5 Mbit/s, optical medium

The Trunk connectors shall be in accordance with the requirements of this standard (see Annex F) for the different fiber PhL variants.

19.6 Fiber specifications 5 Mbit/s, optical medium

The signal characteristics for fiber media and PhL variant at 25 ºC shall be as shown in Table 94, Table 95 and Table 96.

Table 94 — Fiber signal specification 5 Mbit/s, optical medium, short range

Specification	Min.	Nominal	Max.
Fiber			
Distance	0 m	300 m	
Fiber attenuation at λ		6 dB/km	
Fiber technology	Step index, hard clad silica (HCS)		
Core/cladding	200/230 µm		
Numerical aperture	0,5		
System			
BER	10^{-9}		
Power budget	3,9 dB	9,5 dB	
Transmitter			
Wavelength λ	640 nm	650 nm	660 nm
Spectral width	21 nm		
Coupled power, $P_{T\ on}$ (transmit light on)	-16,1 dBm, peak	-12,5 dBm, peak	-8,5 dBm, peak
Coupled power, $P_{T\ off}$ (transmit light off)			- 44 dBm, peak
Optical rise time T_{rise}			
Optical fall time T_{fall}			
Receiver			
$P_{R\ MIN}$ (receive light on)		-25 dBm, pk	-23 dBm, peak
$P_{R\ MAX}$ (receive light on)	-1,0 dBm	+3,0 dBm	
Pulse width distortion			30 ns

Table 95 — Fiber signal specification 5 Mbit/s, optical medium, medium range

Specification	Min.	Nominal	Max.
Fiber			
Distance	0 m	7 km	
Fiber attenuation at λ		1,5 dB/km	
Fiber technology	Graded index, multi-mode		
Core/cladding	62,5/125 µm		
Numerical aperture	0,275		
System			
BER	10^{-9}		
Power budget	11,3 dB	16,4 dB	
Transmitter			
Wavelength λ	1 270 nm	1 300 nm	1 370 nm
Spectral width		130 nm	185 nm
Coupled power, $P_{T\ on}$ (transmit light on)	-15,5 dBm, peak	-13,5 dBm, peak	-12,0 dBm, peak
Coupled power, $P_{T\ off}$ (transmit light off)			- 40 dBm, peak
Optical rise time T_{rise}		1,8 ns	4,0 ns
Optical fall time T_{fall}		2,2 ns	4,0 ns
Receiver			
$P_{R\ MIN}$ (receive light on)	-33,5 dBm, pk	-31,8 dBm, peak	-28,8 dBm, peak
$P_{R\ MAX}$ (receive light on)			
Pulse width distortion			2ns

Table 96 — Fiber signal specification 5 Mbit/s, optical medium, long range

Specification	Min.	Nominal	Max.
Fiber			
Distance			20 km
Fiber attenuation at λ		0,5 dB/km	
Fiber technology	Graded index, single mode		
Core/cladding	10/125 µm		
Numerical aperture	0,1		
System			
BER	10^{-9}		
Power budget	10 dB		
Transmitter			
Wavelength λ	1 270 nm	1 300 nm	1 370 nm
Spectral width		70 nm	
Coupled power, $P_{T\ on}$ (transmit light on)	-18 dBm, pk	- 15 dBm, pk	- 10 dBm, pk
Coupled power, $P_{T\ off}$ (transmit light off)			- 40 dBm pk
Optical rise time T_{rise}		2 ns	4,0 ns
Optical fall time T_{fall}		2,2 ns	4,0 ns
Receiver			
$P_{R\ MIN}$ (receive light on)		- 32 dBm, pk	- 30 dBm, pk
$P_{R\ MAX}$ (receive light On)	- 10 dBm		
Pulse width distortion			2 ns

20 Type 2: Medium attachment unit: network access port (NAP)

20.1 General

Figure 88 shows the location of the network access port (NAP) PhL and Medium within the ISO/OSI reference model.

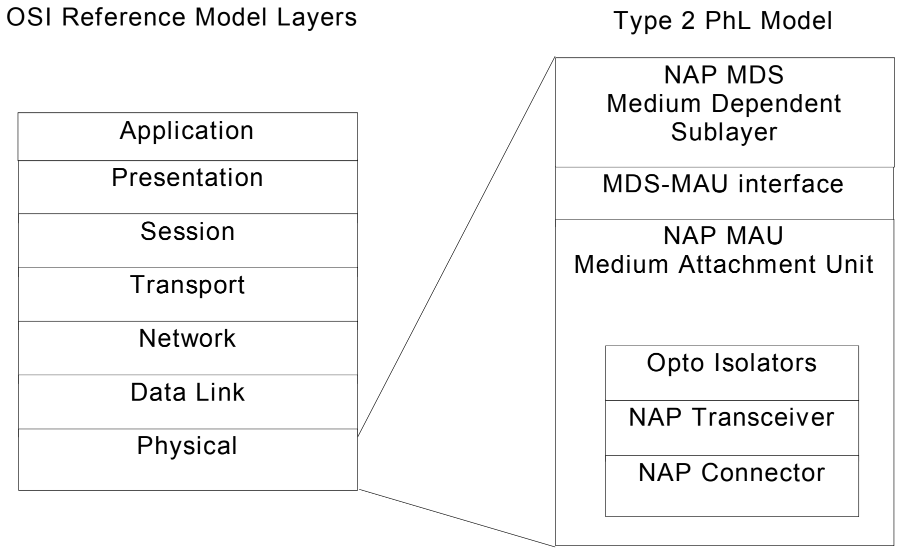


Figure 88 — NAP reference model

Local connection to a computer (desktop or laptop), hand held programming device or other temporary network connection shall be made through the NAP transceiver using protocol and data rates as specified for the trunk. The NAP transceiver shall obtain a single transmit line from the MDS-MAU interface, transmit to and receive from, another node at the other end of the NAP cable and provide a single receive line back to the MDS-MAU interface.

As these are single lines, no representation of carrier on/off shall be present. These signals shall be either a logical 'zero' or a logical 'one' at all times. The medium shall be driven from the single transmit line at all times.

The NAP PhL shall support a point to point connection between two nodes. This topology shall not be multi-dropped to support more than two nodes.

Any topology that supports a single path between any two PhL entities shall be supported. Multiple paths between PhL entities shall not be allowed by an implementation that claims conformance to this clause.

A node, whose primary connection to the link is through the NAP PhL variant, shall be considered a transient network node. A node, whose primary connection to the link is via any other PhL variant, shall be considered a permanent network node. A transient node shall communicate with another transient node or a permanent node using the NAP medium. The permanent node shall utilize the repeater machine (RM) functionality (see Annex G) contained in the DLL of that node to allow the transient node to communicate to other permanent nodes as shown in Figure 89. A permanent node shall function as a transient node when no other PhL medium is connected as shown in Figure 89.

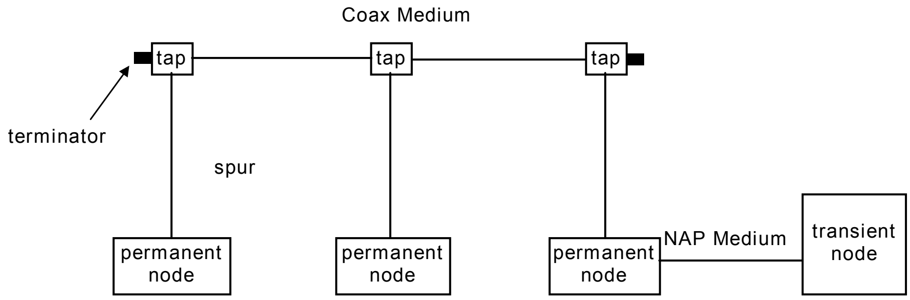


Figure 89 — Example of transient and permanent nodes

This PhL variant may be combined with other PhL variants within the same node, or in different nodes, by using the RM (repeater machine) and/or PhL repeater devices (see Annex G).

20.2 Signaling

The signaling requirements for the NAP port shall be as shown in Table 97.

Table 97 — NAP requirements

NAP interface specification	Design specification	Comments
NAP interface – General		
Coupling	DC	Opto-isolator required for programming nodes
Link configuration	Two uni-directional RS-422 pair	One Rx, one Tx
Connector	Shielded RJ-45	See Annex F
Termination	100 Ω internal on /RxPTC only	
NAP – Transmit		
Output level at NAP medium with /TxPTC = true	2,5 V min.	Measured between Tx_H and GND REF pin with 100 Ω NAP receive load connected (see Table F.2)
Output level at NAP medium with /TxPTC = false	2,5 V min.	Measured between Tx_L and GND REF pin with 100 Ω NAP receive load connected (see Table F.2)
Output level at NAP medium with /TxPTC = true	0,5 V max.	measured between Tx_L and GND REF pin with 100 Ω NAP receive load connected (see Table F.2)
Output level at NAP medium with /TxPTC= false	0,5 V max.	measured between Tx_H and GND REF pin with 100 Ω NAP receive load connected (see Table F.2)
Output level at NAP medium with /TxPTC = data	4,0 V min.	(Tx_H - Tx_L) measured as peak to peak with 100 Ω load (see Table F.2)
Total Transmit Jitter	± 5 ns max.	
Termination	None	
NAP – Receive		
Receive level at NAP medium with /TxPTC = data	2,5 V min.	(Rx_H – Rx_L) measured as peak to peak (see Table F.2)
Receive jitter	± 15 ns max.	
Termination	100 Ω ± 10 %	Across differential lines
Fault receive signal	/RxPTC = true	If medium is disconnected, shorted, receiver turned off or disabled, /RxPTC shall be true

20.3 Transceiver

The NAP MAU block diagram shown in Figure 90 represents both the isolated and non-isolated implementations. The isolated NAP shall be used on transient nodes. Opto-isolation shall be provided to prevent ground loop currents from flowing between nodes at different ground potentials. Opto-isolation shall not be required if the node is self powered and is not grounded. The non-isolated NAP shall be used on permanent nodes.

NOTE 1 A transient node is defined as a node with primary and normal connection to the network through the NAP of another node. This includes, but is not limited to, computer interface cards, configuration nodes and other nodes that are transient or temporary network connections.

NOTE 2 A permanent node is defined as a node with primary and normal connection to the network through a PhL other than the NAP. This includes, but is not limited to: PLCs, I/O rack adapters, controllers, robots, welders and other nodes that are connected to the network on a mostly permanent basis.

If a node can be used as both a transient and permanent node, it shall include opto-isolation in the design of the NAP (unless it is self-powered and cannot be grounded).

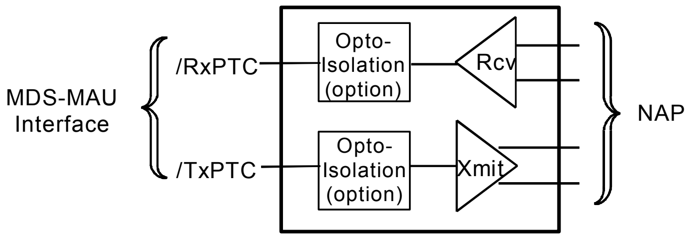


Figure 90 — NAP transceiver

NOTE 3 A reference design example for a Network Access Port MAU is shown in Annex H.2.

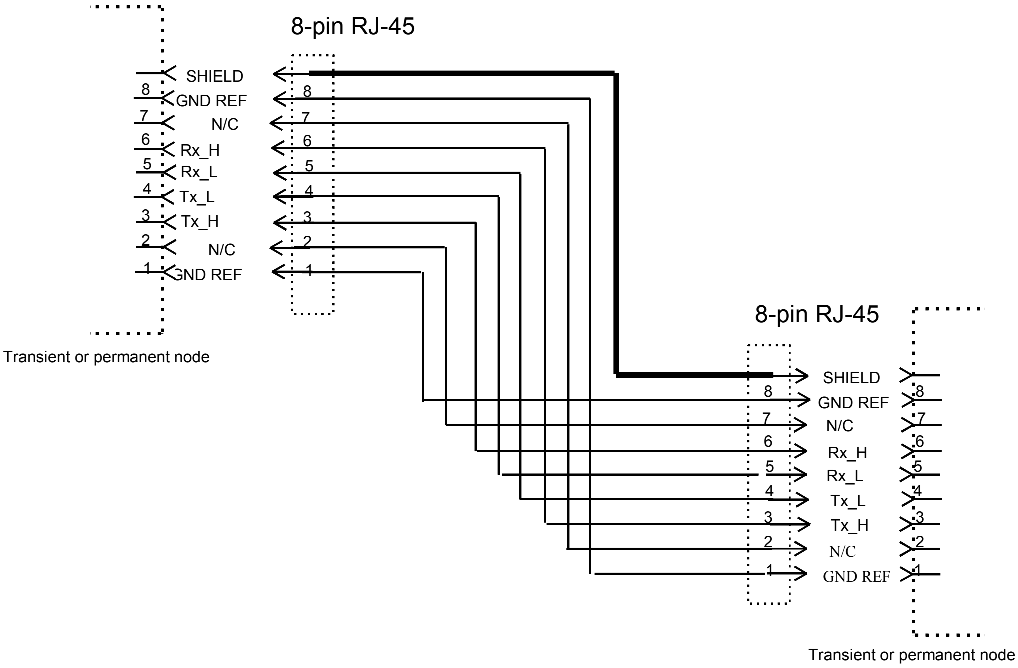
20.4 Connector

The connector used at both ends of a NAP connection shall be a shielded 8-pin RJ-45 type connector, as specified in Annex F.

20.5 Cable

The NAP cable shall have 8 conductors and an overall shield. The shield shall be designed to minimize electromagnetic interference. The cable connector pins shall be as shown in Table F.2.

As the NAP connector and pin connections are the same for both a node and a transient node, the cable shall be built in a way that allows the correct transmit data and receive data connection. This shall be accomplished be reversing the connection on one end of the NAP cable as shown in Figure 91.



NOTE The NAP cable connectors are installed so that the signal lines are reversed to allow the correct connection. This allows the equipment to use the same pinout independent of function.

Figure 91 — NAP cable

The NAP cable shall meet the following requirements:

a) paired line characteristics = 100 Ω;

b) resistance (at 0 Hz) = 0,122 Ω/m;

c) wire gauge = 26 (7 strands, diameter 0,16 mm);

d) conductors = 8 plus overall shield;

e) maximum cable length = 10 m.

21 Type 3: Medium attachment unit: synchronous transmission, 31,25 kbit/s, voltage mode, wire medium

21.1 General

The 31,25 kbit/s voltage-mode MAU simultaneously provides access to a communication network and to an optional power distribution network. Devices attached to the network communicate via the medium and may or may not be powered from it. If bus-powered, power is distributed as direct voltage and current, and communications signals are superimposed on the d.c. power. In Intrinsically Safe applications, available power may limit the number of devices.

The network medium consists of twisted pair cable. Independent of topology, all attached devices, other than possibly the transmitting device, are high impedance to prevent significant network loading. Trapezoidal waveforms are used to reduce electromagnetic emissions.

Bus and tree topologies are supported. In either topology a network contains one trunk cable, terminated at both ends. In the bus topology, spurs are distributed along the length of the trunk. In the tree topology, spurs are concentrated at one end of the trunk. A spur may connect more than one device to the network, the number of devices depending on spur length.

At the power frequency (d.c.), devices appear to the network as current sinks, with a limited rate of change of the supply current drawn from the medium. This prevents transient changes in load current from interfering with communication signals.

21.2 Transmitted bit rate

See 12.2..

21.3 Network specifications

21.3.1 Components

Subclause 12.3.1 applies.

When selecting the individual components, make sure that all components meet the requirements of the FISCO model. Only components that are identified as an intrinsically safe electrical apparatus or as an associated electrical apparatus in accordance with IEC 60079-11 may be installed in intrinsically safe fieldbus segments. To comply with 12.2.5.1 of IEC 60079-14, the permitted values of the input parameters U_I, I_I, and P_I of an intrinsically safe apparatus (e.g. a field devices) must not be less then the certified maximum values of the output parameters U_0, I_0 and P_0 of the associated power device. Additional restrictions applicable to the individual components (e.g., limitation of the supply power of ≤1,2 W) have to be taken into account as well.

Table 98 lists possible combinations of devices from different system categories.

Table 98 — Mixing devices from different categories

Explosion protection of the bus-segment	Explosion protection of the power device	Explosion protection of the field device					
		EEx ia			EEx ib		
		IIC	IIB	IIC/IIB	IIC	IIB	IIC/IIB
EEx ia IIC (Group IIC)	[EEx ia] IIC	x		x			
EEx ia IIB (Group IIB)	[EEx ia] IIB	x	x	x			
	[EEx ia] IIC	x	x	x			
EEx ib IIC (Group IIC)	[EEx ib] IIC	x		x	x		x
	[EEx ia] IIC	x		x	x		x
EEx ib IIB (Group IIC)	[EEx ib] IIB	(x)[1]	x	x	(x)[1]	x	x
	[EEx ib] IIC	x	x	x	x	x	x
	[EEx ia] IIB	(x)[1]	x	x	(x)[1]	x	x
	[EEx ia] IIC	x	x	x	x	x	x

[1] These combinations are possible in theory but in practice they are irrelevant, because the field devices may be certified for group IIC and for group IIB as well (see column IIC/IIB).

By any combination it must be assured that the absolute maximum ratings for the input of the field device fit to the output characteristics of the power device:

$U_I \geq U_O$

$I_I \geq I_O$

$P_I \geq P_O$

Connection of bus-powered devices and local-powered devices on an intrinsically safe fieldbus is permitted if the local-powered devices are provided with suitable isolation in accordance with IEC 60079-11.

Although connection of a fieldbus station (i.e., field device, hand-held terminal, and coupler for the bus master) with its poles reversed does not affect the functionality of the other devices connected to the fieldbus, an incorrectly installed bus station which is not equipped with automatic polarity detection will not be supplied with power or be able to send and receive. Stations with automatic polarity detection operate correctly with any allocation of the input terminals to the wires.

21.3.2 Topologies

A wire MAU shall operate in a network with a linear bus topology, consisting of a trunk, terminated at each end as specified in 21.8.5, to which communication elements are connected via couplers and spurs.

The coupler and communication element may be integrated in one device (i.e. zero length spur).

A tree topology with all the communication elements located at the ends of the trunk is regarded as a special case of a bus for the purpose of this clause of IEC 61158-2.

Several communication elements may be connected to the trunk at one point using a multi-port coupler. An active coupler may be used to extend a spur to a length that requires termination to avoid reflections and distortions. Active repeaters may be used to extend the length of the trunk beyond that of a single segment as permitted by the network configuration rules.

21.3.3 Network configuration rules

A 31,25 kbit/s voltage-mode MAU shall be required to conform to the requirements of this clause when used in a network which complies with these rules.

Rule 1: One fieldbus shall be capable of communication between the following numbers of devices, all operating at the same bit rate:

a) for a non IS fieldbus without power supplied via the signal conductors: between two and 32 devices;
b) for a non IS fieldbus with power supplied via the signal conductors: between two and the number of devices which can be powered via the signal conductors, assuming that a minimum of 120 mA shall be available to devices at the remote end from the power supply communicating with one device at the power supply end drawing 10 mA;
c) for an IS fieldbus: between two and the number of devices that can be powered via the signal conductors, assuming that a minimum of 40 mA shall be available to devices in the hazardous area.

NOTE 1 Rule 1 does not preclude the use of more than the specified number of devices in an installed system. Since the device power consumption is not specified, the number of bus-powered devices cannot be specified. Item b) assumes that the minimum power supply voltage is 20 V d.c. Item c) assumes that the IS barrier operates with a 19 V d.c. output.

Rule 2: A fully loaded (maximum number of connected devices) 31,25 kbit/s voltage-mode fieldbus segment shall have a total cable length, including spurs, between any two devices, of up to 1 900 m.

NOTE 2 1 900 m maximum cable length is the requirement for conformance to this clause but this does not preclude the use of longer lengths in an installed system.

Rule 3: The total number of waveform regenerations by repeaters and active couplers between any two devices shall not exceed four.

Rule 4: The maximum propagation delay between any two devices shall not exceed 20 Tbit.

NOTE 3 For efficiency of the network, that part of the turn-around time of any device on the network caused by a PhE between the end of a received frame and the beginning of the transmitted frame containing an associated immediate response should not exceed 5 bit times, no more than 2 bit times of which should be due to the MAU. As it is not mandatory to expose the DLL – PhL interface or the MDS – MAU interface, that part of the turn-around time of a fieldbus device caused by the PhL or the MAU cannot be specified or conformance tested.

Rule 5: The fieldbus shall be capable of continued operation while a device is being connected or disconnected. Data errors induced during connection or disconnection shall be detected.

Rule 6: Failure of any communication element or spur (with the exception of a short circuit, low impedance, or jabber) shall not interfere with transactions between other communication elements for more than 1 ms.

Rule 7: In polarity sensitive systems the medium twisted pairs shall have distinctly marked conductors that uniquely identify individual conductors. The polarization shall be maintained at all connection points.

Rule 8: The degradation of the electrical characteristics of the signal, between any two devices, due to attenuation, attenuation distortion and mismatching shall be limited to the values indicated below.

a) Signal attenuation: The configuration of the bus (trunk and spur lengths, number of devices, IS barriers, galvanic isolators, and possible matching devices) shall be such that the attenuation between any two devices at the frequency corresponding to the bit rate shall not exceed 10,5 dB.
b) Attenuation distortion: The configuration of the bus (trunk and spur lengths and number of devices, IS barriers, and galvanic isolators) shall be such that between any two devices:

[Attenuation (1,25 f_r) – Attenuation (0,25 f_r)] ≤ 6 dB

Attenuation (1,25 f_r) ≥ Attenuation (0,25 f_r)

where f_r is the frequency corresponding to the bit rate. Attenuation shall be monotonic for all frequencies from 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz).

c) Mismatching distortion: Mismatching (due to spurs or any other effect, including one open circuit spur of maximum length) on the bus shall be such that, at any point along the trunk, in the frequency band 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz):

|Z – Zfr| / |Z + Zfr| ≤ 0,2

where Z_o is the characteristic impedance of the trunk cable and Z is the parallel combination of Z_o and the load impedance at the coupler.

The concentration of couplers shall be less than 15 per 250 m.

NOTE 4 Rule 8 minimizes restrictions on trunk and spur length, number of devices etc. by specifying only the transmission limitations imposed by combinations of these factors. Different combinations may be used depending on the needs of the application.

Rule 9: The following rules shall apply to systems implemented with redundant media:

a) each channel (cable) shall comply with the network configuration rules;
b) there shall not be a non-redundant segment between two redundant segments;
c) repeaters shall also be redundant;
d) if the system is configured (by Systems management) to transmit on more than one channel simultaneously then the propagation time difference between any two devices on any two channels shall not exceed five bit times;
e) channel numbers shall be maintained throughout the fieldbus, i.e. channels 1, 2, 3... from Systems management shall always connect to physical channels 1, 2, 3...

21.3.4 Power distribution rules for network configuration

See 12.3.4.

21.4 Transmit circuit specification for 31,25 kbit/s voltage-mode MAU

21.4.1 Summary

For ease of reference, the requirements of 21.2 and 21.4 are summarized in Table 60 and Table 61 (see 12.4.1).

21.4.2 Test configuration

Figure 54 (see 11.4.2) shows the configuration that shall be used for testing.

Differential signal voltage: $V_d = V_a - V_b$.

Test load resistance R = 50 Ω (0,5 cable Z_o) and C = 10 µF except where otherwise stated in a specific requirement.

21.4.3 Impedance

For both the bus interfaces (i.e., medium attachment unit MAU) of the field devices and coupling elements and the power supplies, 11.4 requires that the input impedance (can be measured from the bus line) in the signal frequency range (7,8 kHz to 39 kHz) does not pass below a minimum value during normal operation. With the exception of the first 10 ms following connection of a field device to a power supply, this requirement applies to all aspects of operation. Table 99 shows the input Impedances of bus interfaces and power supplies

Table 99 — Input Impedances of bus interfaces and power supplies

	Impedance	Voltage range	Current range
Bus interface (e.g., field device)	≥ 3 kΩ	9 V to 32 V	For operating current
Intrinsically safe bus power supply	≥ 400 Ω	For operating voltage	0 to I_{Max}
Non intrinsically safe bus power supply	≥ 3 kΩ	For operating voltage	0 to I_{Max}

The input impedance of the bus interface shall be measured with a sinus signal whose amplitude shall be greater than the receiver sensitivity but always less than 2 Vss.

NOTE No measuring signal is defined for the power supply.

Impedance of the field device and the power supply shall be determined using the measuring circuit shown in Figure 92.

Impedance X of the tested device is calculated from the ratio of the two voltages U_D and U_R.

$$X = R_M \times \frac{U_D}{U_R}$$

The two measured voltages represent complex values whose phase difference is included in the result. If U_R is used as the reference, then:

$$X = R_M \times \frac{|U_D|}{|U_R|} \times e^{j\varphi}$$

where

φ is the phase angle $\varphi(U_D)$- $\varphi(U_R)$

This reduces impedance measurement to a ratio measurement of two voltages and one phase difference measurement.

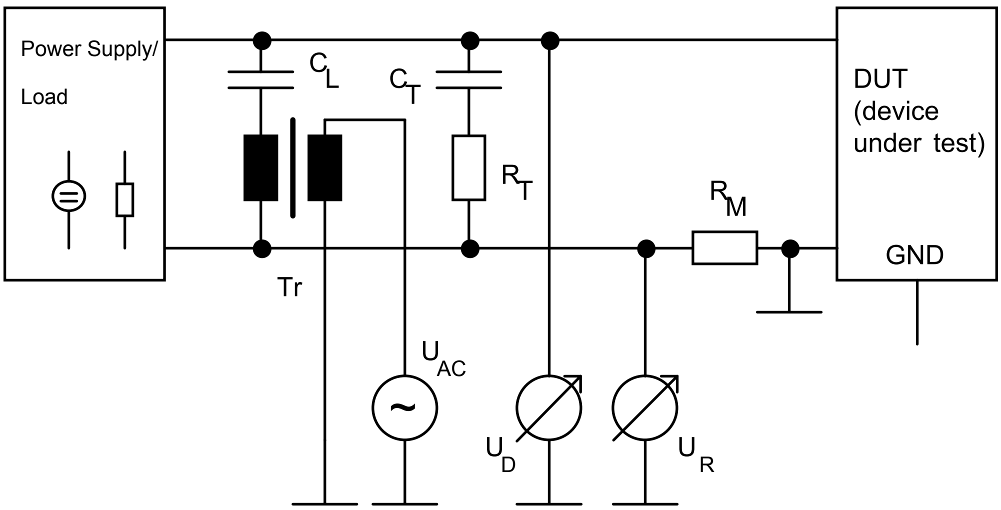


Figure 92 — Circuit diagram of the principle of measuring impedance

Example

CL = CT = 2 µF, RT = RM = 100 Ω

The phase angle can also be negative. If so, the object to be measured represents a negative load that amplifies rather than attenuates. This can be disregarded (it even has positive effects) for the signal frequency range from 7,9 kHz to 39 kHz as long as |X| remains within the specified range.

NOTE There is no specification for the impedance. Its amount can be any low value. In combination with unfavourable outside circuiting conditions (e.g., long stub lines), negative impedance can create an unattenuated oscillating circuit which turns the bus system into an oscillator although the object to be measured remains stabile in the measuring circuit.

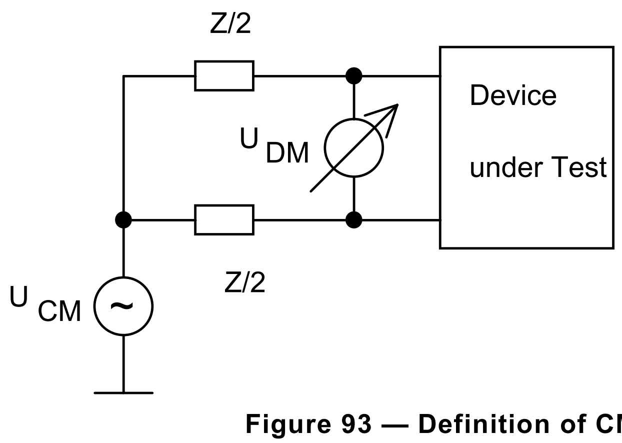
The following sources of errors can affect the result of the impedance measurement.

a) Non-linear distortions. Correction: Use frequency-selective measurement (i.e., only evaluate the fundamental wave) and oscillographic monitoring of the measuring signal.
b) Asymmetries in the measuring setup. Correction: Use symmetrical transformer Tr and avoid ground capacitances. Leave open any ground connection on the test object (e.g., caused by EMC filter) when measuring the impedance.
c) Noise signals generated by the test object. Correction: Measure the background noise. It shall be ≤ 1 mV_{eff} (measured at 50 Ω). If this condition is met, the effect on the impedance measurement can be disregarded.

21.4.4 Symmetry

All bus interfaces shall be isolated from earth. The unbalanced capacitance between the two bus terminals and earth must not exceed 250 pF. That is also required for barriers and power supplies.

Under the condition that the impedance between each of the two bus terminals and earth only contains one capacitive component, measuring the two effective earth capacitances and then calculating the difference can determine asymmetry. Particularly when non-intrinsically safe bus interfaces, which can be coupled to the bus via a transformer, are used, significant inductive components are present. Even when coupling elements are used, which do not contain inductivities as components, inductive behaviour caused by parasitic effects can be detected particularly for higher frequencies. At best, a purely capacitive asymmetry only can be assumed within a limited frequency range. For this reason, it is recommended to determine the Common Mode Rejection Ratio CMRR as defined in Figure 93 to evaluate the characteristics of symmetry.



$$a_u = 20 \cdot \lg \frac{U_{CM}}{U_{DM}}$$

Figure 93 — Definition of CMRR

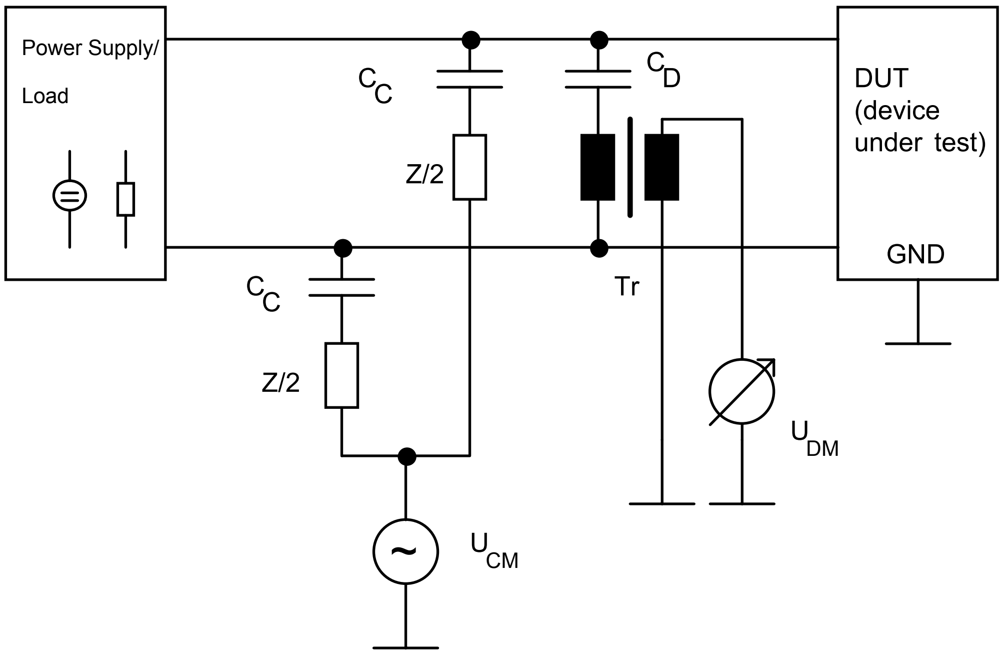


Figure 94 — Block circuit diagram of the principle of measuring CMRR

Example

C_C = C_D = 2 µF, Z/2 = 25 Ω ± 0,1 %.

Field device, barrier or power supply shall meet the required CMRR of Table 100. With regard to the unbalanced capacitance, the CMRR shall be higher than the values listed in Table 100. CMRR of the measuring instrument (e.g. as shown in Figure 94) without the device under test (i.e., DUT) shall be at least 10 dB above the listed values.

Table 100 — Required CMRR

Frequency	kHz	≤ 40	120	400	1 200
CMRR	dB	≥ 50	≥ 40	≥ 30	≥ 20

21.4.5 Output level requirements

See 12.4.3

21.4.6 Output timing requirements

See 12.4.4.

21.4.7 Signal polarity

See 11.4.5.

21.5 Receive circuit specification for 31,25 kbit/s voltage-mode MAU

See 12.5.

21.6 Jabber inhibit

See 12.6.

21.7 Power distribution

21.7.1 General

A device can optionally receive power via the signal conductors or be separately powered.

A device can be certified as Intrinsically safe with either method of receiving power.

NOTE This standard does not include requirements for IS-certification but seeks to exclude conditions or situations that would prevent IS certification.

A separately powered device can be connected to a powered fieldbus.

For ease of reference, the requirements of 21.7 are summarized in Table 101 and Table 102.

Table 101 — Network powered device characteristics for the 31,25 kbit/s voltage-mode MAU

Network powered device characteristics	Limits for 31,25 kbit/s
Operating voltage	9,0 V d.c. to 32,0 V d.c.
Minimum withstand voltage, either polarity, for no damage	35 V
Maximum rate of change of quiescent current (non-transmitting); this requirement does not apply within the first 10 ms after the connection of the device to an operating network or within the first 10 ms after the application of power to the network	1,0 mA/ms
Maximum current; this requirement applies during the time interval of 100 µs to 10 ms after the connection of the device to an operating network or 100 µs to 10 ms after the application of power to the network (see note)	Rated quiescent current plus 10 mA
NOTE The first 100 µs is excluded to allow for the charging of RFI filters and other capacitances in the device. The rate of change specification applies after 10 ms.	

Table 102 — Network power supply requirements for the 31,25 kbit/s voltage-mode MAU

Network power supply requirements	Limits for 31,25 kbit/s
Output voltage, non-IS	≤ 32 V d.c.
Output voltage, IS	Depends on barrier rating
Output ripple and noise	See Figure 95
Output impedance, non-IS, measured over the frequency range 0,25 f_r to 1,25 f_r	≥3 kΩ
Output impedance, IS, measured over the frequency range 0,25 f_r to 1,25 f_r	≥400 Ω (See note)
NOTE The IS power supply is assumed to include an IS barrier.	

21.7.2 Supply voltage

A fieldbus device that includes a 31,25 kbit/s voltage-mode MAU shall be capable of operating within a voltage range of 9 V to 32 V d.c. between the two conductors including ripple. The device shall withstand a minimum voltage of ±35 V d.c. without damage.

NOTE 1 For IS systems the operating voltage may be limited by the certification requirements. In this case the power supply will be located in the safe area and its output voltage will be attenuated by a safety barrier or equivalent component.

A fieldbus device that includes a 31,25 kbit/s voltage-mode MAU shall conform to the requirements of this clause when powered by a supply with the following specifications.

a) The output voltage of the power supply for non-IS networks shall be 32 V d.c. maximum including ripple.

b) The output impedance of the power supply for non-IS networks shall be ≥3 kΩ over the frequency range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz). This requirement does not apply within 10 ms of the connection or removal of a field device.

c) The output impedance of an IS power supply shall be ≥400 Ω over the frequency range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz).

NOTE 2 The IS power supply is assumed to include an IS barrier.

d) The breakdown requirements of the isolation of the signal circuit and the power distribution circuit from ground and from each other shall be in accordance with IEC 61131-2.

NOTE 3 The equivalent test voltage is to be applied between independent isolated circuits or between isolated circuits and accessible conducting parts. For circuits with a nominal voltage ≤ 50 V d.c. or r.m.s., the equivalent test voltages at sea level are 444 V r.m.s., 635 V d.c. and 635 V peak impulse test. For circuits with a nominal voltage between 150 V r.m.s. and 300 V r.m.s., the equivalent test voltages at sea level are 2 260 V r.m.s., 3 175 V d.c. and 3 175 V peak impulse test.

21.7.3 Powered via signal conductors

A fieldbus device which includes a 31,25 kbit/s voltage-mode MAU and is powered via the signal conductors shall be required to conform to the requirements of this clause when operating with maximum levels of power supply ripple and noise as follows:

a) 16 mV peak-to-peak over the frequency range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz);

b) 2,0 V peak-to-peak over the frequency range 47 Hz to 63 Hz for non-IS applications;

c) 0,2 V peak-to-peak over the frequency range 47 Hz to 625 Hz for IS applications;

d) 1,6 V peak-to-peak at frequencies greater than 125 f_r, up to a maximum of 25 MHz;

e) levels at intermediate frequencies generally in accordance with Figure 95.

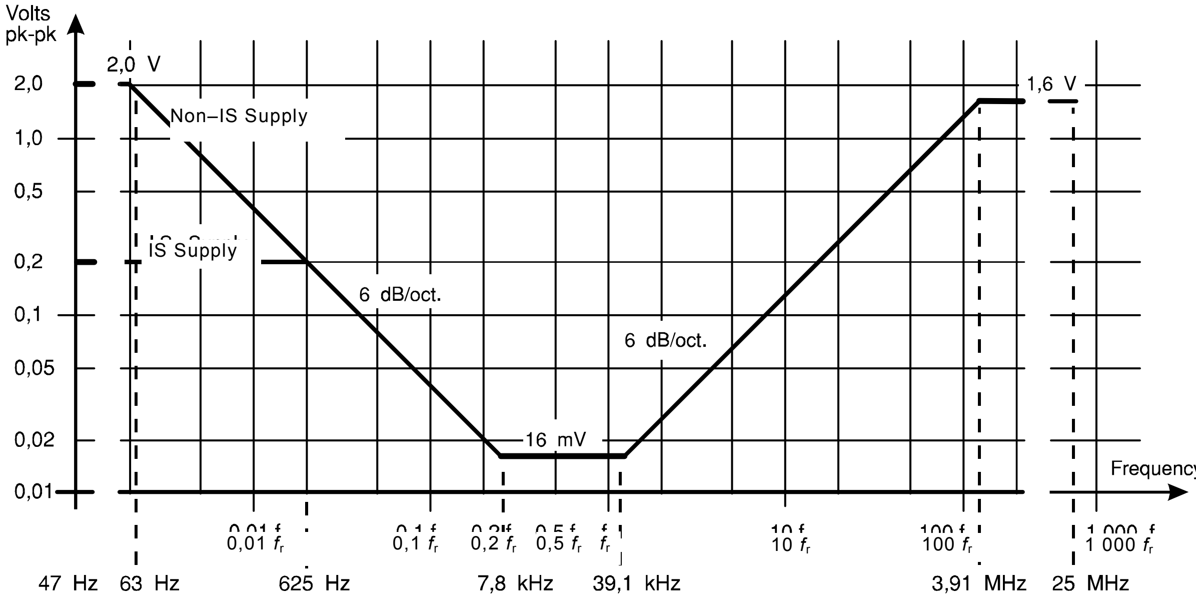


Figure 95 — Power supply ripple and noise

A fieldbus device which includes a 31,25 kbit/s voltage-mode MAU and is powered via the signal conductors shall exhibit a maximum rate of change of current drawn from the network of 1 mA/ms. This requirement does not apply:

- when transmitting;
- within the first 10 ms after the connection of the device to an operating network;
- within the first 10 ms after the application of power to the network;

- upon disconnection from the network or removal of power to the network.

A device shall be marked with a rated quiescent current. A device shall draw no more than 10 mA above its rated current from the network during the time interval of 100 µs to 10 ms after the connection of the device to an operating network or 100 µs to 10 ms after the application of power to the network.

NOTE The first 100 µs is excluded to allow for the charging of RFI filters and other capacitance in the device. The rate of change specification applies after 10 ms.

21.7.4 Electrical isolation

All fieldbus devices that use wire medium, whether separately powered or powered via the signal conductors, shall provide low-frequency isolation between ground and the fieldbus trunk cable.

NOTE 1 This may be by isolation of the entire device from ground or by use of a transformer, opto-coupler or some other isolating component between trunk cable and device.

A combined power supply and communication element shall not require electrical isolation.

For shielded cables, the isolation impedance measured between the shield of the fieldbus cable and the fieldbus device ground shall be greater than 250 kΩ at all frequencies below 63 Hz.

The maximum unbalanced capacitance to ground from either input terminal of a device shall not exceed 250 pF.

The breakdown requirements of the isolation of the signal circuit and the power distribution circuit from ground and from each other shall be in accordance with IEC 61131-2.

NOTE 2 The equivalent test voltage is to be applied between independent isolated circuits or between isolated circuits and accessible conducting parts. For circuits with a nominal voltage ≤ 50 V d.c. or r.m.s., the equivalent test voltages at sea level are 444 V r.m.s., 635 V d.c. and 635 V peak impulse test. For circuits with a nominal voltage between 150 V r.m.s. and 300 V r.m.s., the equivalent test voltages at sea level are 2 260 V r.m.s., 3 175 V d.c. and 3 175 V peak impulse test.

21.8 Medium specifications

21.8.1 Connector

The connector is specified in Annex I.1.

21.8.2 Standard test cable

The cable used for testing fieldbus devices with a 31,25 kbit/s voltage-mode MAU for conformance to the requirements of this clause shall be a single twisted pair cable with overall shield meeting the following minimum requirements at 25 °C:

a) Z_0 at f_r (31,25 kHz) = 100 Ω ± 20 Ω;

b) maximum attenuation at 1,25 f_r (39 kHz) = 3,0 dB/km;

c) maximum capacitive unbalance to shield = 2 nF/km;

d) maximum d.c. resistance (per conductor) = 24 Ω/km;

e) maximum propagation delay change 0,25 f_r to 1,25 f_r = 1,7 µs/km;

f) conductor cross-sectional area (wire size) = nominal 0,8 mm^2;

g) minimum shield coverage shall be 90 %.

NOTE 1 The preceding specification is for conformance testing an MAU. Other types of cable may be used in real installations. (See Annex B.) Cables with improved specifications may enable increased trunk length and/or superior interference immunity. Conversely, cables with inferior specifications may be used subject to length limitations for both trunk and spurs plus possible non-conformance to the RFI/EMI susceptibility requirements.

NOTE 2 For Intrinsically Safe applications special requirements should be met such as specified by relevant Intrinsically Safe standards, e.g. IEC/TS 60079-27 (FISCO).

21.8.3 Coupler

See 12.8.3.

21.8.4 Splices

See 12.8.4.

21.8.5 Terminator

A terminator shall be located at both ends of the trunk cable, connected from one signal conductor to the other. No connection shall be made between terminator and cable shield.

The terminator impedance value shall be 100 Ω ± 2 Ω over the frequency range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz).

NOTE 1 This value is approximately the average cable characteristic impedance value for suitable cables at the relevant frequencies and is chosen to minimize transmission line reflections.

The direct current leakage through the terminator shall not exceed 100 µA. The terminator shall be non-polarized.

All terminators used for IS applications shall comply with isolation requirements (creepage and clearance) commensurate with the required IS approval. Terminators for non-IS applications shall not be required to have IS approval.

NOTE 2 It is acceptable for the functions of power supply, safety barrier, and terminator to be combined in various ways as long as the impedance of the combination is equivalent to the parallel impedance of independent devices meeting the requirements of this clause of IEC 61158-2 and the network configuration rules of 21.3.3 are followed.

21.8.6 Shielding rules

See 12.8.6.

21.8.7 Grounding rules

NOTE 1 Grounding means permanently connected to earth through a sufficiently low impedance and with sufficient current-carrying capability to prevent voltage build-up which might result in undue hazard to connected equipment or persons. Zero volts (common) lines may be connected to ground where they are galvanically isolated from the fieldbus trunk.

Fieldbus devices shall be required to function to the requirements of this clause of IEC 61158-2 with the mid-point of one terminator or one inductive coupler connected directly to ground.

Fieldbus devices shall not connect either conductor of the twisted pair to ground at any point in the network. Signals shall be applied and preserved differentially throughout the network.

NOTE 2 It is best practice for the shield of the fieldbus trunk cable (if applicable) to be effectively grounded at several points along the length of the cable. But the fieldbus devices should allow d.c. isolation of the cable shield from ground. It is also standard practice to connect the signal conductors to ground in a balanced manner at one central grounding point, e.g. by using the center tap of a terminator or coupling transformer. For bus powered systems the grounding of the shield and balanced signal conductors should be close to the power supply unit. For IS systems the grounding should be in accordance to the related Intrinsic safety standards, e.g. prepared by IEC TC 31, SC31G, WG2.

21.8.8 Cable colours

See 12.8.8.

21.9 Intrinsic safety

21.9.1 General

This standard does not attempt to list the requirements by which an item of equipment may be certified as intrinsically safe nor does it require equipment to be intrinsically safe. Rather, it seeks to exclude conditions or situations that would prevent IS certification.

21.9.2 Intrinsic safety barrier

The barrier impedance shall be greater than 460 Ω at any frequency in the range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz). The IS barrier impedance specification shall apply to all barriers used as part of the PhL, whether installed as a separate item of network hardware or embedded in a power supply card. The barrier impedance shall be measured across the terminals on both sides of the barrier. The barrier impedance shall be measured while the network power supply is set at the rated working voltage (not safety voltage) of the barrier.

NOTE It is acceptable for the functions of power supply, safety barrier, and terminator to be combined in various ways as long as the impedance of the combination is equivalent to the parallel impedance of independent devices meeting the requirements of this clause of IEC 61158-2 and the network configuration rules of 21.3.3 are followed.

At the rated working voltage of the barrier, and at any frequency in the range 0,25 f_r to 1,25 f_r (7,8 kHz to 39 kHz), the capacitance measured from the "+" (positive) network terminal (hazardous side) to ground shall differ by no more than 250 pF from the capacitance measured from the "–" (negative) network terminal (hazardous side) to ground.

21.9.3 Barrier and terminator placement

A barrier shall be separated from the nearest terminator by no more than 100 m of cable.

NOTE The barrier can appear as a shunt impedance as low as 460 Ω at the signaling frequencies. The terminator resistance is sufficiently low that when it is placed in parallel with the barrier impedance, the resulting impedance is almost entirely resistive (non-reactive).

21.10 Galvanic Isolators

The communications characteristics of galvanic isolators used on the fieldbus shall comply with the specifications of 21.9.

21.11 Coupling elements

21.11.1 General

Coupling elements are used to connect different Type 3 segments with the same PhL or a different PhL.

With the exception of signal levels this document does not describe the required characteristics of a coupling element. This means that it is the task of the system planner to ensure that "Network Configuration Rules" standard is complied with when coupling elements are used. The following specifications are important.

- Maximum signal delay.

- Maximum deviation from nominal signal zero crossing (signal jitter).

Two types of coupling elements can be used:

- MBP-IS repeaters
- MBP-IS - RS 485 signal couplers

21.11.2 MBP-IS repeater

A MBP-IS repeater connects two MBP-IS segments. It contains a MAU on each segment and a galvanic isolation between the two MAU. The electrical characteristics shown in Table 103 are mandatory for both fieldbus interfaces. MAU related requirements in Clause 12 and 21.1 to 21.10 also apply to repeaters.

Table 103 — Electrical characteristics of fieldbus interfaces

Parameter	Values	Subclause of this standard
Signal coding	Manchester II	9.2.2
Start delimiter	1, N+, N-, 1, 0, N-, N+, 0 (Note 1)	9.2.4
End delimiter	1, N+, N-, N+, N-,1, 0, 1 (Note 1)	9.2.5
Preamble	1, 0, 1, 0, 1, 0, 1, 0	9.2.6
Data transmission rate	31,25 kbit/s ± 0,2 %	21.2
Output level (peak to peak)	0,75 V to 1 V	21.4.5
Max. difference between positive and negative transmit amplitude	± 50 mV	21.4.5
Max. transmit signal distortion (oversvoltage, ringing an drop)	± 10 %	21.4.5
Transmitter noise	1 mV (RMS) (Note 2)	21.4.5
Output impedance	≥ 3 kΩ (Note 3)	21.7.1
Operating voltage	9 V to 32 V (Note 4)	21.7.1
Common Mode Rejection Ratio (CMRR)	≥ 50 dB (Note 5)	
Leakage current (Note 6)	50 μA	

NOTES

1 N+ and N- are non-data symbols.

2 In frequency range of 1 kHz to 100 kHz.

3 In frequency range of 7,8 kHz to 39 kHz.

4 Operational voltage range. Can be limited to 9 V to 17,5 V or to 9 V to 24 V for intrinsically safe devices.

5 Corresponds to a unbalanced capacitance of 250 pF at 39 kHz.

6 Only for intrinsic safety.

Repeaters which are connected to intrinsically safe bus segments must be certified as intrinsically safe apparatus. The certificate must contain a statement that the devices conform to the FISCO model. The specifications of IEC 60079-11 must be adhered to for galvanic isolation.

To be able to determine whether the network configuration rules in 21.3.3 are met, the system planner requires information on the signal delay caused by repeaters and the maximum deviation from the nominal signal zero crossing (i.e., signal jitter). This information shall be documented in the data sheet.

A repeater can be combined with a power supply and with line terminators.

21.11.3 MBP-IS – RS 485 signal coupler

A MBP-IS – RS 485 signal coupler connects a MBP-IS segment with a RS 485 segment. It contains a MAU on each segment, a galvanic isolation between the two MAU, and a Manchester encoding/decoding.

The electrical characteristics shown in Table 103 are mandatory for the MBP-IS interface. MAU related requirements in Clause 12 and 21.1 to 21.10 also apply. Clause 22 apply to the design of the RS 485 bus interface.

Signal couplers which are connected to intrinsically safe bus segments must be certified as intrinsically safe apparatus. The certificate must contain a statement that the devices conform to the FISCO model. The specifications of IEC 60079-11 shall be adhered to for galvanic isolation (see 21.10).

To be able to determine whether the network configuration rules in 21.3.3 are met, the system planner requires information on the signal delay caused by repeaters and the maximum deviation from the nominal signal zero crossing (i.e., signal jitter). This information shall be documented in the data sheet of a signal coupler.

A signal coupler can be combined with a power supply and with a bus terminator.

NOTE Such a device is usually called segment coupler.

21.12 Power supply

21.12.1 General

A power supply must be connected to the bus to supply the field devices with power. The supply voltage depends on the requirements of the particular application.

The power for an intrinsically safe bus can either be provided by a power supply with intrinsically safe output or by a non intrinsically safe power supply supplemented by a barrier.

To prevent any impact on the data transmission, the electrical characteristics in Clause 21 of this standard and listed in Table 104 are mandatory for all power supplies.

The output terminals of a power supply shall be clearly marked with "+" and "-".

Although a power supply isolated against earth is not specifically required, asymmetrical grounding of the bus cable conductors is not permitted. It is essential that any connection between the conductors and earth is balanced. For more details, see 21.8.7.

Table 104 — Electrical characteristics of power supplies

	Not intrinsically safe	Intrinsically safe, IIC FISCO 1)	Intrinsically safe, IIB FISCO 1)	Intrinsically safe, IIC linear barrier 2)
According to FISCO model	no	yes	ja	
Max. DC supply voltage U_0	≤ 32 V	≤ 17,5 V	≤ 17,5 V	≤ 24 V
Max. DC short-circuit current I_0		≤ 360 mA	≤ 380 mA 7)	≤ 250 mA
Max. output power P_0		≤ 2,52 W	≤ 5,32 W	≤ 1,2 W
Ripple, noise	≤ 16 mV 3)	≤ 16 mV 3)	≤ 16 mV 3)	≤ 16 mV 3)
Output impedance 7)	≥3 k Ω 3) 4)	≥ 400 Ω 3) 4)	≥ 400 Ω 3) 4)	≥ 400 Ω 3) 4) 5)
Ripple, noise	≤ 16 mV 3)			
Asymmetry attenuation	≥ 50 dB 6)			≥ 50 dB 5) 6)

1) Power supply with rectangular or trapezoidal characteristic in accordance with the FISCO model.

2) Power supply or barrier with linear characteristic.

3) In frequency range from 7,8 kHz to 39 kHz. Otherwise see Figure 95.

4) With integrated line terminator: 100 Ω ± 2 %. It is recommended to provide each power supply with a terminating resistor.

5) Including barrier if required.

6) No mandatory specification in the standard, but required functionally.

7) The current limit results from a rectangular characteristic.

Power supplies that are used to supply field devices located in potentially explosive areas shall be certified as intrisically safe associated apparatus for use in hazardous locations.

21.12.2 Non-intrinsically safe power supply

Non intrinsically safe power supplies shall have the technical characteristics listed in Table 104.

Non intrinsically safe power supplies can be used together with an approved barrier to supply an intrinsically safe bus.

21.12.3 Intrinsically safe power supply

To supply field devices in potentially explosive areas, a power supply with intrinsically safe output can be connected to the bus instead of the combination of non intrinsically safe power supply and barrier. This device is usually located outside the hazardous area in the control room. In the sense of IEC 60079-11, this is a so-called associated apparatus since, although it is not protected against explosion itself, it does generate an intrinsically safe electric circuit which leads to the potentially explosive area.

In addition to the requirements in Clause 21 especially in Table 104, intrinsically safe power supplies shall meet the safety requirements stated in the IEC 60079-14 and IEC 60079-11.

If the power supply is located within the hazardous area, an additional standardized type of protection must be provided (e.g., installation in a housing of protection type “flameproof enclosure d").

Intrinsically safe power supplies can be part of other fieldbus components (e.g., segment couplers, see 21.11).

The FISCO model is based on a rated DC voltage of 13,5 V. The ignition curves for power supplies with rectangular characteristic indicate that the maximum permissible power considerably decreases if the voltage increases. On the other hand, a low voltage power supply may not be advantageous because of the voltage drop caused by the transmission line. Therefore the voltage of 13,5 V seems to be an acceptable compromise.

Due to tolerances and in order to offer a margin for the signal amplitude the maximum output voltage U_0 of a power device shall be greater than the rated output voltage. The signal amplitude is ≤ 1 V_{PP}, therefore a margin of 0,5 V is needed. If the tolerances are assumed to be ≤ 1 V the calculation results in a guaranteed maximum output voltage U_0 = 15 V. The admissible maximum output current (short circuit current), depending on the gas group, can be taken from available ignition curves or can be derived from ignition tests. In group IIC the allowed output current is I_0 = 128 mA. Other voltage/current combination in accordance with FISCO may be chosen.

Design and implementation of the safety-related voltage, and current limiters depends on the chosen category of the intrisically safe circuit (“ia“ or “ib“) The maximum values of the output parameters have to meet the requirements of FISCO.

An inspection certificate must be obtained for the bus power supply as "associated apparatus" in the sense of IEC 60079-11. This certificate must state that the power supply conforms to the FISCO model.

NOTE In addition to the usual data (i.e maximum output parameters), the certificate may also contain primary specifications applicable to permissible fieldbus configuration. Usually limit values for the maximum permissible external inductancce La and capacity Ca are not required. If these values had been included, it would create the impression that La and Ca are present in the intrinsically safe circuit as unprotected inductivity and capacity, which is not the case for the FISCO model. The cable here is not considered as concentrated inductivity and capacity as long as the parameters of the system remain within the range of limits defined in the FISCO model.

21.12.4 Power supply of the category "ib"

NOTE Since the output current circuit of the power supply should have a low inner resistance for direct current, use of a power supply with a voltage regulator and an active current control (i.e., electronic current limitation) comes to mind. An inner resistance ≥ 400 Ω in the signal frequency range according Table 104 can be achieved by using a frequency-dependent negative feedback, for example.

The ideal output characteristic curve of a power supply (i.e., current/voltage characteristic) is rectangular (see Figure 96). When the output current increases, the output voltage remains constant until the current reaches a certain limit. IEC 60079-11permits such a solution under the assumption that redundant current and voltage limitation has been set up and reliable galvanic isolation (optional) from the non intrinsically safe electric circuits has been provided.

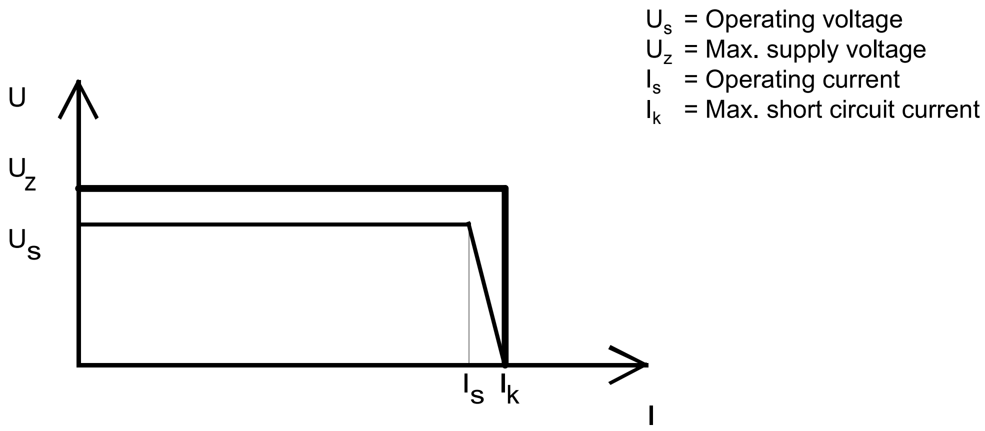


Figure 96 — Output characteristic curve of a power supply of the category EEx ib

NOTE A voltage of 13,5 V direct current seems realistic since higher voltages would restrict the available power. The explosion limit curves for sources with square output characteristic curve show that the permissible power decreases significantly when the voltage increases.

21.12.5 Power supply in category "ia"

Power supplies with electronic current limitation shall be certified in accordance with IEC 60079-11 for category "ib".

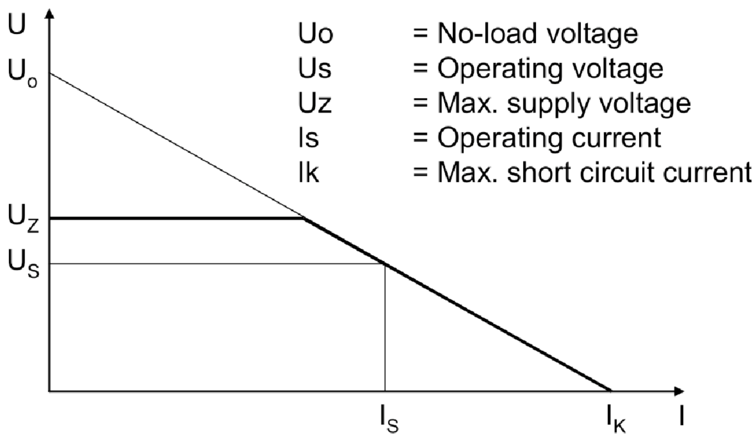


Figure 97 — Output characteristic curve of a power supply of the category EEx ia

The ia-power supply shall be according FISCO. The maximum output current IK of Figure 96 corresponds to the current IZuI (at U = Uz) of

Figure 97.

Example

An example of a power supply suitable for category "ia" contains the following safey-related elements: Voltage source with Uo = 34 V, fixed resistance with R = 158 Ω, and Zener diodes with UZD = 15 V (maximum value). Such a circuit has a trapezoidal output characteristic curve as shown in

Figure 97. The approximate operational values which can be achieved for the power supply are listed below.

U = 13,5 V

I = 120 mA

P = 1,7 W

$$P_{v\,max} = \frac{U_0^2}{R_v} = 7{,}32\ \mathrm{W}$$

NOTE 1 Thus, the operational values are comparable to those of the "ib" concept with electronic current limitation. A disadvantage is the requirement of a relatively high thermal stress of the series resistor and the power loss in the series resistor which is always present under operational conditions.

Applying a safety factor of 1,5, the allowed power dissipation of the resistor shall be 11 W.

NOTE 2 Use of two resistors in series may be helpful.

The maximum power dissipation of the Zener diodes is 1,8 W.

$$P_{v\,max} = \frac{U_o - U_z}{R_v} \times 15\ \mathrm{V} = \frac{34\ \mathrm{V} - 15\ \mathrm{V}}{158\ \Omega} \times 15\ \mathrm{V} = 1{,}8\ \mathrm{W}$$

Taking into account the safety factor, the Zener diodes shall be suitable for a maximum power dissipation of 2,7 W.

NOTE 3 The use of two diodes in series is also possible here.

IEC 60079-14 and IEC 60079-11 apply.

21.12.6 Reverse powering

With the exception of one power supply per segment, the FISCO model does not permit devices that are connected to the intrinsically safe fieldbus to feed power back to the fieldbus, even when a short circuit occurs on the fieldbus line. This is usually ensured by connection in series of two (for EEx ib) or three (for EEx ia) silicon or Schottky diodes in the input electric circuit. The field device conforms to the FISCO model when the leakage current of these diodes (up to the maximum reverse voltage in the permissible temperature range) does not exceed 50 µA. Diode manufacturer specifications (i.e., typical values as per data sheet) usually apply here in addition to a safety factor.

Final judgment of these measures is the responsibility of the certifying authority performing the safety tests and certification of the particular field device.

22 Type 3: Medium attachment unit: asynchronous transmission, wire medium

22.1 Medium attachment unit for non intrinsic safety

22.1.1 Characteristics

This MAU specification describes a balanced line transmission corresponding to ANSI TIA/EIA RS-485-A. Terminators, located at both ends of the twisted-pair cable, enable the PhL to support in particular higher speed transmission. The maximum cable length is 1 200 m for data rates ≤ 93,75 kbit/s. For 1 500 kbit/s the maximum length is reduced to 70 m for type B and 200 m for type A cable. For 12 Mbit/s the maximum length is 100 m (only cable type A, see 22.1.2.2).

NRZ bit encoding is combined with ANSI TIA/EIA RS-485-A signaling targeted to low cost line couplers, which may or may not isolate the station from the line (galvanic isolation); line terminators are required, especially for higher date rates (up to 12 Mbit/s).

Table 105 shows the required characteristics.

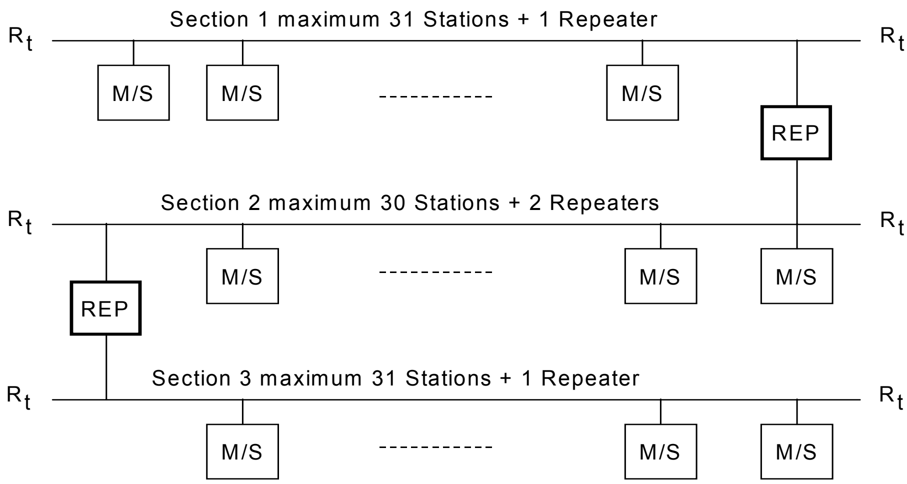
Table 105 — Characteristics for non intrinsic safety

Characteristic	Constraints
Topology:	Linear bus, terminated at both ends, stubs ≤ 0,3 m, no branches; see Note. The total line length includes the sum of the stub lengths.
Medium:	Shielded twisted pair cable recommended, see "Medium specifications"
Line Length:[a]	≤ 1 200 m, depending on the data rate and cable type
Number of stations:[a]	32 (Master stations, slave stations or repeaters)
Data rates:	9,6 / 19,2 / 45,45 / 93,75 / 187,5 / 500 / 1 500 / 3 000 / 6 000 / 12 000 kbit/s, additional data rates can be supported.
[a] Repeater extents the characterists, see Table 106.	
NOTE In contrast to the ANSI TIA/EIA RS-485-A recommendations it is good practice to allow longer stubs, if the total of the capacities of all stubs (Cstges) does not exceed the following values: 0,05 nF at 3, 6 and 12 Mbit/s. 0,2 nF at 1,5 Mbit/s. 0,6 nF at 500 kbit/s. 1,5 nF at 187,5 kbit/s. 3,0 nF at 93,75 kbit/s. 15 nF at 9,6 and 19,2 kbit/s.	

The line length and number of connected stations may be increased by using repeaters. A maximum of 3 repeaters between two stations is permissible. If the data rate is ≤ 93,75 kbit/s and if the linked sections form a chain (linear bus topology, no active star, for example, as in Figure 98) and assuming a conductor cross-sectional are of 0,22 mm^2, the maximum permissible topology is shown in Table 106.

Table 106 — Characteristics using repeaters

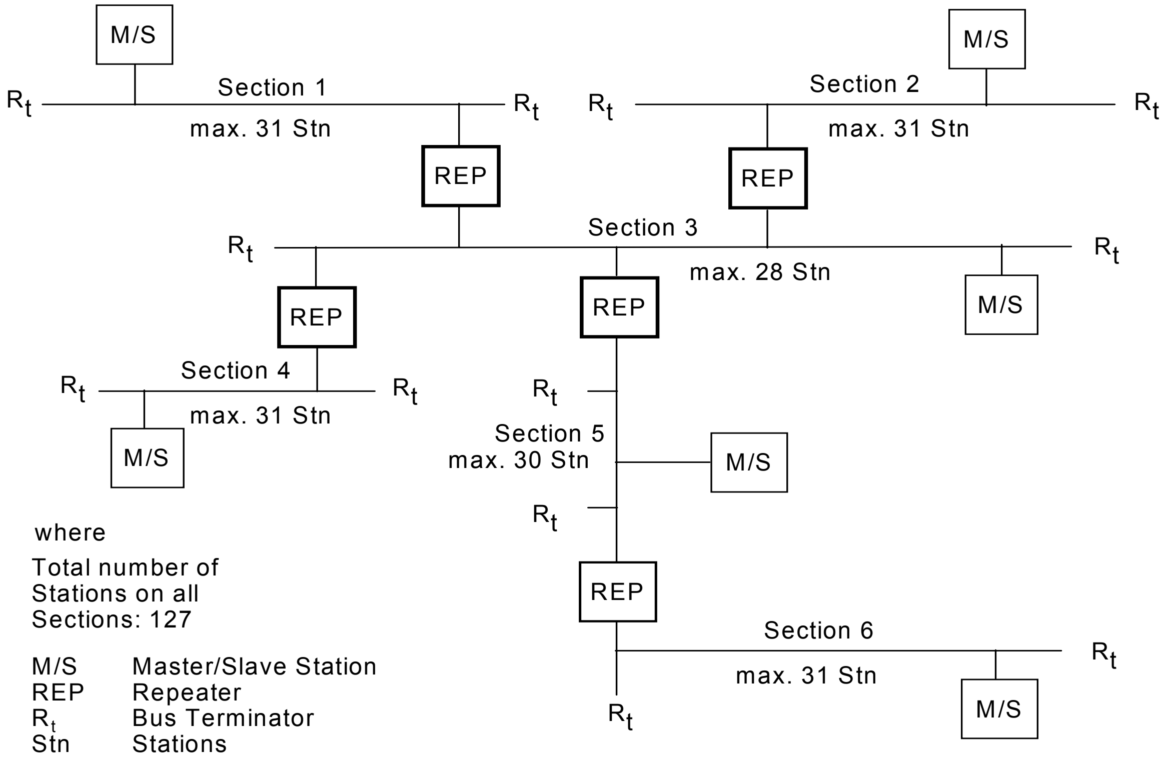
Number of repeaters	Characteristic	Constraints
1	Line Length	< 2,4 km
	Number of stations	62 (Master stations, slave stations or repeaters)
2	Line Length	< 3,6 km
	Number of stations	92 (Master stations, slave stations or repeaters), see Figure 98
3	Line Length	< 4,8 km
	Number of stations	122 (Master stations, slave stations or repeaters)



where
M/S Master/Slave Station
REP Repeater
R_t Bus Terminator

Figure 98 — Repeater in linear bus topology

In a tree topology, for example, as in Figure 99, more than 3 repeaters may be used and more than 122 stations may be connected, for example, 5 repeaters and 127 stations. A large area may be covered by this topology, for example, 4,8 km length at a data rate less than 93,75 kbit/s and a cross-sectional area of 0,22 mm^2.



where

Total number of Stations on all Sections: 127

M/S	Master/Slave Station
REP	Repeater
R_t	Bus Terminator
Stn	Stations

Figure 99 — Repeater in tree topology

22.1.2 Medium specifications

22.1.2.1 Connector

The connector is specified in Annex I.2.1.

22.1.2.2 Cable

The bus medium is a shielded twisted-pair cable. The shield helps to improve the electromagnetic compatibility (EMC). Unshielded twisted-pair may be used, if there is no severe electromagnetic interference (EMI).

The characteristic impedance of the cable shall be in the range between 100 and 220 Ω, the cable capacity (conductor - conductor) should be less than 60 pF/m and the conductor cross-sectional area should be equal or greater than 0,22 mm^2. Cable selection criteria are included in the appendix of the ANSI TIA/EIA RS-485-A.

Two types of cables are defined, as specified in Table 107.

Table 107 — Cable specifications

Cable parameter	Type A	Type B
Impedance	135 to 165 Ω (f = 3 to 20 MHz)	100 to 130 Ω (f > 100 kHz)
Capacity	< 30 pF/m	< 60 pF/m
Resistance	< 110 Ω/km	not specified
Conductor cross-sectional area	≥ 0,34 mm^2	≥ 0,22 mm^2
Colour of sheath non-IS	Violet	Not specified
Colour of inner cable conductor A (RxD/TxD-N)	Green	Not specified
Colour inner cable conductor B (RxD/TxD-P)	Red	Not specified

Table 108 shows the maximum length of cable type A and cable type B for the different transmission speeds.

Table 108 — Maximum cable length for the different transmission speeds

Item	Unit	Value								
Data rate	kbit/s	9,6	19,2	93,75	187,5	500	1 500	3 000	6 000	12 000
Cable type A	m	1 200	1 200	1 200	1 000	400	200	100	100	100
Cable type B	m	1 200	1 200	1 200	600	200	70	Not permissible		

For data rates equal or less 1 500 kbit/s the sum of the stub lengths (total of the capacities of all stubs (Cstges)) is specified in 22.1. For example at 1 500 kbit/s the maximum stub length for cable type A is 6,6 m.

At 3 Mbit/s and higher data rates the total capacities of all stubs shall be less than 0,05 nF. For cable type A the total stub length is therefore 1,6 m. At this data rate it is necessary to integrate impedance into the wiring to avoid reflections.

The following example, Figure 100, shows the integration of inductances L1 to L4 in the connector.

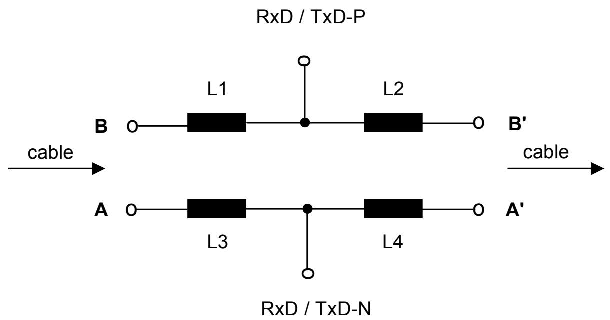


Figure 100 — Example for a connector with integrated inductance

For cable type A the inductances L1 to L4 shall have the value of 110 nH ±22 nH with the following constraint:

The resistance between A and A' as well as B and B' shall be ≤ 0,35 Ω.

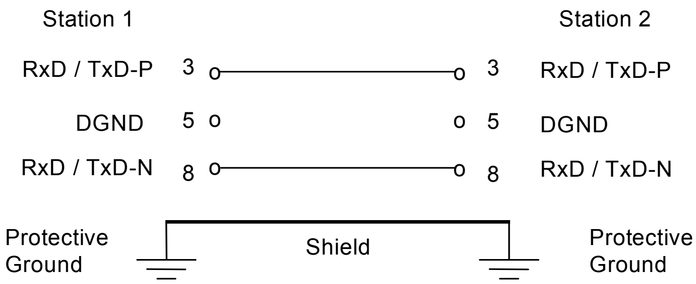
The typical capacity of each connected station (connector, cable to ANSI TIA/EIA RS-485-A Transceivers, Transceivers itself and other parts) shall be: 15 to 25 pF.

NOTE 1 The calculation of the inductance includes the contribution of the connected station. In case of disconnection of such connectors wiring reflections may occur which cause distortion on the bus.

The dependency of the permissible data rate upon the local link expanse (maximum distance between two stations) is shown in Figure 2-A.1 of the ANSI TIA/EIA-422-B (also included in ITU-T V.11).

NOTE 2 The recommendations concerning the line length presume a maximum signal attenuation of 6 dB. Experience shows that the distances may be doubled if conductors with a cross-sectional area ≥ 0,5 mm^2 are used.

The minimum wiring between two stations is shown in Figure 101.



NOTE Inversion of the two wires is not allowed!

Figure 101 — Interconnecting wiring

The wiring shown in Figure 101 allows a common mode voltage between both stations (that is, the voltage difference between the protective grounds) of at most ± 7 V. If a higher common mode voltage is expected, a compensation conductor between the grounding points shall be installed.

22.1.2.3 Grounding and shielding rules

If a shielded twisted-pair cable is used it is recommended to connect the shield to the protective ground at both ends of the cable via low impedance (that is, low inductance) connections. This is necessary to achieve a reasonable electromagnetic compatibility.

Preferably the connections between the cable shield and the protective ground (for example, the metallic station housing) should be made via the metallic housings and the metallic fixing screws of the sub-D connectors. If this is not possible the pin 1 of the connectors may be used.

22.1.2.4 Bus terminator

The bus cable Type "A" and "B" shall be terminated at both ends with R_{tA} respectively R_{tB}. The termination resistor R_t specified in ANSI TIA/EIA RS-485-A shall be complemented by a pulldown resistor R_d (connected to Data Ground DGND) and by a pullup resistor R_u (connected to Voltage-Plus VP), as shown in Figure 102. This supplement forces the differential mode voltage (that is, the voltage between the conductors) to a well-defined value when no station is transmitting (during the idle periods).

Each station that is destined to terminate the line (in common with a bus terminator) shall make Voltage-Plus (for example, + 5 V ± 0,25 V) available at pin 6 of the bus connector.

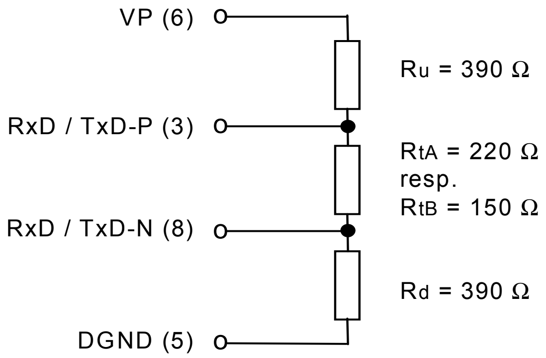


Figure 102 — Bus terminator

Assuming a power supply voltage of +5 V ±0,25 V the following resistor values are recommended:

R_{tA} = 220 Ω ±4,4 Ω, min. 1/4 W;

R_{tB} = 150 Ω ±3 Ω, min. 1/4 W;

R_u = R_d = 390 Ω ±7,8 Ω, min. 1/4 W

The power source supplying pin 6 (VP) shall be able to deliver a current of at least 10 mA within the specified voltage tolerances.

A mixture of both cable types and cable termination resistors as described above is allowed. However, the maximum line length has to be reduced up to the half of the above fixed values if line termination and line impedance do not match.

22.1.3 Transmission method

22.1.3.1 Bit coding

The "Non Return to Zero" (NRZ) coded data from DLL is transmitted via a twisted pair cable. A binary "1" (DL_symbol = "ONE") is represented by a constant positive differential voltage between pin 3 (RxD/TxD-P) and pin 8 (RxD/TxD-N) of the bus connector, a binary "0" (DL_symbol = "ZERO") by a constant negative differential voltage.

22.1.3.2 Transceiver control

When a station is not transmitting the transmitter output shall be disabled (DL_symbol = "SILENCE"), it shall present a high impedance to the line. During the idle periods, that is, when no data is transmitted by any station, the receive line signal shall represent a binary "1" (DL_symbol = "ONE"). Therefore the Bus Terminator shall force the differential voltage between the connector pins 3 and 8 to be positive when all transmitters are disabled. The line receivers shall always be enabled, therefore during idle the binary signal "1" is received by every station.

22.2 Medium attachment unit for intrinsic safety

22.2.1 Characteristics

This MAU specification describes a MAU for explosion protection type Ex i in accordace to IEC 60079-11 and IEC 60079-25 on the basis of balanced line transmission corresponding to ANSI TIA/EIA RS-485-A. Terminators, located at both ends of the twisted-pair cable, enable the PhL to support in particular higher speed transmission. The maximum cable length is 1 200 m for data rates ≤ 93,75 kbit/s. For the maximum transmission rate of 1 500 kbit/s the maximum cable length is reduced to 200 m. Only cable type A, see 22.2.2.2, shall be used with this MAU.

NRZ bit encoding is combined with ANSI TIA/EIA RS-485-A signaling targeted to low cost line couplers. Line terminators are required.

In all devices connected to the fieldbus the bus interface circuit shall be galvanically isolated from all other electrical circuits. Separation distances and insulation voltages between intrinsically safe circuits and/or non-intrinsically-safe circuits must meet the relevant applicable standards (e.g. IEC 60079-11).

Table 112 shows the required characteristics.

Table 109 — Characteristics for intrinsic safety

Characteristic	Constraints
Topology	Linear bus, terminated at both ends, stubs ≤ 0,3 m, no branches
Medium	Shielded twisted pair cable recommended, see "Medium specifications"
Line Length:	≤ 1 200 m, depending on the data rate
Number of stations:	32 (Master stations, Slave stations or fieldbus isolating repeaters and additionally 2 external bus terminators)
Data rates	9,6 / 19,2 / 45,45 / 93,75 / 187,5 / 500 / 1 500 kbit/s

The linear structure, as in Figure 103, permits connection points along the field bus segment similar to the installation of power supply circuits. The field bus cable should be looped through the individual field devices in order to avoid stubs.

A fieldbus isolating repeater or a comparable device normally forms the beginning of an intrinsically safe fieldbus segment. This fieldbus isolating repeater connects a non-intrinsically-safe fieldbus segment with the intrinsically safe fieldbus segment and simultaneously ensures reliable galvanic isolation between the two. The intrinsically safe fieldbus segment is terminated at both ends with an active bus termination. Up to 32 bus participants (field devices, fieldbus isolating repeater, external bus terminators etc.) can be arranged along the fieldbus segment. The bus participants are connected to a segment of the fieldbus in an electrically-floating arrangement.

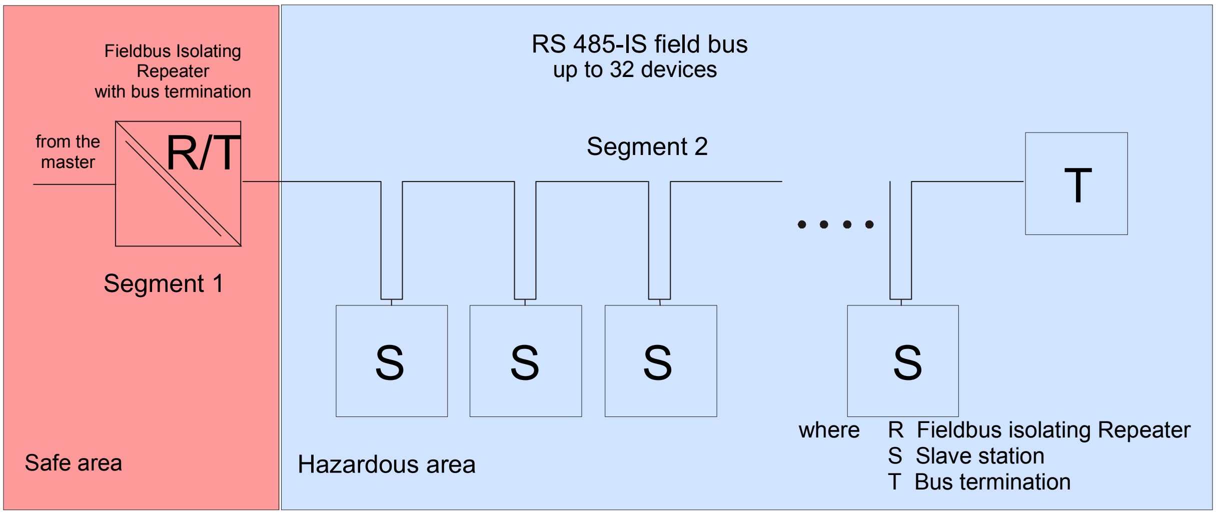


Figure 103 — Linear structure of an intrinsically safe segment

Figure 104 shows an example of the set-up and the segmentation of a fieldbus system with fieldbus isolating repeaters. The fieldbus segments 2 and 3 are intrinsically safe. The fieldbus isolating repeater between the intrinsically safe segments 2 and 3 must maintain galvanic isolation. The number of cascadable repeaters depends on the signal distortion and the delay of the signal (pay attention to the manufacturer's specifications).

Segment 3 in Figure 104 is started by means of a fieldbus isolating repeater in the middle of segment 3. Bus termination is provided at one end by means of an active bus termination and at the other end by means of another fieldbus isolating repeater which opens segment 4 into the safe area.

The bus terminations of an fieldbus segment can be located in a fieldbus isolating repeater, field device, in an active bus termination (as a stand-alone device), or in a connector powered from a filedbus isolating repeater or field device.

The repeater between segments 2 and 3 in Figure 104 shall be installed either outside of the hazardous area, as associated apparatus. The installation in the hazardous area requires additional explosion protection measures (e.g. Ex e, Ex d, Ex I, etc., in accordance with IEC 60079-0).

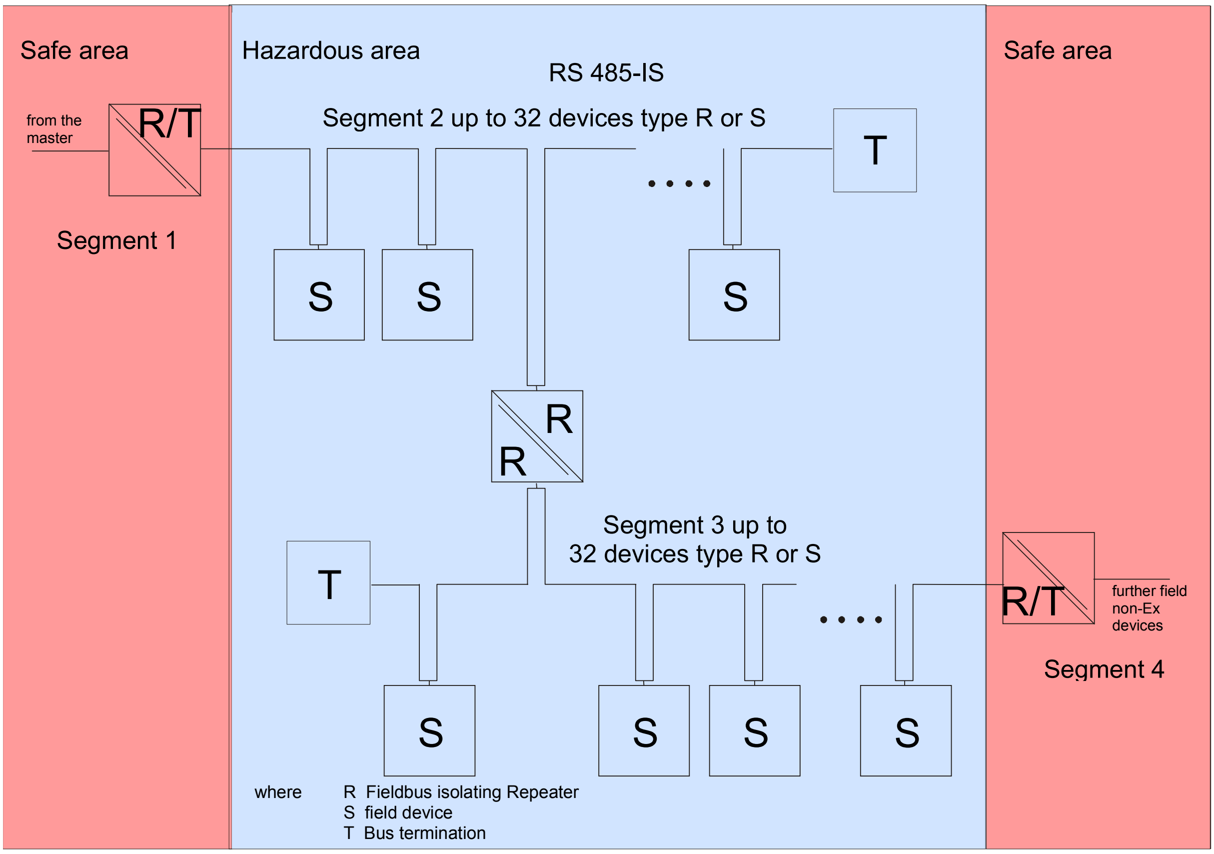


Figure 104 — Topology example extended by repeaters

22.2.2 Medium specifications

22.2.2.1 Connector

The connector is specified in Annex I.2.2.

22.2.2.2 Cable

Table 110 shows the specified cable parameters related to function and intrinsic safety.

Table 110 — Cable specification (function- and safety-related)

Cable parameter	Cable type A (see Note 1)	Limiting safety values
Surge impedance (Ω)	135…165 at a frequency of 3…20 MHz	Not relevant
Working capacitance (nF/km)	≤ 30	Not relevant
Wire diameter (mm)	> 0,64	> 0,1 single wire for a fine-stranded conductor (see Note 2) > 0,35 (see Note 3)
Core cross-sectional area (mm²)	> 0,34	> 0,096 2 (see Note 3)
Loop resistance (Ω/km)	≤ 110	Not relevant
L/R ratio (μH/Ω)	≤ 15	≤ 15 for the lowest ambient temperature (see Note 4)
Colour of sheath IS	Light blue	If colour is used for marking
Colour of inner cable conductor A (RxD/TxD-N)	Green	
Colour inner cable conductor B (RxD/TxD-P)	Red	

NOTE 1 In accordance with IEC 60079-14. The cable must fulfil the requirements for cables.

NOTE 2 In accordance with IEC 60079-14. The wire ends of fine-stranded conductors must be protected against separation of the strands, e.g. by means of cable lugs or core end sleeves,.

NOTE 3 This minimum value applies for a maximum ambient temperature of 40 °C and the temperature class T6 for a total current in the field bus cable of max. 4,8 A. According to IEC 60079-11 To get information on the ampacity at other ambient temperatures, this must be deduced from the existing requirements.In the case of the RS 485-IS, a maximum current of 4,8 A occurs in the field bus cable. This necessitates a wire cross section of ≥ 0,096 2 mm^2 (diameter: ≥ 0,35 mm) for a cable used in T6 and for a maximum ambient temperature of 40 °C. Because the permissible surface temperature of the cable shall not exceed 80 °C in the case of T6, the maximum temperature rise is 40 K for 4,8 A and the above-specified wire cross section. For cables deployed in T4 and higher ambient temperatures than 40 °C, the sum of the ambient temperature and the cable's temperature rise must not exceed 130 °C for a current of 4,8 A. In all cases, the insulation of the cable must be suitable for the maximum expected cable temperatures.

NOTE 4 Cable type A fulfils this requirement for a ambient temperature above –40 °C.

Table 111 shows the permissible maximum cable length depending on the transmission speeds.

Table 111 — Maximum cable length for the different transmission speeds

Item	Unit	Value					
Data rate	kbit/s	9,6	19,2	93,75	187,5	500	1 500
Cable type A	m	1 200	1 200	1 200	1 000	400	200

22.2.2.3 Grounding and shielding rules

NOTE 1 Grounding means permanently connected to earth through a sufficiently low impedance and with sufficient current-carrying capability to prevent voltage build-up which might result in undue hazard to connected equipment or persons. Zero volts (common) lines may be connected to ground where they are galvanically isolated from the fieldbus trunk.

Fieldbus devices shall not connect either conductor of the twisted pair to ground at any point in the network. Signals shall be applied and preserved differentially throughout the network.

NOTE 2 The fieldbus devices should allow d.c. isolation of the cable shield from ground. For intrinsically safe installations the grounding shall be in accordance to IEC 60079-14.

For shielding, see 12.8.6.

22.2.2.4 Bus terminator

The bus cable Type "A" shall be terminated at both ends with R_t. The termination resistor R_t specified in ANSI TIA/EIA RS-485-A shall be complemented by a pulldown resistor R_d (connected to Bus termination ground ISGND) and by a pullup resistor R_u (connected to Bus termination plus ISP), as shown in Figure 105. This supplement forces the differential mode voltage (that is, the voltage between the conductors) to a well-defined value when no station is transmitting (during the idle periods).

The termination of this MAU specification for explosion protection type Ex i differs from the specification of the non-intrinsic safe MAU on account of the modified electrical specification. In this context, the resistance values of the bus termination (see Figure 105) and the modified arrangement of the bus termination (see I.2.2) shall be paid attention when integrated into communication devices or plug connectors.

Each station that is destined to terminate the line (in common with a bus terminator) shall make a internal supply voltage U+ of + 3,3 V ± 5 % available.

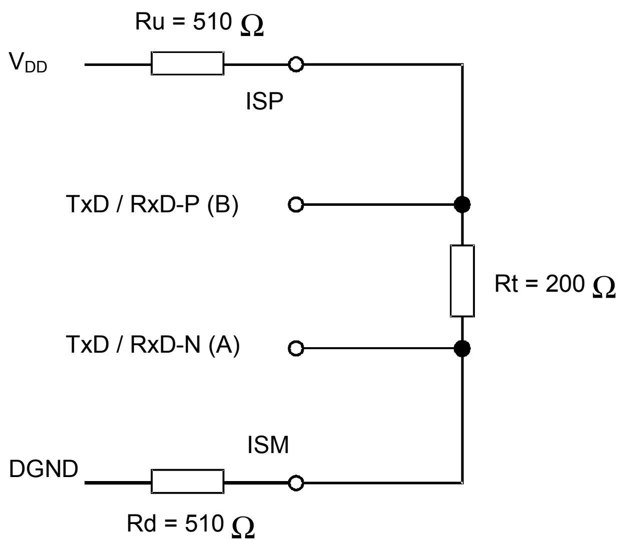


Figure 105 — Bus terminator

22.2.3 Transmission method

22.2.3.1 Bit coding

See 22.1.3.1.

22.2.3.2 Transceiver control

See 22.1.3.2.

22.2.3.3 Signal characteristics

22.2.3.3.1 Signal specification

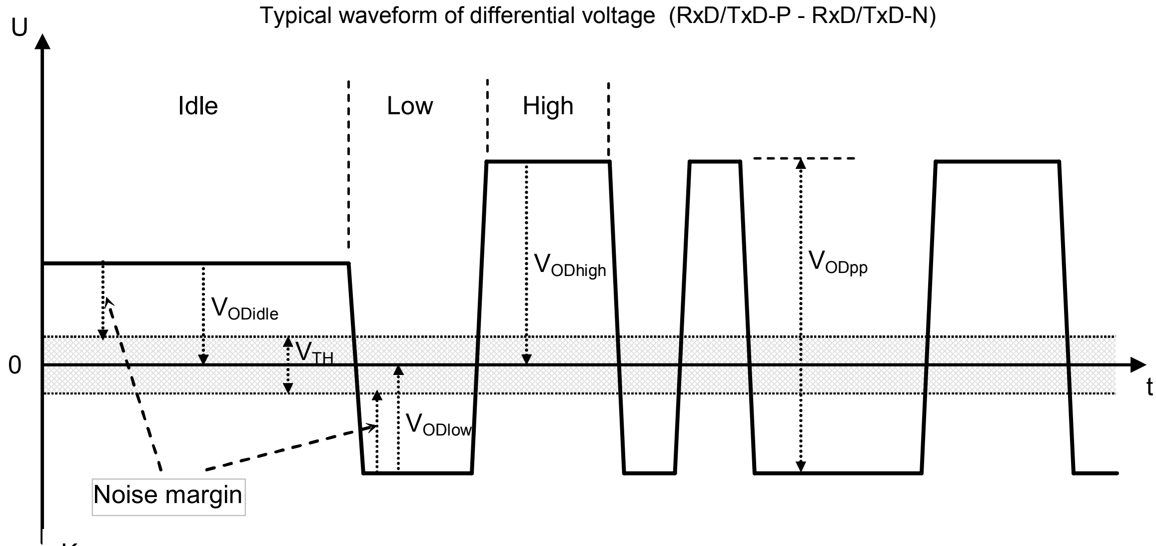
A typical voltage waveform on the intrinsically safe fieldbus is shown in Figure 106. Three phases are defined in which characteristic signal levels are generated on the bus:

idle state with V_{ODidle}

low phase with V_{ODlow}

high phase with V_{ODhigh}

The noise margin plays a crucial role in the definition of signal levels. The noise margin of a signal level is always the difference between the voltage corresponding to this level and the threshold voltage. The threshold voltage U_{TH} is an attribute of the ANSI TIA/EIA RS-485-A receiver according to ANSI TIA/EIA RS-485-A and is defined in the range of ±0,2 V. For reliable data transmission the noise margin shall be as large as possible. In the case of the MAU for intrinsically safe fieldbus, a minimum noise margin of 0,2 V shall be assured under "worst case" conditions.



Key

V_{ODidle} = differential voltage in the idle state (no transmitter active)
V_{ODlow} = differential voltage in the low phase
V_{ODhigh} = differential voltage in the high phase
V_{ODpp} = full output level (peak-to-peak)
V_{TH} = threshold voltage of the receiver (±0,2V acc. to ANSI TIA/EIA-485-A)

Figure 106 — Waveform of the differential voltage

The parameters listed in Table 112 are mandatory for the communication devices.

Table 112 — Electrical characteristics of the intrinsically safe interface

Parameter	Description	Value	Remark
Minimum idle level	V_{ODidle} [V]	0,50	Only relevant for devices with an integrated or a connectable bus termination
Transmission level on the bus connection (peak-to-peak)	V_{ODss} [V]	≥ 2,7	For the worst-case bus configuration and maximum load on the transmitter
Positive and negative transmission level on the bus connection	V_{ODhigh} [V]	≥ 1,5	For the worst-case bus configuration and maximum load on the transmitter
	V_{ODlow} [V]	≤ – 1,1	
Signal level on the receiver input	V_{IDhigh} [V]	≥ 0,8	For the worst-case bus configuration
	V_{Idlow} [V]	≤ – 0,4	
Data transmission rates	kbit/s	9,6; 19,2; 45,45; 93,75; 187,5; 500; 1 500	A field device can be designed with limited data transmission rate
Input impedance (receiver)	R_{IN} [kOhm] C_{IN} [pF] L_{IN}	≥ 12 ≤ 40 ≈ 0	For a device supplied or not supplied
Supply voltage RS 485 driver and bus termination	V_{DD} [V]	3,3 ±5 %	

22.2.3.3.2 Test circuits

22.2.3.3.2.1 General

The purpose of these measurements is the verification of the signal levels required by Table 112. The measurements should be performed statically at a low data transmission rate so that the existing reactances, like input capacitances, do not influence the measurement results. Furthermore, the bus cable is substituted by an equivalent resistance corresponding to the loop resistance for the maximum length of the bus cable.

NOTE Only the measurements which are specific for the intrinsically safe interface are described here. Additionally the compliance with ANSI TIA/EIA RS-485-A should be verified.

22.2.3.3.2.2 Measurement of the idle level

This measurement determines the characteristics of the termination resistance. For this reason, this measurement must only be performed on devices under test which are either equipped with a bus termination, see Figure 107, or provide a power supply for an external bus termination (the connections ISM and ISP are realised), see Figure 108.

NOTE The additional components as well as switch and resistors should be connected directly to the DUT terminals (5..15 cm). When a connecting cable must be used, the length of the cable must not exceed 1m.

The measurement is undertaken in two steps:

Step 1: the open circuit voltage V_1 is measured and must be greater than specified in Table 112, line 1.

Step 2: the voltage V_2 is measured under load conditions (330 Ω load). V_2 must be in a specified range ($0,65 \cdot V_1 \leq V_2 \leq 0,72 \cdot V_1$). That guarantees that the termination resistor is in the range 130 Ω to 180 Ω.

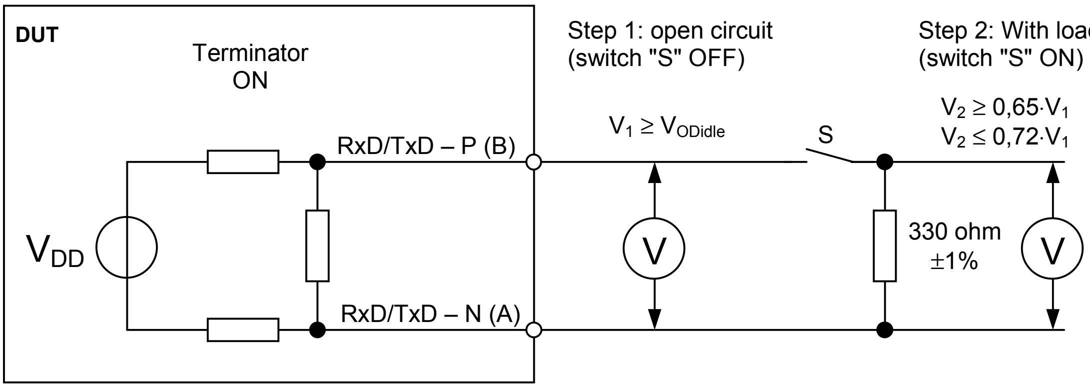


Figure 107 — Test set-up for the measurement of the idle level for devices with an integrated termination resistor

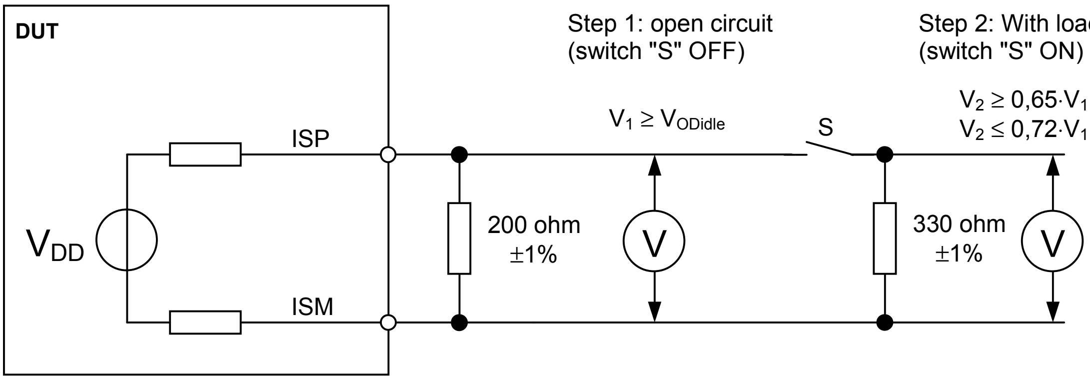


Figure 108 — Test set-up for the measurement of the idle level for devices with a connectable termination resistor

22.2.3.3.2.3 Measurement of the signal levels

For the measurement set-ups below A compliant fieldbus isolating repeater must be employed for connection on the master system. During the test, the intrinsically safe fieldbus shall be terminated at both ends in accordance with 22.2.2.4. If the bus termination is not integrated in the device under test, then an external compliant bus termination shall be used.

NOTE 1 In order to measure the signals on the intrinsically safe fieldbus without external influences, it is necessary to connect an electrically isolated oscilloscope (e.g. a hand-held with a battery supply).

NOTE 2 The additional components as well as resistor and resistor network should be connected as short as possible to the terminals of the DUT and the fieldbus isolating repeater. When a connecting cable must be used, the entire length of the cable(s) must not exceed 2 m. The oscilloscope can be attached to any suitable terminals according to set-up.

The measurement shown in Figure 109 determines the transmission levels on the transmitter connections and for a worst-case load. This is the case for a fieldbus cable length equal to zero. In this case, the output current of the transmitter and consequently the load is at maximum. The rated values for the transmission levels are shown in Table 112, lines 2 and 3.

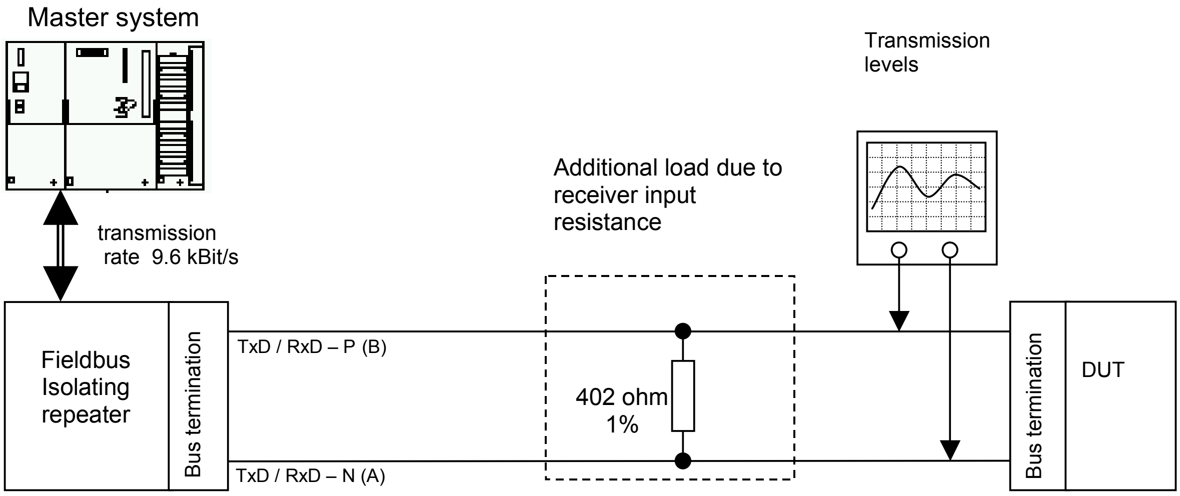


Figure 109 — Test set-up for measurement of the transmission levels

The measurement shown in Figure 110 attempts to verify the capability of the transmitter to generate a sufficient level for every receiver for a worst-case load. For a maximum fieldbus cable length of 1 200 m and additional load, this is the case roughly in the middle of the cable. The measurement values shall fulfill the requirements of Table 112, line 4.

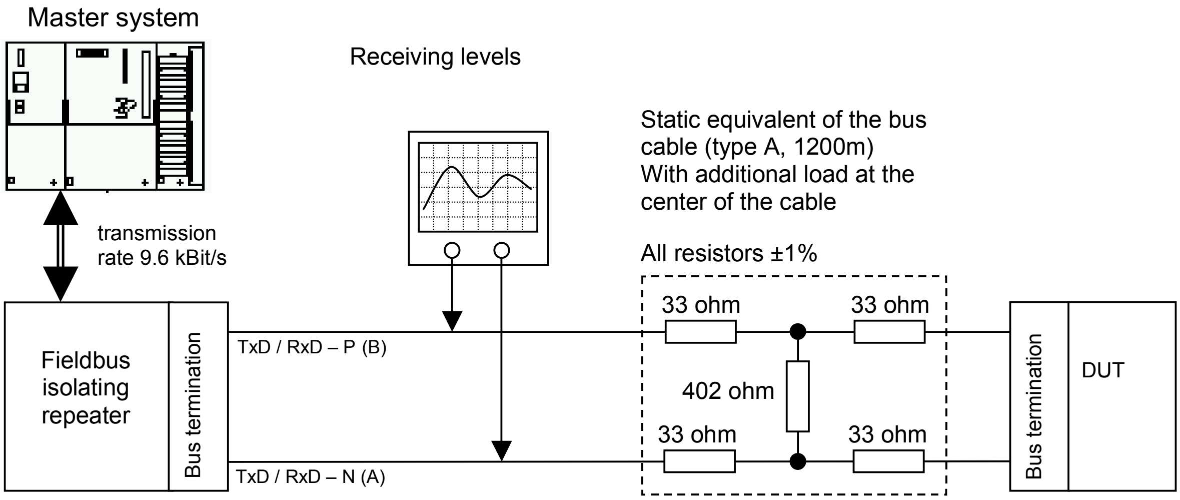


Figure 110 — Test set-up for the measurement of the receiving levels

22.2.4 Intrinsic safety

22.2.4.1 General

This standard does not attempt to list the requirements by which an item of equipment may be certified as intrinsically safe nor does it require equipment to be intrinsically safe. Rather, it seeks to exclude conditions or situations that would prevent intrinsic safety certification.

22.2.4.2 Fieldbus model for intrinsic safety

The intrinsically safe fieldbus is based on a model, in which all devices are active. All devices are supplied from outside and can provide power to the field bus. In an intrinsically safe circuit, only a maximum amount of energy is permissible when considering the inductances and capacitances which exist. This maximum amount of energy is described by the ignition curves.

NOTE 1 The analysis carried out by the PTB (Physikalisch-Technische Bundesanstalt) forms the basis for the intrinsically safe fieldbus." PTB-Mitteilungen, 113 Jahrgang, Heft 2/2003, Die Bewertung der Zündfähigkeit eigensicherer Stromkreise anhand eines Rechenverfahrens. Abschnitt: Der eigensichere RS 485 Feldbus als Anwendungsbeispiel."

A basic set-up of the fieldbus model is shown in Figure 111. A fieldbus isolating repeater is (usually) located in the non-hazardous area for the safe separation of the intrinsically-safe bus segment from the non-intrinsically-safe bus segment. Other connected communications devices are located in the hazardous area. The bus cable is terminated at both ends by means of an external active bus termination or a bus termination integrated in a field device. All communications devices are supplied by external voltage sources and possess the means of safely limiting the current and voltage on the bus.

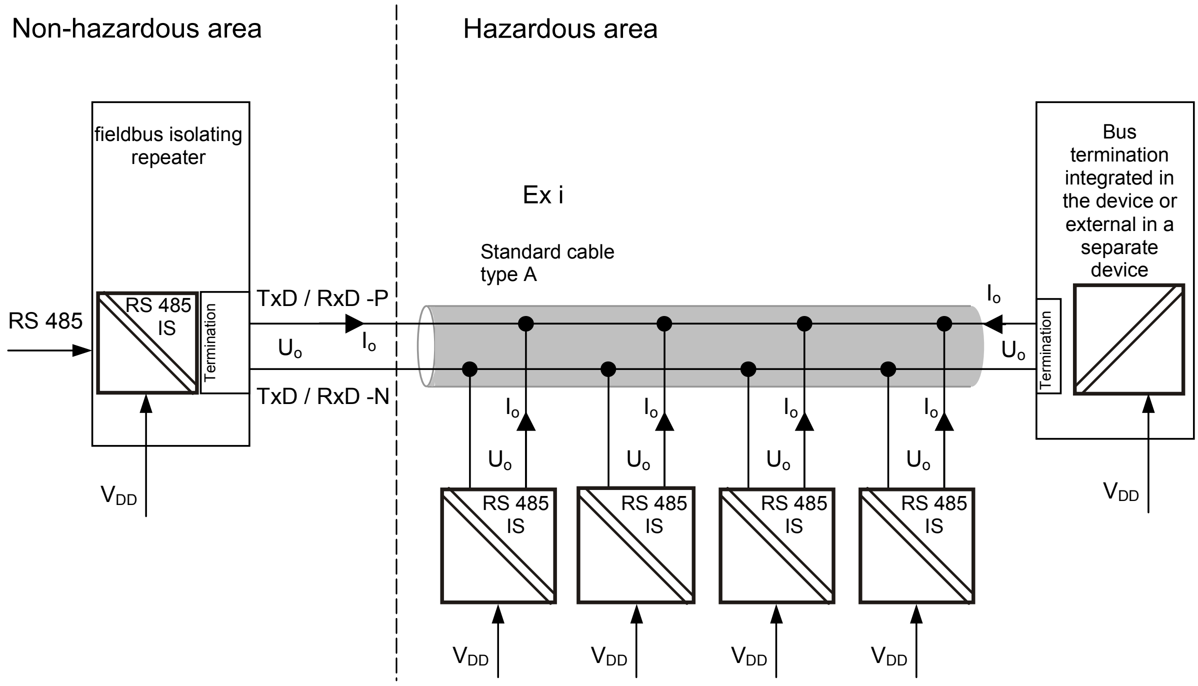


Figure 111 — Fieldbus model for intrinsic safety

NOTE 2 Under certain circumstances, devices which are installed in the hazardous area must be protected with additional explosion measures (e.g. Ex e, d, m in accordance with IEC 60079-0).

22.2.4.3 Model of a communication device

A circuit diagram for the RS 485-IS interface is described in Figure 112. The interface is composed of the components for galvanic isolation, voltage limitation, current limitation and an RS 485 transceiver.

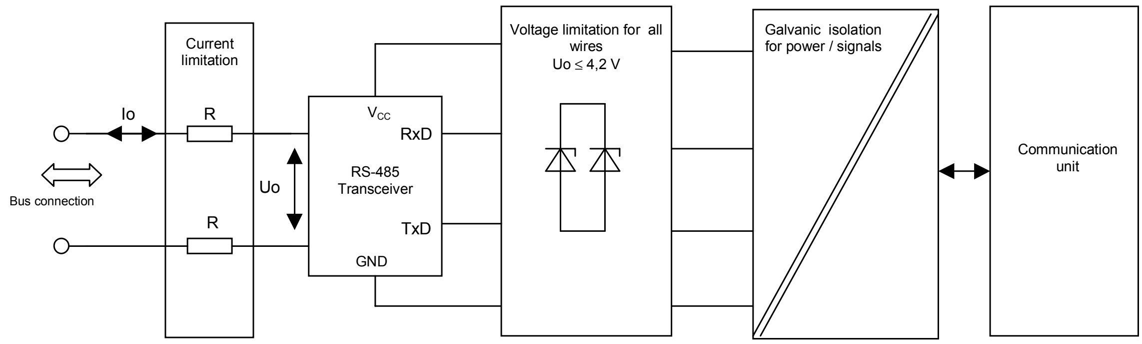


Figure 112 — Communication device model for intrinsic safety

To meet the limit for U_o given in Table 113 all connections to the bus interface (power supply and data lines) must be limited by appropriate voltage limiting components. In this context, the tolerances and the maximum power rating of the components must be taken into account. Under certain circumstances, suitable measures for power limitation should be introduced in the communications unit / power supply.

In all devices connected to the intrinsically safe the bus interface circuit shall be galvanically isolated from all other electrical circuits.

Separation distances and insulation voltages between intrinsically safe circuits and/or non-intrinsically-safe circuits shall meet IEC 60079-11.

NOTE Current limitation is determind by the maxium output voltage and the sum of the internal resistance. The internal resitace is formed by the series resistors of the data lines RxD/TxD-N and RxD/TxD-P and series resistors Ru and Rd for the supply of the bus terminator.

In this context, the tolerances and power ratings of the resistances must also be taken into account. Detailed requirements for the current- and voltage-limiting components are outlined in IEC 60079-11.

22.2.4.4 Maximum safety values

Table 113 shows the safety relevant parameters and their values for the entire fieldbus system.

Table 113 — Maximum safety values

Parameter	Description	Value	Remark
Bus system			
Maximum input voltage	U_I [V]	|±4,2|	
Maximum input current	I_I [A]	4,8	The characteristic of the circuit is linear Rs = Uo/Io
Maximum inductance to resistance ratio (see note)	L'/R' [μH/Ω]	15	For the whole operation temperature range of the bus system
Number of devices	N_{TN}	≤ 32	A field device can be designed with limited data transmission rate
Communication Device			
Maximum output voltage	Uo [V]	|±4,2|	
Maximum output current	Io [mA]	149	Total current from wires A, B and supply for bus termination
Maximum input voltage	U_I [V]	|±4,2|	
Maximum internal inductance	L_I [H]	0	No concentrated inductances are permissible along the fieldbus
Maximum internal capacitance	C_I [nF]	N/A	Insignificant for safety
External active bus termination			
Maximum output voltage	Uo [V]	|±4,2|	
Maximum output current	Io [mA]	16	
Maximum input voltage	U_I [V]	|±4,2|	
Maximum internal inductance	L_I [H]	0	No concentrated inductances are permissible along the fieldbus
Maximum internal capacitance	C_I [nF]	N/A	Insignificant for safety
NOTE For a voltage less than 10 V, the cable capacitance does not cause any additional danger. However, for functional reasons, the cable capacitance for the bus cable is limited to C' < 40 nF/km.			

NOTE For functional reasons, the current limitation resistance should be subdivided symmetrically.

22.2.4.5 Fieldbus isolating repeater

In order to create or connect intrinsically safe fieldbus segments, fieldbus isolating repeaters (see Figure 103 and Figure 104) are required. The intrinsically safe fieldbus interfaces of these devices must also be implemented in accordance with this MAU specification. In particular, the maximum safety data (see 22.2.4.4) and the galvanic isolation from all other circuits (see 22.2.1) shall be considered from the safety point of view.

The fieldbus isolating repeater shall be designed as associated apparatus. If the fieldbus isolating repeaters are to be installed in the hazardous area, additional explosion-protection measures are necessary.

23 Type 3: Medium attachment unit: asynchronous transmission, optical medium

23.1 Characteristic features of optical data transmission

Table 114 shows the characteristic features of an optical data transmission.

Table 114 — Characteristic features

Item	Feature
Transfer medium	Fiber optic cable (FOC) manufactured from quartz or plastic
Characteristics	- Large range, independent of the transmission speed - Insensitivity to electromagnetic disturbance - Galvanic isolation between the connected nodes - Non-reacting connection – even to existing implementations - Configuration of the optical components with economical, standard components
Network structure	Star, ring, line and mixed topologies (tree) Connection to electrical network segments
Network components	Active star coupler Repeater Opto-electrical converter } with or without retiming
Data rates	9,6 kbit/s; 19,2 kbit/s; 45,45 kbit/s; 93,75 kbit/s; 187,5 kbit/s; 500 kbit/s; 1,5 Mbit/s; 3 Mbit/s; 6 Mbit/s; 12 Mbit/s
Network range and number of nodes	Dependent on the number and type of network components used EXAMPLE 1 Network segment with 1 active star coupler and glass fiber optic cable (multimode) : - 3 400m (independent of the number of nodes). EXAMPLE 2 Network segment with 1 active star coupler and plastic fiber optic cable: - 88 m (independent of the number of nodes). NOTE Increasing of ranges and numbers of nodes is possible through linking network segments.

Figure 113 shows the optical MAU beside an ANSI TIA/EIA RS-485-A MAU. This means that the optical MAU shall be connected over a DL-Ph interface to a DLL in the same manner as an ANSI TIA/EIA RS-485-A MAU. The mentioned interface is described in 5.4.2.

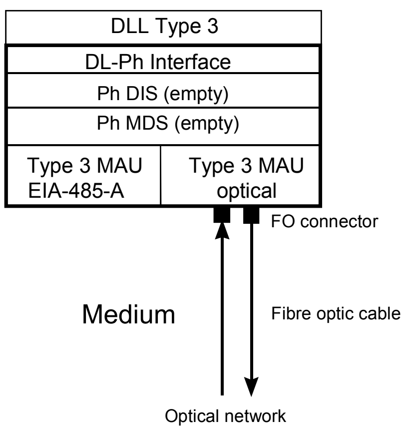


Figure 113 — Connection to the optical network

23.2 Basic characteristics of an optical data transmission medium

An optical data transmission medium is characterized by:

– Insensitivity to electromagnetic interference, i.e.:
  a) no cross talk between different fiber optic signal lines,
  b) immunity to interference injection from and to electrical lines,
  c) immunity to interference from electromagnetic fields which can occur e.g. when switching large electrical loads.
– Galvanic isolation between the connected nodes, i.e.:
  a) no equalizing currents between differing ground potentials
  b) no special lightning protection measures are required for the transmission link.
– The capability to use fiber optics to bridge large distances at high transmission speeds.
– Simple and economical installation of shorter networks based on plastic fibers.
– Low weight.
– No corrosion.
– Simplified standard cabling of buildings through identical reference fibers for many other communication standards.

23.3 Optical network

Significant components of the optical MAU of a node are the electro-optical converters that interface the electrical part of the MAU and an optical network medium.

An optical transmitter converts electrical signals into optical ones and feeds these signals into the optical medium. Conversely, an optical receiver converts the received optical signals from the optical medium into electrical signals.

Figure 114 shows the principal structure of an optical network.

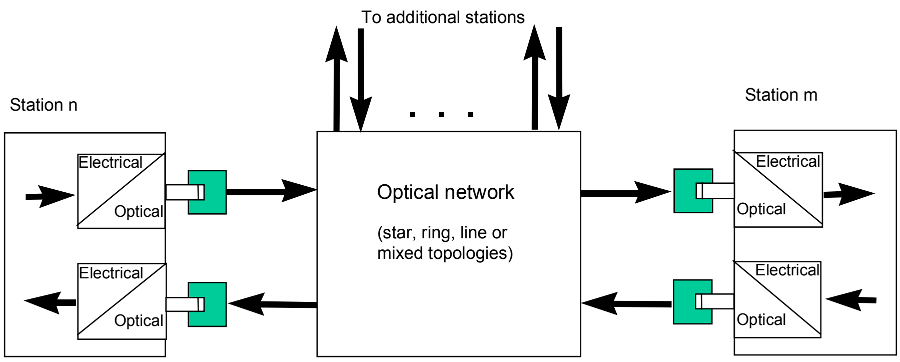


Figure 114 — Principle structure of optical networking

Electrical-optical converters with a specific signal level budget that take into account of the physical differences between glass and plastic fibers are specified for each fiber type.

The user can “consume” the signal level budget as attenuation along the optical link.

23.4 Standard optical link

The standard optical link is a theoretical construction that is used to specify the admissible range of signal levels and signal distortions, see Figure 115.

Network topologies of any complexity can be calculated from the standard optical link. The standard optical link consists of

- an electro-optical converter (transmitter) that converts an electrical signal into an optical signal which lies within the admissible limits specified by the signal template (see Figure 116);
- a passive optical link consisting of a fiber optic cable and characterized by signal amplitude attenuation and signal timing distortion;
- an opto-electrical converter (receiver) that detects the received optical signal as described in 23.7.3 and converts this signal to an electrical signal with characteristics specified in 23.8.

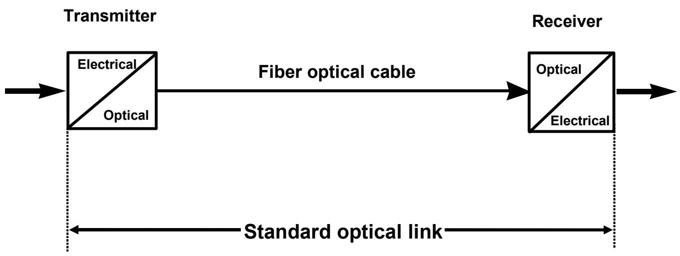


Figure 115 — Definition of the standard optical link

23.5 Network structures built from a combination of standard optical links

According to the definition above, a standard optical link forms an end-to-end connection. Standard optical links can be interconnected (chained) to build complex networks by interconnecting the electric interfaces. Chaining rules are specified in 23.8.3.

The user can thus specify the network structure by choosing the signal distribution to best meet the requirements of the system to be networked.

The following topologies are supported: star, ring or linear topologies, as well as their combination to form a mixed topology. Coupling of optical and electrical segments of the network (such as ANSI TIA/EIA RS-485-A MAU) is both possible and permissible.

23.6 Bit coding

NRZ bit coding (non return to zero) from the DLL is represented with optical signals as follows:

– binary "1" (DL_symbol = "ONE") means no light on the FOC,

– binary "0" (DL_symbol = "ZERO") means light on the FOC.

The idle state (DL_symbol = "SILENCE") has the “1” binary state, i.e. no light.

23.7 Optical signal level

23.7.1 General

Taking into account the physical differences between glass and plastic fibers, a specific level budget is applicable for both fiber types.

23.7.2 Characteristics of optical transmitters

The transmitted power is specified in dBm.

The specified levels are defined at the end of a 1m long glass fiber optic cable or a 0,5 m long plastic fiber optic cable and measured with a large detector area. Cladding modes must not be included in the measured value. The fiber optic cable must be connected to the transmitter using the connector specified in 23.10. That is, the attenuation of the connector at the optical transmitter is included in the measured value.

The signal level tolerances are applicable for the entire operating temperature range (ambient temperature of the transmitter element).

All values specified in the following Table 115 to Table 118 are based on the shape of the transmit signal specified by the signal template in Figure 116. The technical terms used in the table (peak wavelength, etc.) are explained in IEC 60050-731.

Table 115 — Characteristics of optical transmitters for multi-mode glass fiber

Quantity	Value	Unit
Peak wavelength	790 to 910	nm
Spectral width	≤ 75	nm
Operating temperature	0 to 70	°C
Test fiber (graded index) (see note)	62,5/125	µm
NA (numerical aperture of the test fiber)	0,275 ± 0,015	
$P_{Smax“0“}$ (max. transmit power for binary “0“)	-10	dBm
$P_{Smin“0“}$ (min. transmit power for binary “0“)	-15	dBm
$P_{Smax“1“}$ (max. transmit power for binary “1“)	-40	dBm
P_{Sost} (max. overshoot, transmit power for binary “0“)	-8,8	dBm
NOTE Test fiber as specified in IEC 60793, Type A1b.		

Table 116 — Characteristics of optical transmitters for single-mode glass fiber

Quantity	Value	Unit
Peak wavelength	1 260 to 1 380	nm
Spectral width	≤ 120	nm
Operating temperature	0 to 70	°C
Test fiber (graded index) (see note)	9/125	µm
NA (numerical aperture of the test fiber)	0,113 ± 0,02	
$P_{Smax“0“}$ (max. transmit power for binary “0“)	-10	dBm
$P_{Smin“0“}$ (min. transmit power for binary "0“)	-20	dBm
$P_{Smax“1“}$ (max. transmit power for binary “1“)	-40	dBm
P_{Sost} (max. overshoot, tx power for “0“)	-8,8	dBm
NOTE Test fiber as specified in IEC 60793, Type B1.1, B3.		

Table 117 — Characteristics of optical transmitters for plastic fiber

Quantity	Value		Unit
Peak wavelength	640 to 675		nm
Spectral width	≤ 35		nm
Operating temperature	0 to 70		°C
Test fiber (graded index) (see Note)	980/1 000		µm
NA (numerical aperture of the test fiber)	0,5 ± 0,15		
Transmitter power level	Standard	Increased	
$P_{Smax“0“}$ (max. transmit power for binary “0“)	-5,0	0	dBm
$P_{Smin“0“}$ (min. transmit power for binary “0“)	-11	-6	dBm
$P_{Smax“1“}$ (max. transmit power for binary “1“)	-42	-42	dBm
P_{Sost} (max. overshoot, transmit power for binary “0“)	-4,3	2,3	dBm
NOTE Test fiber as specified in IEC 60793, Type A4a.			

Table 118 — Characteristics of optical transmitters for 200/230 µm glass fiber

Quantity	Value	Unit
Peak wavelength	640 to 675	nm
Spectral width	≤ 35	nm
Operating temperature	0 to 70	°C
Test fiber (stepped index) (see Note)	200/230	µm
NA (numerical aperture of the test fiber)	0,37 ± 0,02	
$P_{Smax“0“}$ (max. transmit power for binary “0“)	-8	dBm
$P_{Smin“0“}$ (min. transmit power for binary “0“)	-17	dBm
$P_{Smax“1“}$ (max. transmit power for binary “1“)	-44	dBm
P_{Sost} (max. overshoot, transmit power for binary “0“)	-6,8	dBm
NOTE Test fiber in IEC 60793, Type A3c: NA = 0,4 ± 0,04.		

23.7.3 Characteristics of optical receivers

The input sensitivity of receivers is also specified in dBm see Table 119 to Table 122 The input sensitivity is measured at the end of the specified reference fiber with a large detector area. Cladding modes shall not be included in the measured value.

The signal level tolerances are applicable for the entire operating temperature range (ambient temperature of the receiver element). They shall be maintained throughout the specified lifetime of the receive element. The shape of the receive signal is based on the shape of the transmit signal shown in the signal template in Figure 116.

The receiver shall tolerate an overshoot of the input signal at the beginning of a binary “0” pulse. However, the receiver shall not require an overshoot, e.g. to maintain a required signal distortion.

Table 119 — Characteristics of optical receivers for multi-mode glass fiber

Quantity	Value	Unit
Peak wavelength	790 to 910	nm
Operating temperature	0 to 70	°C
$P_{Emax“0“}$ (max. receive power for binary “0“)	-10	dBm
$P_{Emin“0“}$ (min. receive power for binary “0“)	-24	dBm
$P_{Emax“1“}$ (max. receive power for binary “1“)	-42	dBm

Table 120 — Characteristics of optical receivers for single-mode glass fiber

Quantity	Value	Unit
Peak wavelength	1 260 to 1 380	nm
Operating temperature	0 to 70	°C
$P_{Emax“0“}$ (max. receive power for binary “0“)	-10	dBm
$P_{Emin“0“}$ (min. receive power for binary “0“)	-27	dBm
$P_{Emax“1“}$ (max. receive power for binary “1“)	-40	dBm

Table 121 — Characteristics of optical receivers for plastic fiber

Quantity	Value		Unit
Peak wavelength	640 to 675		nm
Operating temperature	0 to 70		°C
Receiver for tx performance level	Standard	Increased	
$P_{Emax“0“}$ (max. receive power for binary “0“)	-5	0	dBm
$P_{Emin“0“}$ (min. receive power for binary “0“)	-20		dBm
$P_{Emax“1“}$ (max. receive power for binary “1“)	-42		dBm

Table 122 — Characteristics of optical receivers for 200/230 µm glass fiber

Quantity	Value	Unit
Peak wavelength	640 to 675	nm
Operating temperature	0 to 70	°C
$P_{Emax“0“}$ (max. receive power for binary “0“)	-8	dBm
$P_{Emin“0“}$ (min. receive power for binary “0“)	-22	dBm
$P_{Emax“1“}$ (max. receive power for binary “1“)	-44	dBm

23.8 Temporal signal distortion

23.8.1 General

The following sections describe the signal distortion due to each of the elements in the transmission link.

Evaluation of the electrical digital signals always takes place at the intersection with 50 % of the signal amplitude.

23.8.2 Signal shape at the electrical input of the optical transmitter

The permissible signal distortion at the electrical input of the optical transmitter of a station or a component with retiming is shown in Table 123.

Table 123 — Permissible signal distortion at the electrical input of the optical transmitter

Signal	Limits for data rates < 1,5 Mbit/s	Limits for data rates ≥ 1,5 Mbit/s (Note 1)
t_{BIT} (Note 2)	1/ Data_rate × (1 ± 0,3 %)	1/ Data_rate × (1 ± 0,03 %)
t_{SBIT} (only for stop bit) (Note 3)	t_{BIT} × (1 ± 6,25 %)	

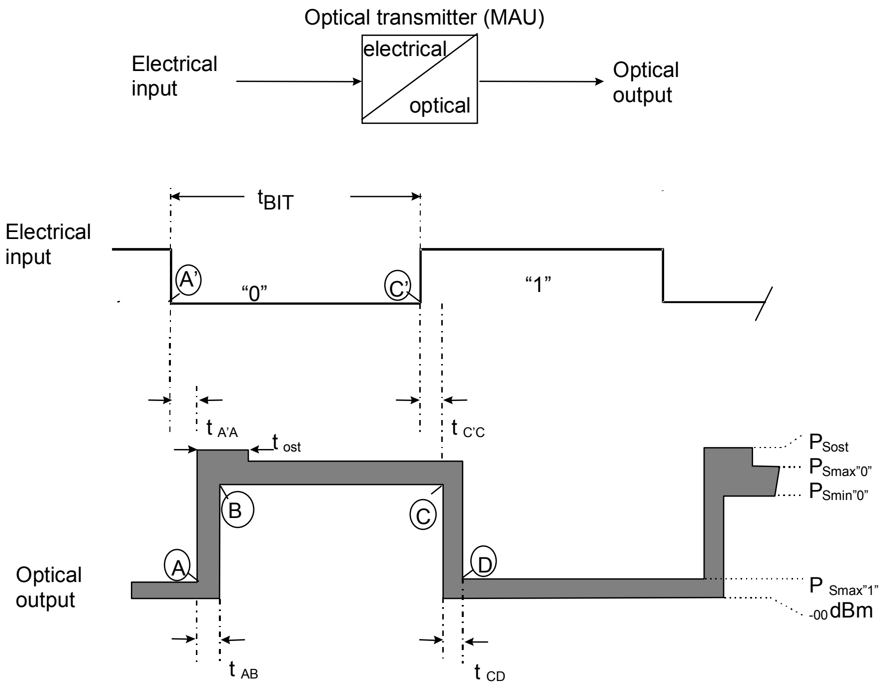
NOTE 1 Data rate is the nominal data rate specified in Table 114.

NOTE 2 t_{BIT} is the time, which elapses during the transmission of one bit. It is equivalent to the reciprocal value of the transmission rate.

NOTE 3 t_{SBIT} is the extended tolerance for the permissible bit duration in the optical network that applies exclusively to the transmitted stop bit. This extension of the tolerance allows repeaters with retiming to equalize deviations in the receive and transmit clocks.

23.8.3 Signal distortion due to the optical transmitter

To meet the specified requirements, the transmit signal of the optical transmitter shall be within the shaded section of the signal template in Figure 116, with parameters as given in Table 124.



where

t_{ost} = the maximum duration that the maximum optical transmit power can be exceeded dynamically.

t_{AB} = the rising edge of the optical signal must pass through $P_{Smax“1“}$ to $P_{Smin“0“}$ within this time.

t_{CD} the falling edge of the optical signal must pass through $P_{Smin“0“}$ to $P_{Smax“1“}$ within this time.

$t_{A'A}$ the shortest duration signal delay due to the electro-optical converter for a level change from “1“ to “0“ (rising optical edge).

$t_{C'C}$ the shortest duration signal delay due to the electro-optical converter for a level change from “0“ to “1“ (falling optical edge).

Figure 116 — Signal template for the optical transmitter

The optical transmitter shall meet the template specifications at ≤1,5 Mbit/s and 3 Mbit/s to 12 Mbit/s as shown in Table 124.

Table 124 — Permissible signal distortion due to the optical transmitter

Time	≤ 1,5 Mbit/s	3 Mbit/s to 12 Mbit/s	Unit
t_{ost}	200	20	ns
t_{AB}	40	25	ns
t_{CD}	95	25	ns
$t_{A'A}$ - $t_{C'C}$	65	5	ns

23.8.4 Signal distortion due to the optical receiver

The maximum distortion of the receiver’s electrical output signal compared to the optical input signal is specified in Table 125. This applies to the entire input level range specified in 23.7.3.

Table 125 — Permissible signal distortion due to the optical receiver

Time	≤ 1,5 Mbit/s	3 Mbit/s to 12 Mbit/s	Unit
$t_{dis“0“}$ (see note)	-20 to 95	-25 to 25	ns
NOTE $t_{dis“0“}$ describes the permissible limits of the bit duration distortion for a “0“ bit.			

23.8.5 Signal influence due to coupling components

Coupling components, such as active star couplers, ANSI TIA/EIA RS-485-A/optical-MAU converters or repeaters contain internal logic that influences the propagated signal beyond that due to the electro-optical converter that was described above.

The maximum influence shall be within the limits specified in Table 126:

Table 126 — Permissible signal influence due to internal electronic circuits of a coupling component

Time	≤ 1,5 Mbit/s	3 Mbit/s to 12 Mbit/s	Unit
t_{log} (see Note 1)	-0 to 10	-0 to 10	ns
t_{delay} (see Note 2)	≤ 3 t_{BIT}	≤ 8 t_{BIT}	ns
NOTE 1 t_{log} describes the maximum permissible signal distortion due to the internal logic of a coupling component (for example an active star coupler) with no retiming. This factor must be considered when chaining standard optical links and is already taken into account in Table 127. NOTE 2 t_{delay} describes the maximum permissible signal delay between any input and output when passing through a coupling component (for example an active star coupler).			

23.8.6 Chaining standard optical links

If the network consists of standard optical links connected in series (chaining), the sum of the distortions of individual links shall not exceed the overall permissible bit duration distortion of a node interface, which is 25 % (≤ 1,5 Mbit/s) or 30 % (12 Mbit/s).

Since the distortions of the electro-optical converters represent absolute values, they become increasingly important at higher data transmission rates.

If standard optical links are chained without a retiming device, the calculated maximum number of links between two nodes and/or retiming components shall not exceed the values shown in Table 127.

Table 127 — Maximum chaining of standard optical links without retiming

Data rate	Number of links in series (≤1,5 Mbit/s, see Note 1)	Number of links in series (3 Mbit/s to 12 Mbit/s, see Note 2)
12 Mbit/s	–	1
6 Mbit/s	–	2
3 Mbit/s	–	4
1,5 Mbit/s	1	8
500 kbit/s	3	24
187,5 kbit/s	8	64
93,75 kbit/s	16	128
45,45 kbit/s	33	264
19,2 kbit/s	78	625
9,6 kbit/s	156	1 250
NOTE 1 Devices designed for max. data transmission rate of 1,5 Mbit/s.		
NOTE 2 Devices designed for max. data transmission rate of 12 Mbit/s.		

Any required degree of chaining is possible if the coupling components re-establish the timing between the optical links (retiming).

23.9 Bit error rate

A maximum bit error rate (BER) of 10^{-9} is permitted at the electrical output of a standard optical link.

23.10 Connectors for fiber optic cable

The connectors are specified in Annex I.2.2.

23.11 Redundancy in optical transmission networks

A redundant optical link analogous to the Type 3 electrical transmission technology is also possible. The functional principle is described in Annex J.

24 Type 4: Medium attachment unit: RS-485

24.1 General

The RS-485 MAU can be used to connect up to 125 fieldbus devices on the same cable. The length of the cable can be up to 1 200 m, and the Baud rate can be 9 600, 19 200, 38 400 or 76 800.

24.2 Overview of the services

The MDS-MAU interface makes services available to connect the MDS with a corresponding MAU. The TxS and RxS services are defined as logical signals that the MAU sublayer directly converts into physical signals. The TxE service is defined as a logical signal that is used internally in the MAU. The services of the RS-485 MDS-MAU interface are shown in Table 128.

Table 128 — Services of the MDS-MAU interface, RS-485, Type 4

Signal name	Mnemonic	Direction
Transmit Signal	TxS	To MAU
Transmit Enable	TxE	To MAU
Receive Signal	RxS	From MAU

24.3 Description of the services

24.3.1 Transmit signal (TxS)

This service transmits the PhPDU from the MDS to the MAU, where it shall be transmitted on to the medium if Transmit Enable (TxE) is set to logic 1 (high level).

24.3.2 Transmit enable (TxE)

The Transmit Enable service (TxE) shall provide the MDS with the facility to enable the MAU to transmit. TxE shall be set to logic 1 (high level) by the MDS immediately before the transmission begins, and to logic 0 (low level) minimum 3, maximum 10 bit periods after transmission ends.

24.3.3 Receive signal (RxS)

This service transmits the PhPDU from the MAU to the MDS.

24.4 Network

24.4.1 General

This MAU operates in a network that consists of the following components:

– cable;

– connectors;

– devices (containing at least one communication element).

24.4.2 Topology

This MAU shall operate in a bus structure organized as a physical ring without termination. Up to 125 fieldbus devices are connected directly or via stubs of maximum length 2 m. The total length of the cable shall not exceed 1 200 m.

24.5 Electrical specification

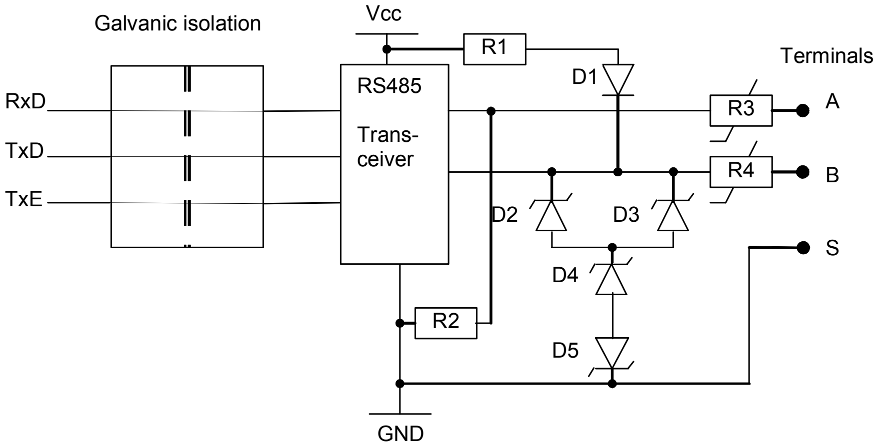
The voltage levels of the transmitter and receiver can be taken from ANSI TIA/EIA-485-A.

24.6 Time response

The time response of the transmitter and receiver can be taken from ANSI TIA/EIA-485-A.

24.7 Interface to the transmission medium

A recommended circuit for coupling to the transmission medium is shown in Figure 117.



Component values:

R1, R2	15 kΩ
R3, R4	PTC, max 13 Ω; hold current 100 mA
D1	100 mA small signal diode
D2, D3, D4, D5	3.9 V / 1 W Voltage regulator diode

Figure 117 — Recommended interface circuit

24.8 Specification of the transmission medium

24.8.1 Cable connectors

Normally, fieldbus devices are equipped with screw terminals marked A, B and S for shield.

24.8.2 Cable

A shielded twisted pair cable with conductors with minimum 0,22 mm^2 cross section and a characteristic impedance of 100 to 120 Ω.

25 Type 4: Medium attachment unit: RS-232

25.1 General

The RS-232 MAU can be used to connect two fieldbus devices (point-to-point). The devices may be connected directly with an RS-232 cable, or can be connected through for example an external or a built-in modem or radio transmitter. Therefore, signal levels, cable and connectors are not defined for this MAU. Depending on selected medium, the baud rate can be 9 600, 19 200, 38 400, 76 800 or 230 400.

If two devices are connected directly with an RS-232 cable, signal levels and timing shall follow the recommendations in ANSI TIA/EIA-232-F.

25.2 Overview of the services

The MDS-MAU interface makes services available to connect the MDS with a corresponding MAU. The TxS and RxS services are defined as logical signals that the MAU sublayer directly converts into physical signals. The RTS and CTS services are defined as logical signals that are used internally in the MAU. The services of the RS-232 MDS-MAU interface are shown in Table 129.

Table 129 — Services of the MDS-MAU interface, RS-232, Type 4

Signal name	Mnemonic	Direction
Transmit signal	TxS	to MAU
Receive signal	RxS	from MAU
Request-to-send	RTS	to MAU
Clear-to-send	CTS	from MAU

25.3 Description of the services

25.3.1 Transmit signal (TxS)

This service transmits the PhPDU from the MDS to the MAU, where it shall be transmitted on to the medium.

25.3.2 Receive signal (RxS)

This service transmits the PhPDU from the MAU to the MDS.

25.3.3 Request-to-send (RTS)

This service can be used to activate the transmitting part of the MAU, or can be used as a local handshake signal between MDS and MAU. If this is not required, the RTS signal can be locally looped directly to CTS.

25.3.3.1 Clear-to-send (CTS)

This service can be used to indicate that the transmitting part of the MAU is activated, or can be used as a local handshake signal between MDS and MAU. If this is not required, the RTS signal can be locally looped directly to CTS.

26 Type 6: *This clause has been removed*

NOTE This clause is a placeholder in this edition to minimize the disruption to existing national and multi-national standards and consortia documents that reference the clause numbering of the prior edition.

27 Type 8: Medium attachment unit: twisted-pair wire medium

27.1 MAU signals

A MAU of an outgoing and incoming interface is shown in Figure 118 and Figure 119.

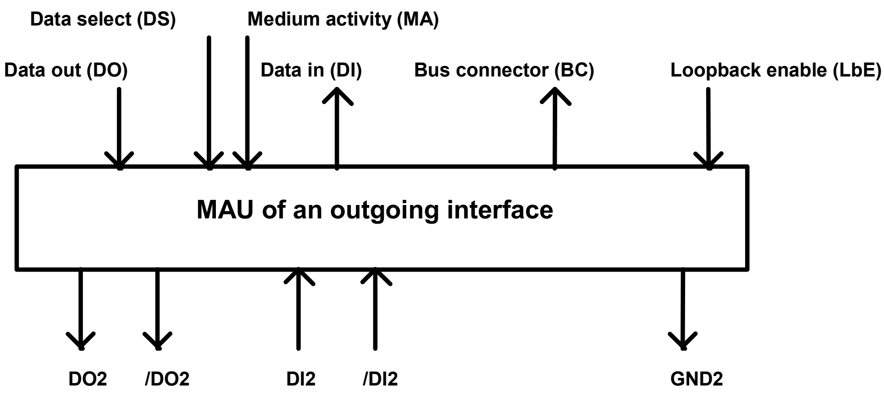


Figure 118 — MAU of an outgoing interface

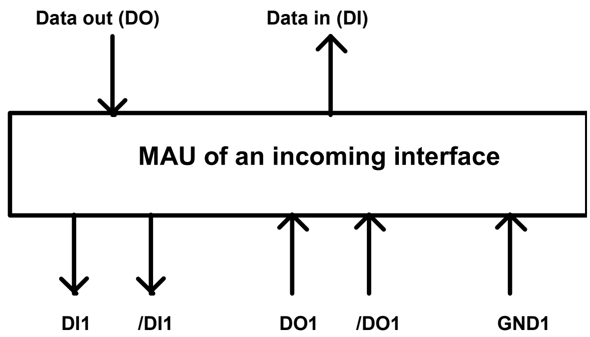


Figure 119 — MAU of an incoming interface

27.2 Transmission bit rate dependent quantities

Four bit rates are defined for the twisted pair wire medium attachment unit (MAU). A given MAU shall support at least one of these bit rates. Table 130 defines the bit rates and bit rate dependent quantities.

Table 130 — Bit rate dependent quantities twisted pair wire medium MAU

Quantity	Value				Unit
Nominal bit rate (see note)	0,5	2	8	16	Mbit/s
Maximum deviation from bit rate	± 0,1 %	± 0,1 %	± 0,1 %	± 0,1 %	—
Nominal bit duration (T)	2 000	500	125	62,5	ns
Minimum remote bus length	0	0	0	0	m
Maximum remote bus length	400	150	125	100	m
Maximum transmitted bit cell jitter	± 240	± 60	± 15	± 7,5	ns
NOTE Average transmission bit rate for 13 bits.					

27.3 Network

27.3.1 General

A twisted-pair wire medium MAU operates in a network that consists of the following components:

- cable;
- connectors;
- Electrical isolation;
- devices (with at least one communication element).

27.3.2 Topology

The twisted-pair wire medium MAU shall operate in one remote bus with one further device. A remote bus link (see Figure 120) consists of two point-to point connections. The connections are unidirectional. Thus each MAU has one transmitter and one receiver.

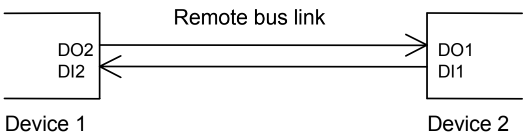


Figure 120 — Remote bus link

A remote bus link shall be between 0 and the maximum length for a given bit rate (see Table 130).

27.4 Electrical specification

The voltage levels of the transmitter and receiver shall be taken from ANSI TIA/EIA-422-B.

27.5 Time response

The time response of the transmitter and the receiver shall be taken from ANSI TIA/EIA-422-B.

27.6 Interface to the transmission medium

27.6.1 General

The coupling to the transmission medium is effected via one incoming (optional) and one or several outgoing interfaces which are independent of the medium (see Figure 121).

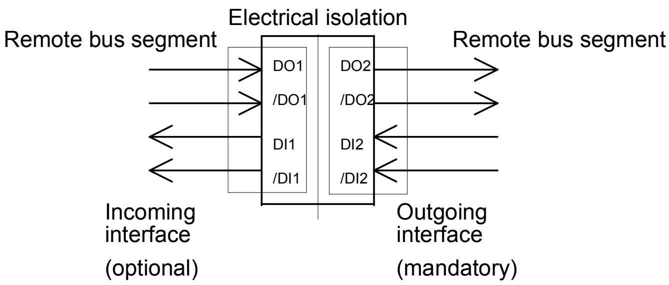


Figure 121 — Interface to the transmission medium

27.6.2 Incoming interface

The incoming interface comprises five signal lines (see Table 131) for the connection to the network. These signal lines have to be electrically isolated from the device. The isolation voltage shall amount to ≥500 V (direct voltage).

Table 131 — Incoming interface signals

Short name	Name
DO1	Receive data line +
/DO1	Receive data line -
DI1	Send data line +
/DI1	Send data line -
GND1	Ground line

27.6.3 Outgoing interface

The outgoing interface comprises five signal lines (see Table 132) for the connection to the network.

Table 132 — Outgoing interface signals

Short name	Name
DO2	Send data line +
/DO2	Send data line -
DI2	Receive data line +
/DI2	Receive data line -
GND2	Ground line

27.7 Specification of the transmission medium

27.7.1 Cable connectors

If used, the 9-position subminiature D connectors shall use a standard connector pin assignment (see M.1.1).

Field termination elements, such as screw-clamp or flat-type connectors and fixed connectors, can also be used. In this case the connector pin assignment given in M.1.2 should be used.

27.7.2 Cable

A shielded cable with two twisted cable pairs is to be used as a bus cable. The shielding is to improve the electromagnetic compatibility (EMC). The remote bus cable should at least fulfil the requirements indicated in Table 133.

Table 133 — Remote bus cable characteristics

Characteristic quantity (20 °C)	Value	Test method
Number of wires (twisted pairs)	3 x 2, twisted pair	
Cross section	Min. 0,20 mm^2	
Direct current conductor resistance/100 m	Max. 9,6 Ω	IEC 60189-1, 5.1
Characteristic impedance	120Ω ± 20 % at f = 0,064 MHz 100 Ω ± 15 Ω at f > 1 MHz	IEC 61156-1, 3.3.6
Dielectric strength - Conductor/conductor - Conductor/shield	 1 kV_{rms}, 1 min 1 kV_{rms}, 1 min	 IEC 60189-1, 5.2
Insulation resistance (after dielectric strength test)	Min 150 MΩ for a cable of 1 km in length	IEC 60189-1, 5.3
Maximum transfer impedance - at 30 MHz	 250 mΩ/m	 IEC 60096-1
Mutual capacitance (at 800 Hz)	Max. 60 nF for a cable of 1 km in length	IEC 60189-1, 5.4
Min. near end cross talk loss (NEXT) for a cable of 100 m - at 0,772 MHz - at 1 MHz - at 2 MHz - at 4 MHz - at 8 MHz - at 10 MHz - at 16 MHz - at 20 MHz	 61 dB 59 dB 55 dB 50 dB 46 dB 44 dB 41 dB 40 dB	IEC 61156-1, 3.3.4
Max. attenuation for a cable of 100 m - at 0,256 MHz - at 0,772 MHz - at 1 MHz - at 4 MHz - at 10 MHz - at 16 MHz - at 20 MHz	 1,5 dB 2,4 dB 2,7 dB 5,2 dB 8,4 dB 11,2 dB 11,9 dB	IEC 61156-1, 3.3.2

The minimum wiring with a shield between two communicating devices is shown in Figure 122.

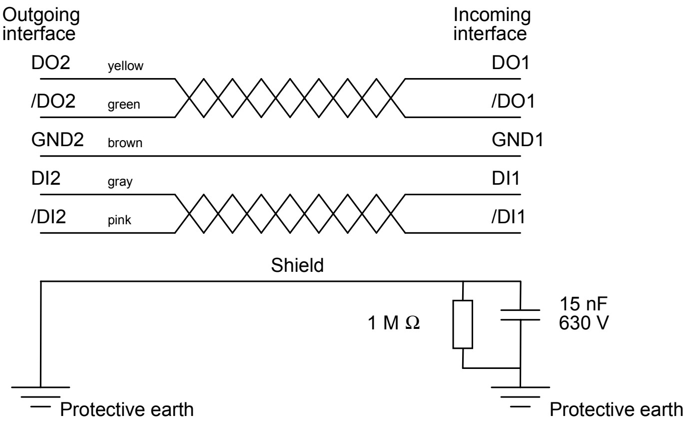


Figure 122 — Wiring

27.7.3 Terminal resistor

The cable pair of the receive line is to be connected with a resistor network (see Figure 123) directly before the receiver of the MAU. The circuit may be used for the polarisation of the MAU, for the detection of a short or open circuit on a wire. It shall be observed that the resulting equivalent resistance is at least 100 Ω.

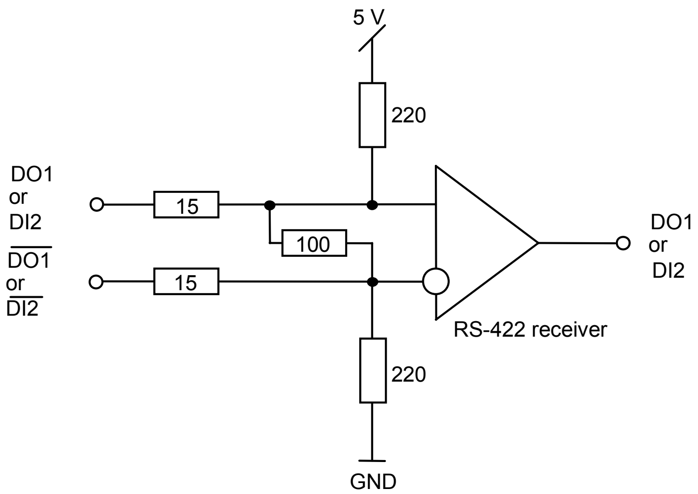


Figure 123 — Terminal resistor network

28 Type 8: Medium attachment unit: optical media

28.1 General

The object of this clause is to give the operating and optical specifications of the duplex fiber mode optical MAU.

The fiber optic remote bus cable consists of a pair of optical fiber (see Figure 124) waveguides providing bidirectionality by use of a separate fiber for each direction of signal propagation. These dual fibers connect to the CPIC of a network device.

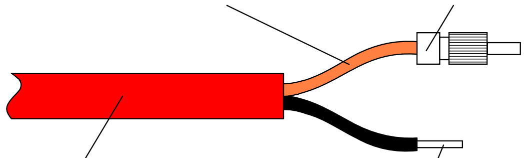


Figure 124 — Fiber optic remote bus cable

Two optical fiber types are supported:

– polymer optical fiber;
– plastic clad silica fiber.

28.2 Transmission bit rate dependent quantities

Four bit rates are defined for the optical medium attachment unit (MAU). A given MAU shall support at least one of these bit rates. Table 134 defines the bit rates and bit rate dependent quantities.

Table 134 — Bit rate dependent quantities optical MAU

Transmit timing characteristics	Value				Unit
Nominal bit rate	0,5	2	8	16	Mbit/s
Maximum deviation from bit rate	± 0,1 %	± 0,1 %	± 0,1 %	± 0,1 %	
Nominal bit duration (T)	2 000	500	125	62,5	ns

28.3 Network topology

An optical MAU operates in a network that consists of the following components:

– optical cable;
– connectors;
– devices (containing at least one communication element).

An optical MAU shall operate in one remote bus with one further device. A remote bus link (see Figure 125) consists of two point-to-point connections. The connections are unidirectional. Thus each MAU has one fiber optic transmitter and one fiber optic receiver.

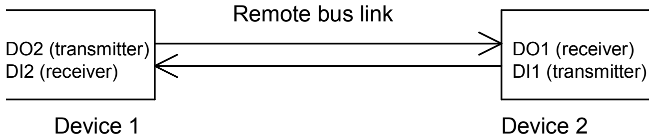


Figure 125 — Optical fiber remote bus link

The cable length shall be in the range specified in Table 135.

Table 135 — Remote bus fiber optic cable length

Fiber type	Minimum length	Maximum length
Polymer optical fiber	1 m	50 m (see notes 1, 2)
Plastic clad silica fiber	1 m	300 m (see notes 1, 2)

NOTE 1 This does not exclude longer distances between two devices, e.g. by using receive circuits with a lower minimum optical receiver sensitivity than specified in 28.5.2.

NOTE 2 The maximum length may be reduced in cases where special cables with higher attenuation than the standard cables specified in 28.6.2 are used.

28.4 Transmit circuit specifications

28.4.1 Data encoding rules

NRZ Coding is specified for the optical transmission following the encoding rules given in Table 136.

Table 136 — Encoding rules

Logical symbol bit	Encoding
1	Low optical output level
0	High optical output level

In the case of no bus activity an idle state of logic 0 shall be used.

28.4.2 Test configuration

The output level, spectral and timing specifications are measured at the end of a standard test fiber (as specified in 28.6.4) connected to the CPIC.

The requirements relative to this subclause are summarized in Table 137 and Table 134.

28.4.3 Output level specification

An optical MAU transmit circuit shall conform to the following output level and spectral requirements. The specified level and spectral characteristics shall be maintained over the whole temperature range specified for the network device. Output level is the effective launch power of logic 0. The output level specification is shown in Table 137.

Table 137 — Transmit level and spectral specification summary for an optical MAU

Transmit level and spectral characteristics (values referred to CPIC with standard test fiber)	Polymer optical fiber (980/1 000 µm fiber)		Plastic-clad silica fiber (200/230 µm fiber)
Maximum peak emission wavelength (λp)	660 nm	520 nm	660 nm
Typical spectral full width half maximum (Δλ)	< 30 nm		< 30 nm
Maximum output level	- 2,0 dBm		- 8 dBm
Minimum output level	- 6,2 dBm		- 16,9 dBm
Maximum effective launch power of a logic 1	- 43 dBm	- 41 dBm	- 45 dBm
NOTE Standard test fiber specification, see 28.6.4.			

28.4.4 Output timing specification

An optical MAU transmit circuit shall conform to the following output timing requirements (see Figure 126). Timing characteristics shall be maintained over the whole temperature range specified for the network device.

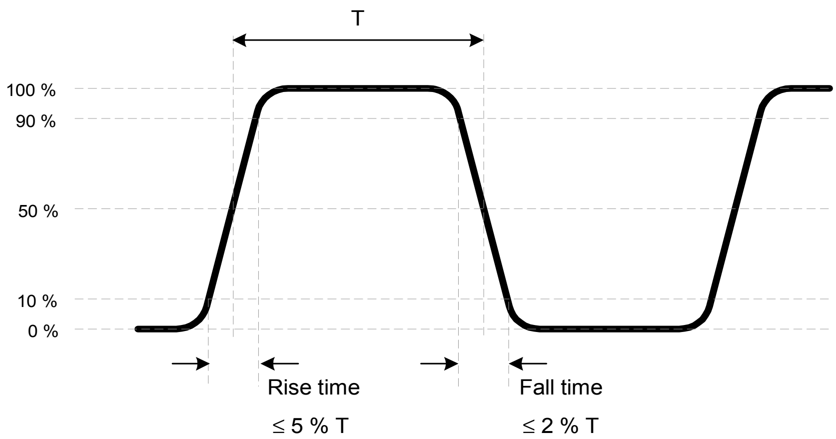


Figure 126 — Optical wave shape template optical MAU

NOTE 1 For ease of reference, the requirements of 28.4.4 are summarized in Table 134.

NOTE 2 0 % effective power is the low optical output power state (logic 1).

NOTE 3 100 % effective power is the high optical output power state (logic 0).

Rise time, fall time and bit cell jitter shall be chosen in that manner, that the electrical output timing specifications of the optical MAU receive circuit given in Table 138 are still fulfilled.

28.5 Receive circuit specifications

The requirements relative to this subclause are summarized in Table 138.

28.5.1 Decoding rules

Decoding rules according to Table 136 shall be used.

28.5.2 Fiber optic receiver operating range

An optical MAU receive circuit shall have the minimum optical receiver sensitivity defined in Table 138 over the whole temperature range specified for the network device. The maximum optical power for logic 0, measured with a standard test fiber specified in 28.6.4, of an optical MAU receive circuit shall not exceed the value defined in Table 138 .

The fiber optic receive circuit used for 0,5 Mbit/s and 2 Mbit/s systems shall be capable of detecting a 01010 bit stream after a 200 ms long idle state where the optical power level of the second logical 0 is reduced by up to 65 % against the others. This capability shall be maintained over the whole fiber optic receiver operating range.

28.5.3 Maximum received bit cell jitter

The receive circuit shall accept a NRZ encoded signal transmitted in accordance with 28.4. In addition, the fiber optic receiver shall accept signals with the time variation between any two adjacent signal transition points (50 % crossing) of ± 25 %.

Table 138 — Optical MAU receive circuit specification summary

Receive circuit characteristics (values referred to the CPIC)	Polymer optical fiber (980/1 000 µm fiber)	Plastic-clad silica fiber (200/230 µm fiber)
Minimum optical receiver sensitivity	≤ -21,6 dBm	≤ -23 dBm
Maximum optical power for logic 0	- 2,0 dBm	- 8 dBm
Maximum received bit cell jitter	± 25 % of nominal bit time	± 25 % of nominal bit time

28.6 Specification of the transmission medium

28.6.1 Connector

Cable connectors, if used, shall be in accordance with the specification given in Annex M.2.

28.6.2 Fiber optic cable specification: polymer optical fiber cable

28.6.2.1 General

A polymer optical fiber cable for fixed routing in indoor installations shall be compatible to the following specifications. Special fiber optic cables used for special environmental or physical applications where e.g. high flexibility of the cable is essential may differ from the following specification concerning the cable attenuation.

28.6.2.2 Fiber optic waveguide

A fiber optic waveguide of a polymer optical fiber cable for a network optical MAU shall fulfil the following requirements given in Table 139.

Table 139 — Specification of the fiber optic waveguide

Parameter	Value
Core diameter	(980 ± 60) µm
Cladding diameter	(1 000 ± 60) µm
Cladding non-circularity	≤ 6 %
Core material	Polymethylmethacrylate (PMMA)
Numerical aperture	0,47 ± 0,03
Refractive index profile	Step index
Bandwidth at 660 nm	≥ 10 MHz × 100 m
Attenuation at 650 nm (monochromatic)	≤ 160 dB/km
Attenuation at 660 nm (measured with LED and 50 m cable length)	≤ 230 dB/km

28.6.2.3 Single fiber

A single fiber of a polymer optical fiber cable for an optical MAU shall conform to the following requirements given in Table 140.

Table 140 — Specification of the single fiber

Parameter	Value
Buffer material	Polyamide (PA)
Buffer color	Black or orange
External diameter	2,20 mm ± 0,07 mm
Minimum long term bending radius	30 mm

28.6.2.4 Cable sheath and mechanical properties of the cable

The sheath of a polymer optical fiber cable for an optical MAU should conform to the following requirements given in Table 141.

Table 141 — Specification of the cable sheath and mechanical properties of the cable

Parameter	Value
Sheath material	Polyurethane (PUR)
Sheath color	Red
Strain relief elements	Non-metallic
Marking	Running length in m, production date
Temperature range (in operation)	-20 °C to +70 °C
Minimum long-term bending radius	≤ 65 mm
Maximum long-term tensile strength	≥ 100 N
Maximum long-term lateral pressure	≥ 20 N/cm

28.6.2.5 Material properties of the cable

The polymer optical fiber cable for an optical MAU should have the following further material properties as shown in Table 142.

Table 142 — Recommended further material properties of the cable

Parameter	Value
Oil resistance	ASTM Oil No. 2, 100 °C, IEC 60811-2-1
Halogen-free	IEC 60754-2
Ozone resistance	IEC 60811-2-1
UV resistance	ISO 4892-1
Abrasion resistance	IEC 60794-1-2:1999 method E2A Minimum 5 000 cycles, 1 mm radius of the point of the steel needle, 500 g
NOTE Dependent on the application, other material properties may also be required, for example, free from substances impairing paint-wetting performance (chloroform test).	

28.6.3 Fiber optic cable specification: plastic clad silica fiber cable

28.6.3.1 General

A plastic clad silica fiber optic cable for fixed routing in indoor installations shall be compatible to the following specifications. Special plastic clad silica fiber optic cables used for special environmental applications such as outdoor cables may differ from the following specification concerning the cable attenuation.

28.6.3.2 Fiber optic waveguide

A fiber optic waveguide of a plastic clad silica fiber optic cable for an optical MAU shall fulfil the following requirements given in Table 143.

Table 143 — Specification of the fiber optic waveguide

Parameter	Value
Core diameter	(200 ± 8) µm
Cladding diameter	(230 ± 10) µm
Cladding non-circularity	≤ 6 %
Numerical aperture	0,40 ± 0,04
Refractive index profile	Step index
Bandwidth at 650 nm	≥ 17 MHz × km
Attenuation at 650 nm	≤ 10 dB/km

28.6.3.3 Single fiber

A single fiber of a plastic clad silica fiber optical cable for an optical MAU shall conform to the following requirements given in Table 144.

Table 144 — Specification of the single fiber

Parameter	Value
Buffer material	FRNC material
Buffer color	Red or green
External diameter	2,2 mm or 2,9 mm
Minimum long term bending radius	30 mm

28.6.3.4 Cable sheath and mechanical properties of the cable

The sheath of a plastic clad silica fiber optic cable for an optical MAU should conform to the following requirements given in Table 145.

Table 145 — Specification of the cable sheath and mechanical properties of the cable

Parameter	Value
Sheath color	Red
Strain relief elements	Non-metallic
Marking	Running length (m); production date
Temperature range (in operation)	-20 °C to +70 °C
Minimum long-term bending radius	≤ 50 mm
Maximum long-term tensile strength	≥ 200 N
Maximum long-term lateral pressure	≥ 100 N/cm

28.6.3.5 Material properties of the cable

The plastic clad silica fiber optic cable for an optical MAU should have further material properties as shown in Table 142.

28.6.4 Standard test fiber

The cable used for testing network devices with an optical MAU for conformance to the requirements of the clause shall be a cable with one or more fiber optic waveguides whose characteristics are as shown in Table 146.

Table 146 — Specification of the standard test fiber for an optical MAU

Parameter	Polymer optical fiber (980/1 000 µm fiber)	Plastic-clad silica fiber (200/230 µm fiber)
Length	1 m	1 m
Core diameter	(980 ± 60) µm	(200 ± 8) µm
Cladding diameter	(1 000 ± 60) µm	(230 ± 10) µm
Cladding non-circularity	≤ 6 %	≤ 6 %
Numerical aperture	0,47 ± 0,03	0,40 ± 0,04
Bandwidth for 660 nm	≥ 10 MHz × 100 m	≥ 17 MHz × 1 km
Attenuation for 660 nm (monochromatic)	≤ 160 dB/km	≤ 10 dB/km
Buffer diameter	2,2 mm	2,9 mm
Insertion loss (see note)	1,5 dB to 2,0 dB	1,0 dB to 1,5 dB
NOTE Measured in conformance with IEC 61300-3-4 (insertion procedure B).		

29 Type 12: Medium attachment unit: electrical medium

29.1 Electrical characteristics

This MAU specification describes a balanced line unidirectional transmission via a pair of wires corresponding to ANSI TIA/EIA-644-A. A terminator, located at receiving end of the wire, enables the PhL to support in particular higher speed transmission. The maximum wire length should not exceed 20 m. This transmission method is offered in addition to the ISO/IEC 8802-3 technologies known as 100BASE-TX and 100BASE-FX. Its main purpose is to connect devices within a control cabinet. Thus, it assumes a common signal ground.

Manchester bit encoding is combined with ANSI TIA/EIA-644-A signaling targeted to low cost line couplers, which may not isolate the station from the line (galvanic isolation); a line terminator is required (recommended resistor value is 100 Ω).

The topology supported is a pair of wires with exactly one sender and one receiver on a single pair.

A connection consists or two pairs of wire which connects exactly two DTE.

The term wire specifies a media which is able to transmit signals according to ANSI TIA/EIA-644-A at the specified length. A conformance statement of the device manufacturer shall specify these parameters.

29.2 Medium specifications

29.2.1 Connector

There is no connector specified for this media. A conformance statement of the device manufacturer shall specify the connection capabilities.

29.2.2 Wire

The medium is a pair of wires. Shielding can be used to improve the electromagnetic compatibility (EMC). Unshielded wires can be used, if there is no severe electromagnetic interference (EMI).

The characteristic impedance Z_O of the wire pair should be in the range between 80 and 120 Ω, the wire capacity (conductor - conductor) should be less than 60 pF/m. Wire selection criteria should follow the ANSI TIA/EIA-644-A implementation guidelines, especially for backplane and PCB interconnection.

NOTE Assuming an output common-mode voltage of approximately 1,2 V, the output resistor can be modelled as two 50 Ω resistors in series with their center-tap sitting at 1,2 V. This provides a match to a typical PCB trace characteristic impedance (Z_O) of 50 Ω and minimizes reflections.

A pair of wire should have a symmetrical design (same length, closely related to each other and same distance to ground signal). The two pair of wires shall have the same length. A skew of less than 2 ns is acceptable.

29.3 Transmission method

29.3.1 Bit coding

The Manchester coded data from DLL is transmitted via a pair of wires. A binary "1" (N+ or first half of DL_symbol = “ONE” or second half of DL_symbol = “ZERO”) is represented by a constant positive differential voltage on TxS/RxS and a binary "0" (N- or first half of DL_symbol = "ZERO" or second half of DL_symbol = “ONE”) by a constant negative differential voltage on TxS/RxS.

29.3.2 Representation as ANSI TIA/EIA-644-A signals

TxS will be represented as OUT+ and OUT- in ANSI TIA/EIA-644-A terms. RxS inputs at ANSI TIA/EIA-644-A level will be denominated as IN+ and IN-.

NOTE Assuming an output current of 3,5 mA common-mode voltage of approximately 1,2 V, the nominal voltage difference between OUT+ and OUT- is 350 mV (in a range between 247 mV and 454 mV). A differential voltage of 100 mV is needed to detect a signal.

30 Type 16: Medium attachment unit: optical fiber medium at 2, 4, 8 and 16 Mbit/s

30.1 Structure of the transmission lines

The structure of the optical transmission line is shown in Figure 127.

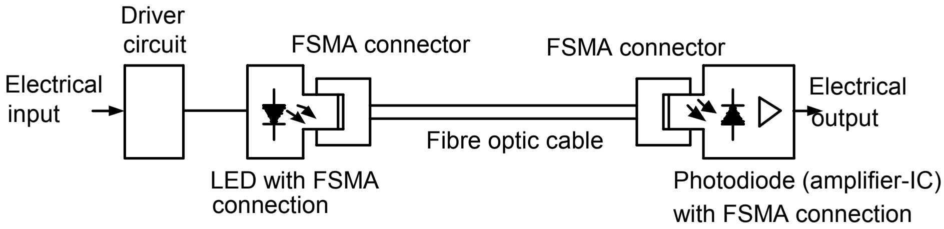


Figure 127 — Optical transmission line

The driver circuit for the transmitting LED shall be activated by an electrical impulse. The high-performance LED (transmitter) shall emit light of a wavelength of 650 nm. The transmission power shall be switchable between “low attenuation” and “high attenuation”, using a manually operated switch.

The fiber optic cable shall be made of plastic or glass and have a step index profile or graded index profile. Fiber optic cables and cores may be used depending on application. Attenuation taking place along the transmission line is caused by the fiber optic cable and possibly other couplings. These additional couplings can become necessary when routing through a wall, for example. The factors which contribute to attenuation along the line are explained in more detail in O.2.

NOTE For fiber optic materials currently in use, the attenuation is approximately 220 dB/km for plastic and 6 dB/km for glass.

The receiver component shall consist of a photodiode and an integrated amplifier circuit.

It shall be possible that the signal is inverted while passing through a slave (i.e., a light-on signal at the optical slave input shall not necessarily lead to a light-on signal at the optical output).

30.2 Time performance of bit transmission

30.2.1 Introduction

The distance between rising and falling edges of the optical signal is specified in this clause. An edge is a change in level between the optically low and optically high levels. The specification is based on an envelope which has been defined for the optical signal. Any optical output signal of a transmitter shall remain within this specific envelope at all times.

Furthermore, the run-time performance between optical slave input and output is specified. A slave shall be synchronized to the transmission clock of the bit stream coming into its optical input. Although the transmission clock of a slave can deviate from the clock at its input for a short time, the slave needs to be synchronized to the predetermined clock (e.g., by means of a phase locked loop). Thus, all units connected to the network are required by definition to transmit the same averaged transmission clock pulse. In other words, all units shall use the transmission clock pulse of the master.

The slave shall be synchronized to the transmission clock on its optical input by means of light-on edges (rising edges).

30.2.2 Master and slave in test mode

30.2.2.1 Introduction

In this clause, the run-time performance at the optical output of the master is specified while the master is operating both in its normal and test modes.

It shall be possible to activate the test mode externally by special means (e.g. pressing a key). Master and slave shall then be able to provide a continuous signal light, as well as a zero bit stream at the optical output, without the presence of an input signal.

30.2.2.2 Continuous light signal test mode

A continuous light signal implies a logical high level without a level change at the optical output. This mode is only required for the master. The slave may generate a continuous light signal, depending on whether or not a continuous light signal comes in at the optical input. Due to its function as a repeater, the slave shall be able to echo the light at its optical output, which it receives at its optical input (or the lack thereof).

NOTE Optical signal inversion by the slave shall be possible.

30.2.2.3 Zero bit stream test mode

The zero bit stream test mode implies that the transmitter shall transmit consecutive zeros which, based on the NRZI code, result in continuous level changes in the signaling pattern of the transmission clock (this results in a 1 MHz signal for a data rate at 2 Mbit/s). A slave shall use its local clock to synchronize the transmitting clock at its optical output signal. No clock adjustments may occur at the optical output (e.g., due to the phase locked loop, $\rightarrow t_{cad}$) and only statistically distributed jitter of the optical signal is allowed. This requirement is important because it allows the system to isolate and separate jitter noise ($\rightarrow J_{noise}$) from possible clock adjustments due to the phase locked loop ($\rightarrow t_{cad}$), as will be discussed later. The curve shapes of optical signals which are generated while the system is in the zero bit stream test mode, are not allowed to deviate from the signals during normal mode near the rising and falling edges (e.g. different rise and fall times, different excess levels during the test mode). Specifically, the same driver circuit shall be used during the zero bit stream test mode as is used during normal mode.

The following parameters shall be used to specify the optical output signal of the master and slave (see Figure 128 and Figure 129):

t_r: This is the time delay between points 1 and 2 (= 1-1' or 2-2'). It shall be the upper limit of the time required by the optical signal to pass through P_{TmaxL} to P_{TminH} on the rising edge. This time does not correspond to the rise time of the transmitter which is given between 10 % and 90 % of the optical signal in the data sheet.

t_f: This is the time delay between points 3 and 4 (= 3-3' or 4-4'). It shall be the upper limit of the time required by the optical signal to pass through P_{TminH} to P_{TmaxL} on the falling edge. This time does not correspond to the fall time of the transmitter, which is given between 10 % and 90 % of the optical signal in the data sheet.

NOTE See item remark below regarding t_r and t_f.

t_{os}: This parameter indicates length of time the maximum optical transmission power may be exceeded dynamically. This interval shall start at time ① (see Figure 128).

t_{BIT}: This is the arithmetic mean value (measured over several seconds) of the transmission clock period (duration of a bit cell) by the master (not in test mode) and shall correspond to the reciprocal value of the data rate. The nominal duration shall be described by t_{BITnom}. t_{BIT} shall be measured between edges with the same direction (= 2 × t_{BIT}) at optical power levels of 0,5 × P_{TminH} ± 20 %. t_{BIT} shall be considered to be constant in the range of seconds. Only fluctuations due to noise are allowed. Relatively long measurement duration of t_{BIT} ensures that the influence of short-term deviations of the delays between edges (jitter → J_{noise}) is negligible. Hence, t_{BIT} shall describe the time between points 1 and 3, as well as the time between points 3 and 5 (which shall correspond to point 1 of the next period) (see Figure 128).

$t_{BITtest}$: This is the arithmetic mean value measured over several seconds of the master or slave transmission clock period (duration of a bit cell) in the zero bit stream test mode. All measurements and properties of $t_{BITtest}$ shall correspond to t_{BIT}.

J_{noise}: This parameter describes the jitter of the optical signal. It shall be the purely statistical deviation of the distance between both edges, compared with the value $t_{BITtest}$ measured over a long time interval. J_{noise} shall be obtained by overlaying the signals of several periods (e.g. on an oscilloscope) such that they come together at one optical power level (e.g. P_{TmaxL} on the falling or rising edge). The jitter of the optical signal is then determined by the width of the overlaid optical signals (which gives a time). This width shall not exceed the value J_{noise} in the power region between P_{TmaxL} and P_{TminH} vice versa. By this definition, the jitter of the optical signals is limited, that is, the signal curve shapes shall be reproducible in the power region P_{TmaxL} through P_{TminH} vice versa.

NOTE The times t_r and t_f are not fully available as rise time and fall time. Due to non-symmetrical ON/OFF performance of the driver circuit (duty cycle, propagation delay), the falling edge can be time-shifted with respect to the rising edge, resulting in a remaining difference for $t_{BITtest}$. In this case, the high level can be extended by some time interval and the low level could be shortened by the same interval. This extending/shortening interval is not considered part of the rising and falling interval. In addition, the signal with added J_{noise} must remain completely within the envelope, which implies that the jitter shall be taken into consideration for the times t_r and t_f.

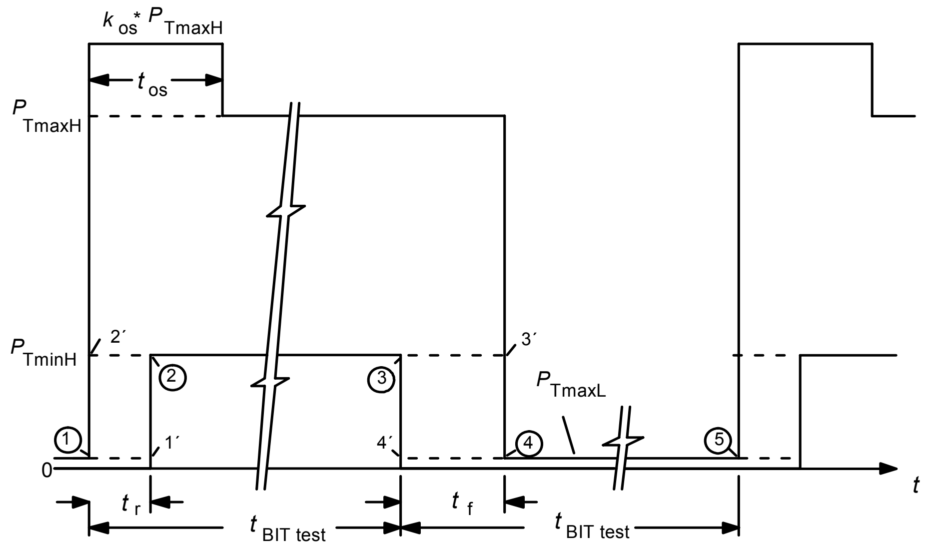


Figure 128 — Optical signal envelope

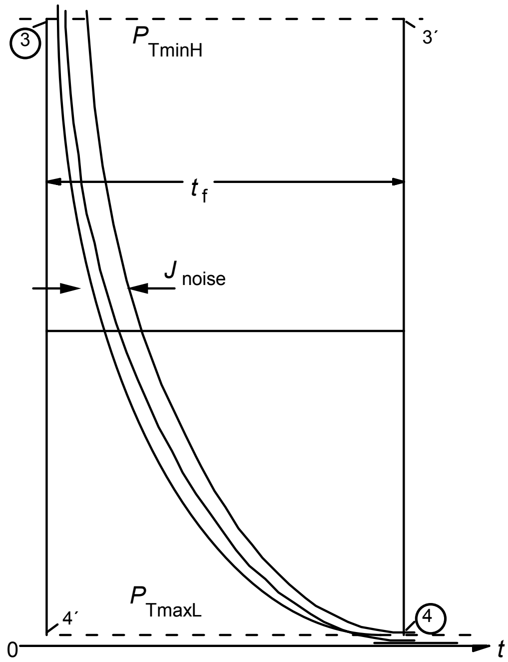


Figure 129 — Display of jitter (J_{noise})

30.2.3 Data rate

The data rate is the baud rate measured at the optical output of the master. Its nominal value shall be 2 Mbit/s, 4 Mbit/s, 8 Mbit/s or 16 Mbit/s. The measured value is allowed to deviate by ±0,01 %. The data rate is a time average measured over several seconds. The short-term performance (nanoseconds range) may deviate slightly and is specified through J_{noise} (see Table 148).

Table 147 specifies which data rates shall be supported by Type16, and the way baud rate shall be selected, for two performance classes called CP16/1 and CP16/2.

Table 147 — Transmission rate support

Performance class	CP16/1	CP16/2
2 Mbit/s	Mandatory	Mandatory
4 Mbit/s	Optional	Optional
8 Mbit/s	No	Optional
16 Mbit/s	No	Optional
Baud rate	Manual setting (e.g. switch)	Manual setting (e.g. switch), or automatic baud rate recognition

Table 148 — Transmission data parameters

Transmission rate (data rate)	Bit times			
	2 Mbit/s ± 0,2 kbit/s	4 Mbit/s ± 0,4 kbit/s	8 Mbit/s ± 0,8 kbit/s	16 Mbit/s ± 1,6 kbit/s
t_{BIT} [ns]	500 ± 0,05	250 ± 0,025	125 ± 0,012 5	62,5 ± 0,006 25
t_{BITnom} [ns]	500	250	125	62,5
$t_{BITtest}$ [ns]	500 ± 0,05	250 ± 0,025	125 ± 0,012 5	62,5 ± 0,006 25
Data frequency (max.)	1 MHz	2 MHz	4 MHz	8 MHz
Times for curve shapes				
t_{os} [ns]	200	100	50	25
t_r [ns]	100	40	20	10
t_f [ns]	150	110	25	15
Jitter [ns]	$0 \le J_{noise} \le 10$	$0 \le J_{noise} \le 10$	$0 \le J_{noise} \le 5$	$0 \le J_{noise} \le 5$

30.2.4 Input-output performance of the slave

30.2.4.1 General

In this clause, the input-output performance of the slave synchronization performance is specified. A slave shall receive a signal with a certain clock at its optical input. The mean value of this clock is equal to the transmitting clock of the master. In the long run, a slave shall be synchronized to this clock (by evaluation of one of the rising or falling edges).

The slave shall generate its own local clock. This local clock shall be used to receive and to transmit data. The local clock of a slave shall run freely between the synchronizing edges of the incoming bit stream. During synchronization, the slave shall adjust the phases of the local clock (phase locked loop). This performance can be observed at the optical output because the duration of the high or low level becomes shortened or lengthened with respect to the average bit duration (t_{BIT}). The amount of shortening or lengthening shall be called clock adjustment time t_{cad}.

Clock adjustment time shall not exceed a specific value (t_{cadmax}). In addition, the implemented maximum clock adjustment time ($t_{cadreal}$) of every slave shall be specified by the manufacturer (e.g. $t_{BIT}/16$).

The optical signal shall run through the range P_{TmaxL} - P_{TminH} resp. vice versa of the envelope always at the same position (taking J_{noise} into account). The envelope can be shifted over the optical signal (due to short rise and fall times), but this possible shift shall not be taken into account as a “bonus” to the clock adjustment.

A slave shall be able to receive signals correctly if its clock adjustment time is smaller or equal to the maximum clock adjustment time, $t_{cadreal}$, implemented in that slave. If the slaves are physically located in the ring in an ascending $t_{cadreal}$ sequence, the system shall make sure that correct receiving conditions are established for any slave. The receiver of the master, being the last unit in the ring, shall be able to process the maximum allowable clock adjustment time t_{cadmax}.

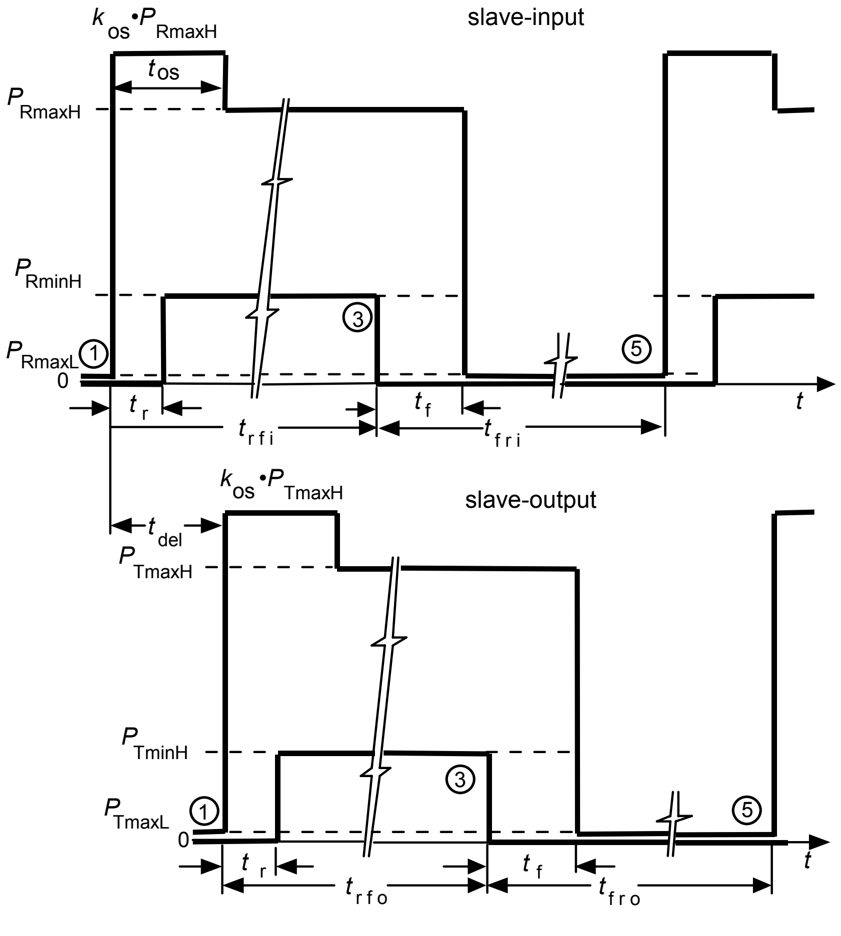


Figure 130 — Input-output performance of a slave

In addition to the clock adjustment time just described, a minimum clock adjustment time (t_{cadmin}) shall be specified. Every slave shall be able to process data if the clock has been adjusted by t_{cadmin} at its input. The input/output performance of a slave is specified by the following parameters.

t_{rfi}: this is the time between points 1 and 3 in Figure 130 on the receiver input.

t_{fri}: this is the time between points 3 and 5 in Figure 130 on the receiver input.

$t_{cadreal}$: This is the maximum clock adjustment time (shortening or lengthening a level) which a slave generates at its optical output. This value shall be specified by the manufacturer. The slave shall also be able to correctly process this maximum clock adjustment time at its input, within the scope of the specified bit error rate.

t_{cadmin}: this is the minimum clock adjustment time which a slave shall be able to process correctly within the scope of the specified bit error rate.

t_{cadmax}: this is the upper limit for $t_{cadreal}$ and also describes the maximum clock adjustment time that the master shall be able to process correctly within the scope of the specified bit error rate.

t_{rfo}: this is the time between points 1 and 3 in Figure 130 at the transmitter output.

t_{fro}: this is the time between points 3 and 5 in Figure 130 at the transmitter output.

t_{del}: this is the time delay of the envelope between the optical input and output, measured at the slave (see Figure 130). This parameter describes the signal delay (run-time) of the optical signal through a slave in a repeater mode (see also Table 153). The delay shall be measured between the light-ON edge at the optical input and the associated light signal edge at the optical output (in non-inverting slaves, this is the light-ON edge; in inverting slaves, this is the light-OFF edge).

t_{del}-optic: max. delay in the electro-optical elements of receiver and transmitter.

t_{del}-electric: max. delay of the electric signal routing through the slave (e.g. using an ASIC).

A receiver shall be provided with an input signal as defined by cases a) or b) of Table 149. Changing between cases a) and b) is not allowed. Thus the clock adjustment time will shorten or lengthen only the high level, or only the low level.

Table 149 — Possible slave input signals

Case	t_{rfi}	t_{fri}
a)	$i \times t_{BIT} - t_{cadreal} \leq t_{rfi} \leq i \times t_{BIT} + t_{cadreal}$	$j \times t_{BIT}$
b)	$i \times t_{BIT}$	$j \times t_{BIT} - t_{cadreal} \leq t_{rfi} \leq j \times t_{BIT} + t_{cadreal}$
NOTE 1 i and j are ordinary digits; i is not identical to the sequence of networks as given in the abbreviations. NOTE 2 For normal operation i = 1 to 8 and j = 1 to 8, so that I + j = 2 to 16. When switching from telegram to fill signal and vice versa, i = 1 to 12 and j = 1 to 12, but I + j = 2 to 20.		

With these specific input signals, the slave shall be able to perform following tasks:

a) receiving and processing data correctly within the scope of the bit error rate;

b) generating valid output signals.

Valid output signals shall have a signal timing within the specified limits and be generated according to cases c) or d) of Table 150. The slave shall be able to either shorten or lengthen only the high level or only the low level through clock adjustment. Alternating between the two is not allowed.

Table 150 — Possible slave output signals

Case	t_{rfo}	t_{fro}
c)	$m \times t_{BIT} - t_{cadreal} \leq t_{rfo} \leq m \times t_{BIT} + t_{cadreal}$	$n \times t_{BIT}$
d)	$m \times t_{BIT}$	$n \times t_{BIT} - t_{cadreal} \leq t_{rfo} \leq n \times t_{BIT} + t_{cadreal}$
NOTE m and n are ordinary digits. They are not identical to the explanation given in the abbreviations.		

Four cases (shown in Table 151) shall be distinguished for the allowable values m and n:

Table 151 — Valid slave output signals

Status / slave	Non-inverting slave		Inverting slave	
Repeater	**i = m; j = n**		**i = n; j = m**	
Slave transmits own telegram	Normal operation i, j = 8 m, n = 1 .. 8 m + n = 2 .. 16	When switching from telegram to fill signal (1 .. 12) (2 .. 20)	Normal operation i, j =8 m, n = 1 .. 8 m + n = 2 .. 16	When switching from telegram to fill signal (1 .. 12) (2 .. 20)
NOTE Numbers in brackets represent values which may occur when switching from telegram to fill signal.				

30.2.4.2 Clock adjustment

The limit values of clock adjustment times are specified in Table 152.

Table 152 — Specifications of the clock adjustment times

Time	Value
t_{cadmin}	= t_{BITnom} / 64
t_{cadmax}	= t_{BITnom} / 11
$t_{cadreal}$	$0 \leq t_{cadreal} \leq t_{cadmax}$

30.2.4.3 Signal delay due to the slave

Signal delay due to the slave (in repeater mode) is specified in Table 153.

Table 153 — Optical signal delay in a slave

Baud rate	t_{del}-max	t_{del}-electric	t_{del}-optic
2 Mbit/s	750 ns	400 ns	350 ns
4 Mbit/s	375 ns	200 ns	175 ns
8 Mbit/s	250 ns	100 ns	150 ns
16 Mbit/s	200 ns	50 ns	150 ns

30.2.5 Idealized waveform

The idealized waveform is characterized by status changes of the optical signal. The optical signal is replaced by rectangular wave shapes of equal height and infinitely short rise and fall times. The status change (edge) of the idealized waveform (rectangle) is defined at the transmitter output as the instant of time at which the optical power is 0,5 × P_{TminH} ± 20 %. Both threshold levels (low attenuation and high attenuation) shall always fall within the interval P_{TmaxL} and P_{TminH}.

All subsequent times shall be measured between the status changes defined above.

30.3 Connection to the optical fiber

30.3.1 Introduction

In this clause, the connections to the optical fiber for master and slave as well as their interaction are described in more detail.

Table 154 shows all basic functions that shall be performed by a connection.

Table 154 — Basic functions of the connection

Function to be performed by →		Master	Slave
1	Retrieve clock from received signal	x	x
2	Regenerate and transmit received signal		x
3	Transmit 0111 1111 as fill signal	x	
4	Transmit own telegram	x	x
5	Phase-correct and spike-free transition between numbers	4 → 3 3 → 4	4 → 2 2 → 4

30.3.2 Master connection

30.3.2.1 Function

Figure 131 shows the functions that a master connection shall have.

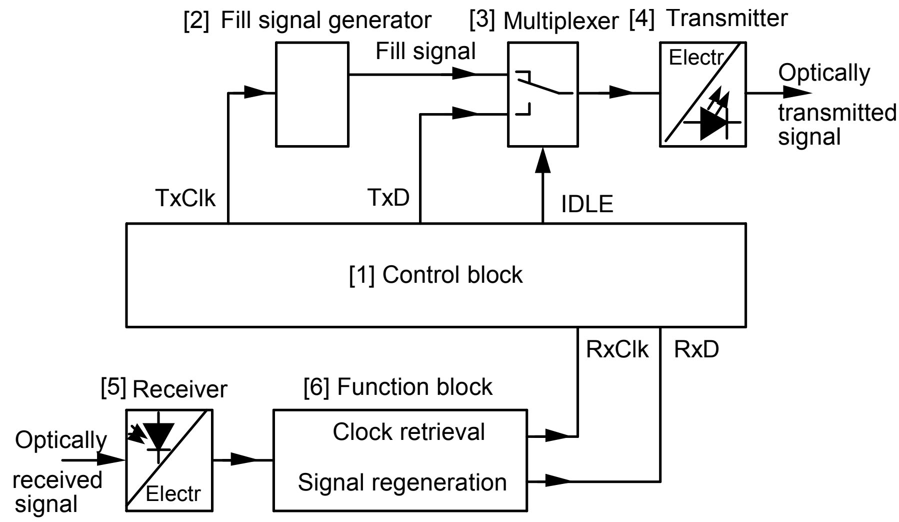


Figure 131 — Functions of a master connection

The control block – [1] in Figure 131 – shall construct the telegram to be sent according to Figure 131 and convert it into a NRZI-coded signal. When receiving a telegram, the master's control block shall recognize the NRZI-coded and regenerated telegram as one for the master based upon its telegram delimiters and the address field. In addition, the control block [1] shall check the telegram and transmit only correct data fields to the signal processing unit.

Except for NRZI coding/decoding and the generation/recognition of the telegram delimiters, the functions above will be discussed with higher protocol layers.

30.3.2.2 Generating a fill signal

According to Figure 131, the control block [1] shall generate the transmitting clock (TxClk) for the master. This shall be sent to the fill signal generator – [2] in Figure 131 –, where the fill signal is generated according to 9.10.2, Figure 52.

When the master is transmitting the fill signal (IDLE = 1), the signal shall reach the electro-optical converter [4] via the switch [3]. The switch shall work in such a way that a signal change at its output always coincides with the pattern of the transmitting clock. In this way, subsequent units can use phase locked loops for clock retrieval. Thus, they can always be synchronized to the transmitting clock of the master.

Function block [6] will be discussed in 30.3.3.

30.3.2.3 Switching from fill signal to telegram delimiters and vice versa

During transitions from fill signal 0111 1111 to telegram delimiters:

a) it shall be possible to interrupt the bit string 0111 1111 at any point;

b) it shall be possible to insert up to two arbitrary (transitioning) bits xx (e.g., for simplifying implementation).

All signal changes generated this way, however, shall be synchronized with the transmitting clock.

Figure 132 shows some examples of valid signal patterns of the transmitting signal during transitions from fill signal to a telegram to be sent, where occasionally inserted (transitioning) bits are shaded.

As shown in Figure 132, bit sequences having several delimiters can be generated. The receiver shall be able to recognize the highlighted, double-lined signal as the leading telegram delimiter.

During the transition from telegram delimiters to fill signals, i.e. after the bit sequence 01111110_B (delimiter):

a) up to four arbitrary transitioning bits can be inserted;

b) followed by switching to an arbitrary point in the bit sequence 0111 1111 (fill bits).

All generated signal changes shall be synchronized to the transmitting clock. Figure 133 shows some examples. Occasionally inserted (transitioning) bits are shaded. It is possible to have several delimiters appear. A receiver shall be able to recognize the first delimiter as an enclosing telegram delimiter.

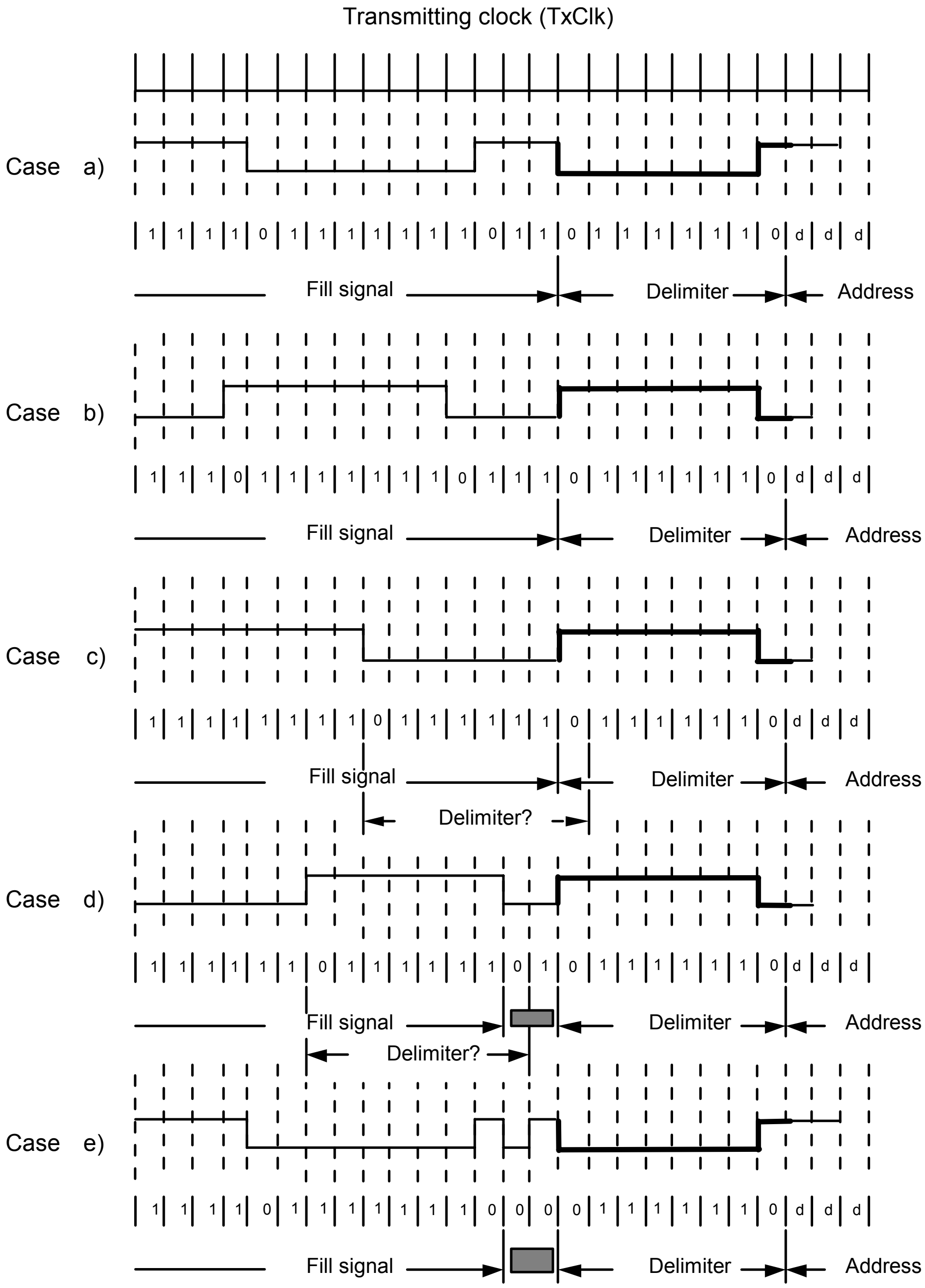


Figure 132 — Valid transmitting signals during the transition from fill signal to telegram delimiters

In Figure 133, case e) is identified by the fact that two consecutive edges of opposite directions shall be separated by a maximum of 12 transmitting clock cycles (t_{BIT}) and two sequential edges with the same direction shall be separated by a maximum of 20 transmitting clock cycles (t_{BIT}). This is important for the proper operation of a DPLL.

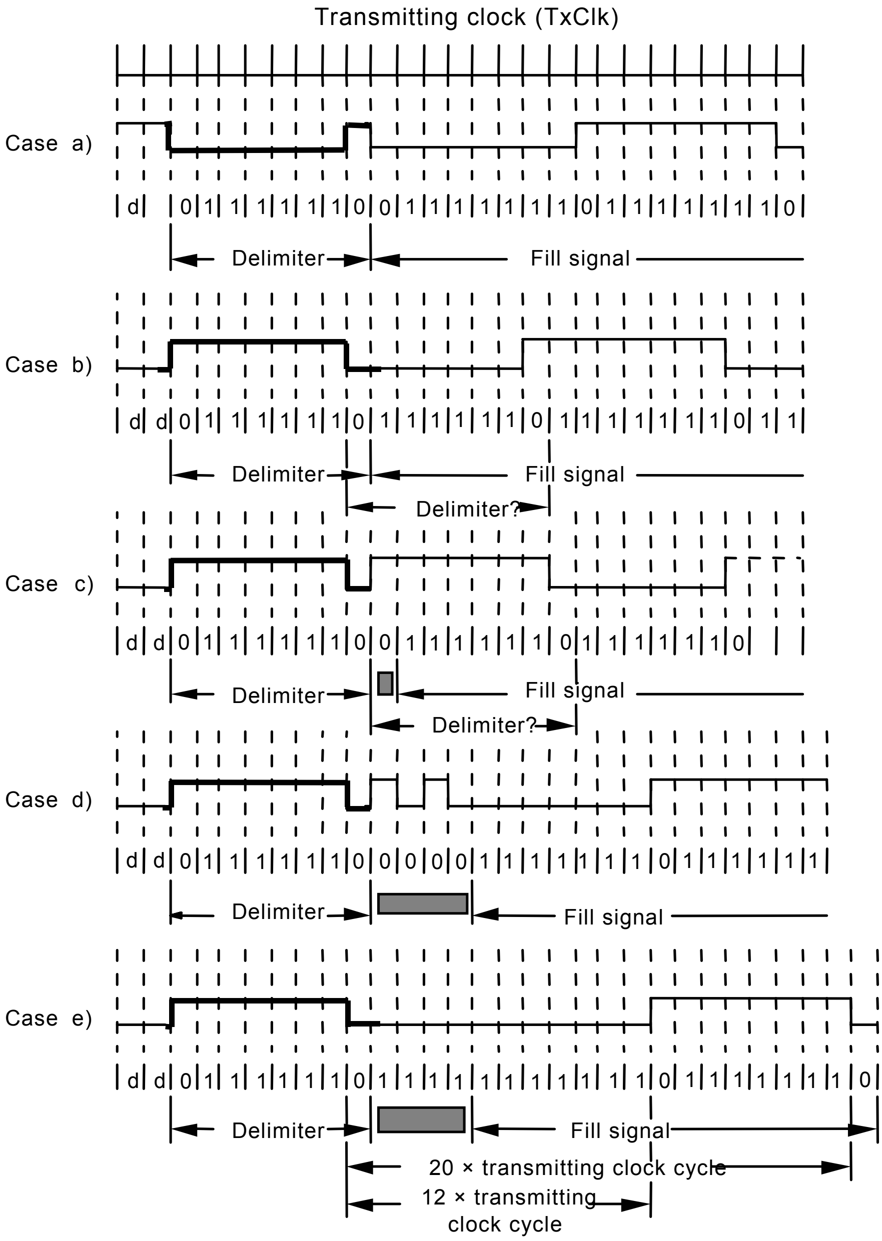


Figure 133 — Valid transmitting signals during the transition from telegram delimiter to fill signal

30.3.3 Slave connection

Figure 134 shows the functions that a slave connection shall have.

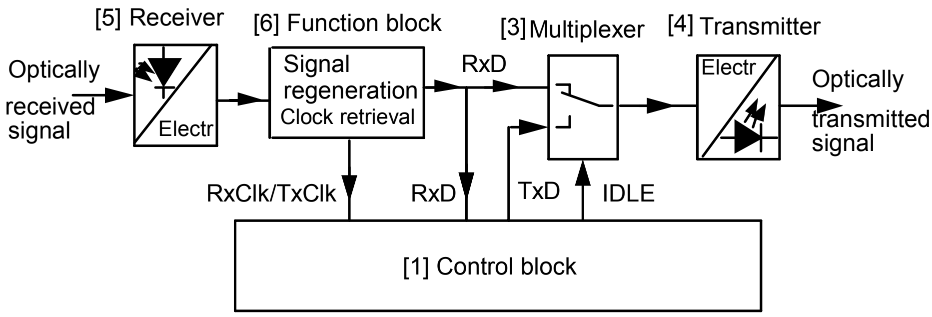


Figure 134 — Functions of a slave connection

The function block [6] has the following tasks:

a) Retrieving the clock from the electrical received signal (clock retrieval, possibly with DPLL). The clock retrieved in [6] shall be used as transmitting and receiving clock for [1] (for the master, transmitting and receiving clocks are different signals);

b) Regenerating the received signal, care shall be taken that any signal changes occur synchronously with the clock retrieved in a). If the slave does not need to transmit its own telegram, the regenerated received signal shall be sent (repeater mode, IDLE = 1).

The multiplexer [3] shall work according to the transitioning parameters as shown in 30.3.2.3.

Power supply:

In order to perform the above functions, the electronic components shall continue to work (e.g. during start-up and diagnostics), even if the power supply of the associated devices is shut-down. The slaves shall at least be able to regenerate the stream of data and to function as repeaters by transmitting the data.

30.3.4 Interactions of the connections

In Figure 135, the interaction of the connection of two slaves in a network is illustrated. The assumption is made that slave 1 is in the process of transmitting a telegram to the master. The multiplexer [3] in the master shall pass the fill signal so that the function block [6] of slave 1 can retrieve the clock. Slave 2 multiplexer [3] shall pass its regenerated received signal (i.e., the slave 1 telegram) to the master. The master, in turn, shall retrieve the receiver clock from the received signal by means of its function block [6]. All three phase locked loops in Figure 135 shall be synchronized at any time. This synchronization shall always be maintained, even if a transition [3] is activated. During switch over of [3], it is important to avoid any signal edges which do not follow the clock pattern.

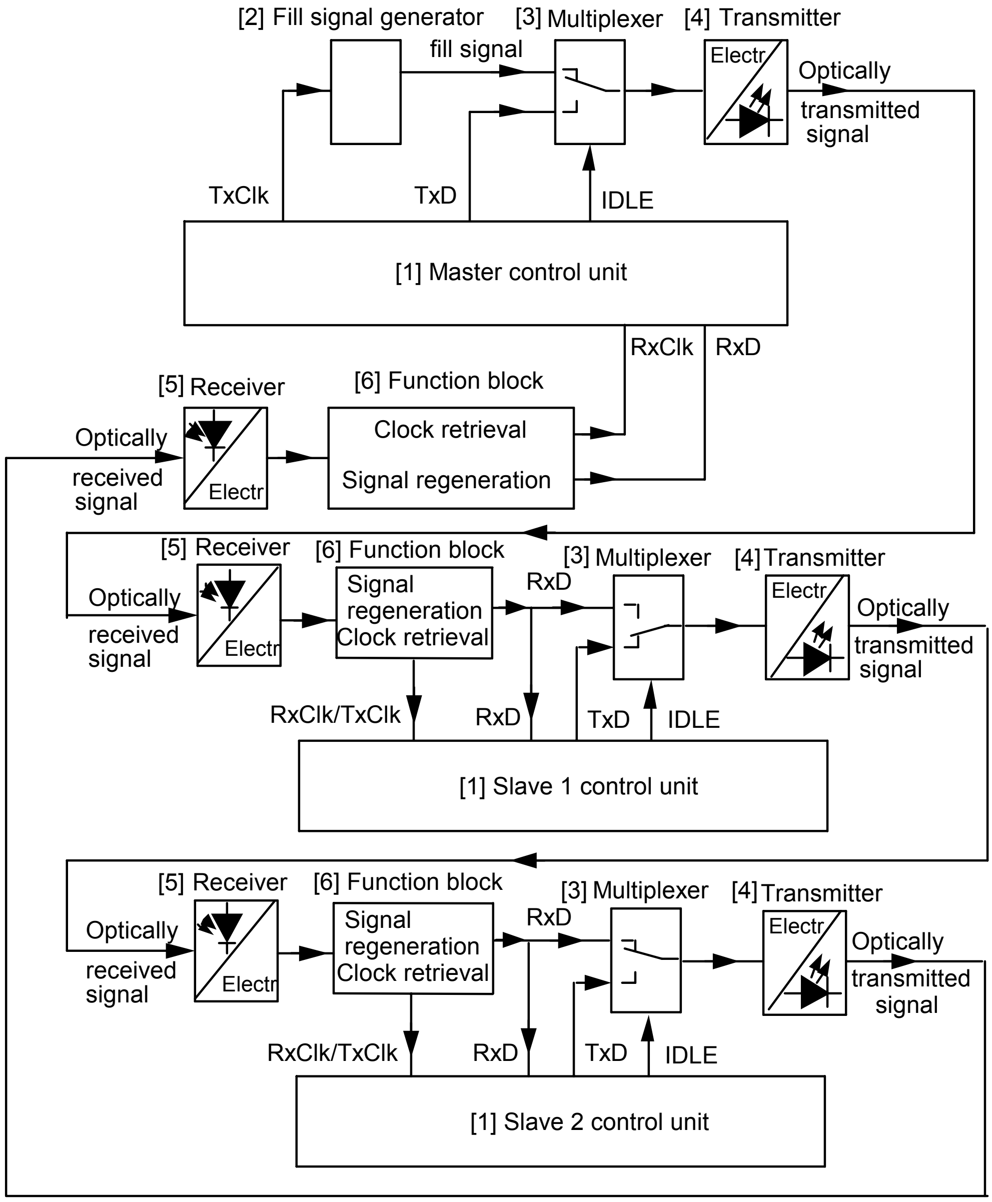


Figure 135 — Network with two slaves

31 Type 18: Medium attachment unit: basic medium

31.1 General

Type 18-PhL-B implements an MAU compliant with ISO/IEC 8482 twisted pair multipoint interconnections, named TPMI throughout the remainder of this clause, and is a derivative of ANSI TIA/EIA-485-A.

Added to the TPMI requirements are the following:

- data signal encoding specifications
- MAU bus signal loading
- signal conveyance requirements
- media specifications
  - — topology descriptions
  - — cable specifications
  - — transmission line termination specifications
- endpoint and branch trunk cable connectors
- recommended interface circuitry

The resulting Type 18-PhL-B bus can support bit rates as high as 10 Mbit/s and transmission lengths as long as 1,2 km.

NOTE Throughout this subclause, the term *station* refers to a network device and is used for consistency with the Type 18 DLL and AL where various types of stations are defined.

31.2 Data signal encoding

Type 18-PhL-B specifies NRZI (Non-Return to Zero Inverted) data signal encoding as defined by ISO/IEC 9314-1. Accordingly, a Mark-to-Space transition or a Space-to-Mark transition represents a PhPDU logical one; and a lack of transition (Mark-to-Mark or Space-to-Space) presents a PhPDU zero.

31.3 Signal loading

A Type 18-PhL-B MAU communication element implementation requires transceiver devices that are specified not to exceed 0,5 Unit Loads (UL). Thus, the maximum number of connected devices is 64.

31.4 Signal conveyance requirements

The minimum wiring between communicating devices is shown in Figure 136.

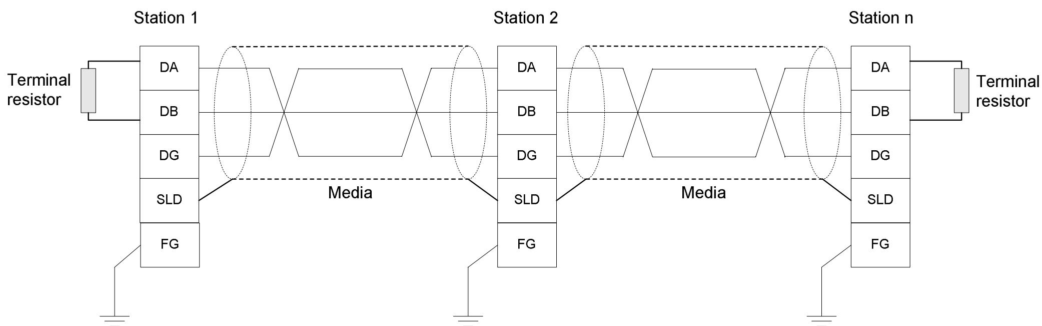


Figure 136 — Minimum interconnecting wiring

It is recommended to connect the SLD (shield) to the FG (field ground) at both ends of the trunk line cable via low impedance (that is, low inductance) connections. This is necessary to achieve a reasonable electromagnetic compatibility.

31.5 Media

31.5.1 General

The medium of each bus segment (trunk) and spurs (branches) is a shielded twisted-pair cable. The shield helps to improve the electromagnetic compatibility (EMC).

31.5.2 Topology

31.5.2.1 Pass-through topology

A dedicated cable is configured with a pass-through type connector for each device as shown in Figure 137.

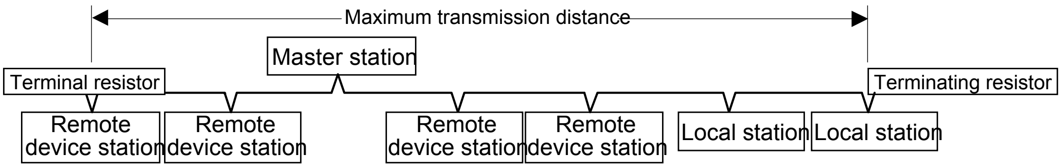


Figure 137 — Dedicated cable topology

31.5.2.2 T-branch topology

A T-branch topology is configured with T-connectors as couplers to provide node points for spurs (branches) as shown in Figure 138.

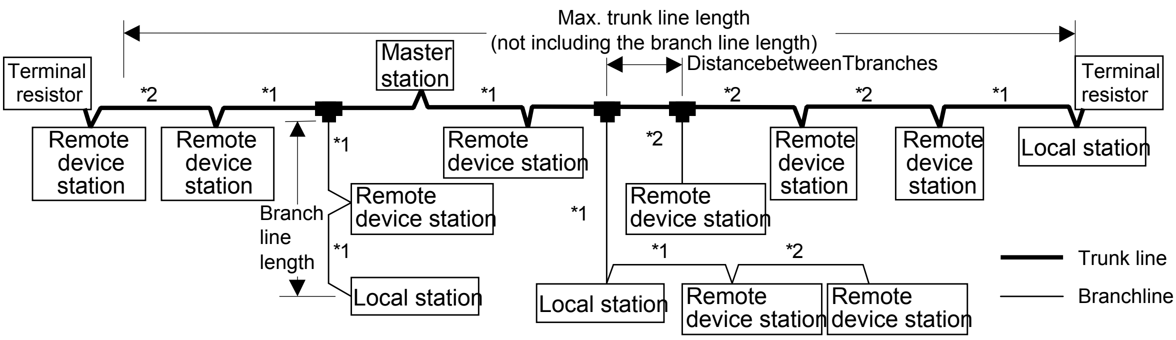


Figure 138 — T-branch topology

31.5.2.3 Topology requirements

31.5.2.3.1 Pass-through topology

The maximum cable length as a function of bit-rate is specified in Table 155. The minimum cable distance device-to-device is 20 cm.

Table 155 — Pass-through topology limits

Bit rate(kbit/s)	Max. cable length (m)
10 000	100
5 000	160
2 500	400
625	900
156	1 200

31.5.2.3.2 T-branch topology

The only allowable bit rates for the T-branch topology are 156 kbit/s and 625 kbit/s. The maximum cable lengths (as a function of bit-rate) and other topology limitations are specified in Table 156. See Figure 138 for a description of the referenced bus components.

Table 156 — T-branch topology limits

Parameter		Value	Comment
Max. trunk length	625 kbit/s	100 m	
	156 kbit/s	500 m	
Max. branch length	625 kbit/s	50 cm	Cable length per branch (spur)
	156 kbit/s	200 cm	
Max. overall branch length		8 m	Total length of all branch lines combined
Max. distance between T-branches		No limit	This distance measured on trunk line
Max. number of stations connected per branch		6	
Min. distance to master station		2 m	See ***1** in Figure 138. This parameter is reduced to 1 m for systems configured without Local Stations or Intelligent Device Stations.
Min. distance between stations		30 cm	See ***2** in Figure 138.
NOTE Station types (e.g., master station) are defined in Type 18 DLL and AP.			

31.5.3 Signal cable specifications

The 3-core twisted-pair cable Type 18-PhL-B medium is specified in Annex R.1.

31.5.4 Media termination

The trunk line segment shall be terminated at each end with its characteristic impedance. Requirements for these two transmission line terminating resistors are specified in Table 157.

Table 157 — Terminating resistor requirements

Parameter	Value
Resistance	110 Ω
Power	0,5 W
Tolerance	<10 %

31.6 Endpoint and branch trunk cable connectors

There is no physical connector specified for use with Type 18-PhL-B.

The type of connector shall be a screw-compression type with each terminal able to accommodate two conductors of the type specified for the media cable. It is also required that sufficient terminals are provided for all five connection points, or alternatively, four connection points with a separate connection point provided for the FG circuit.

It is recommended that two-piece connectors be implemented for disconnecting online devices. It is further recommended that the implementer evaluate appropriate industry partnership associations and consortia for commonly implemented connector solutions for the industry of targeted application. See the IEC 61784 series for references to these and other related specifications.

31.7 Recommended type 18-PhL-B MAU circuitry

Galvanic isolation of the communications element is not required, but it is recommended and strongly encouraged for stable performance. It is minimally recommended that the communications element be configured with galvanic isolation as shown in Figure 139. It is further recommended that the input/output element be configured with its own galvanic isolation as shown in Figure 140.

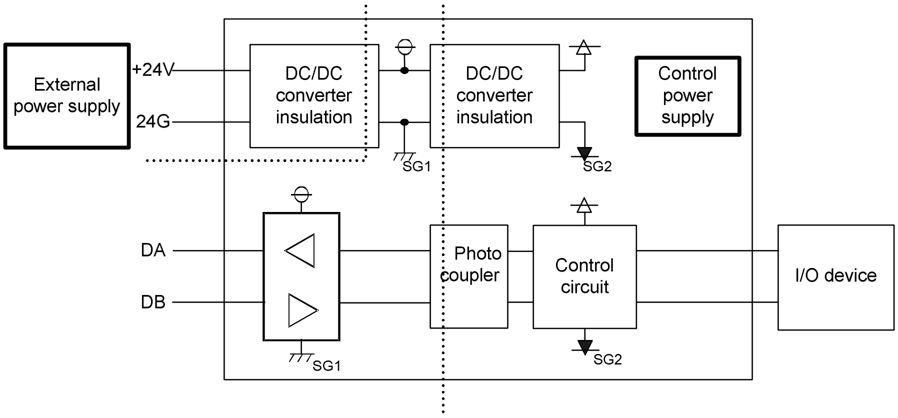


Figure 139 — Communication element isolation

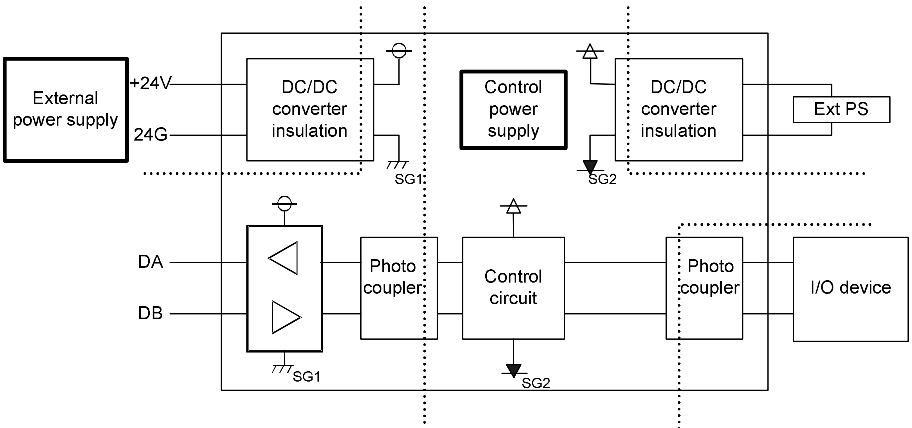


Figure 140 — Communication element and I/O isolation

32 Type 18: Medium attachment unit: powered medium

32.1 General

Type 18-PhL-P implements a MAU compliant with ISO/IEC 8482 twisted pair multipoint interconnections, named TPMI throughout the remainder of this clause, and is a derivative of ANSI TIA/EIA-485-A.

Added to the TPMI requirements are the following:

- data signal encoding specifications
- MAU bus signal loading
- signal conveyance requirements
- media specifications
  - topology descriptions
  - cable specifications
  - transmission line termination specifications
- endpoint and branch trunk cable connectors
- embedded power distribution
- recommended interface circuitry

The resulting Type 18-PhL-P bus can support bit rates as high as 2,5 Mbit/s and transmission lengths as long as 500 m.

NOTE Throughout this subclause, the term *station* refers to a network device and is used for consistency with the Type 18 DLL and AL where various types of stations are defined.

32.2 Data signal encoding

Type 18-PhL-U specifies NRZI (Non-Return to Zero Inverted) data signal encoding as defined by ISO/IEC 9314-1. Accordingly, a Mark-to-Space transition or a Space-to-Mark transition represents a PhPDU logical one; and a lack of transition (Mark-to-Mark or Space-to-Space) presents a PhPDU zero.

32.3 Signal loading

Type 18-PhL-U MAU communication element implementation requires transceiver devices that are specified not to exceed 0,5 Unit Loads (UL). Thus, the maximum number of node devices is 64.

32.4 Signal conveyance requirements

The minimum wiring between two communicating devices is shown in Figure 141.

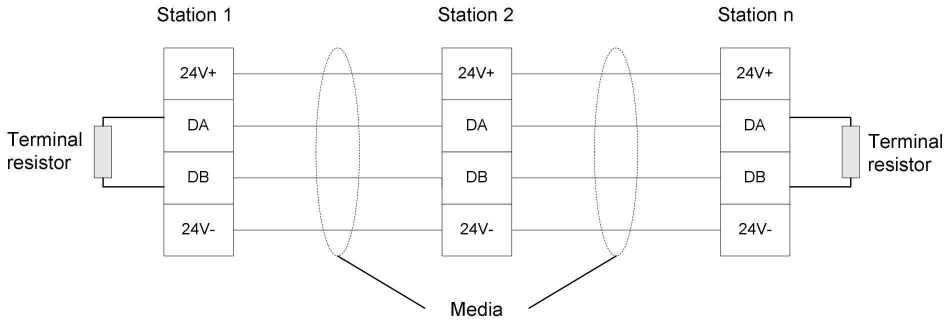


Figure 141 — Minimum interconnecting wiring

32.5 Media

32.5.1 General

The medium of each bus segment (trunks) and spurs (braches) is a 4-core unshielded cable. These cables are specified in both flat cable and round cable configurations with conductors for both communications and embedded power distribution.

32.5.2 Topology

32.5.2.1 General

An example flat cable configuration with embedded power distribution is shown in Figure 142. The bus contains a trunk and may contain spurs (branches).

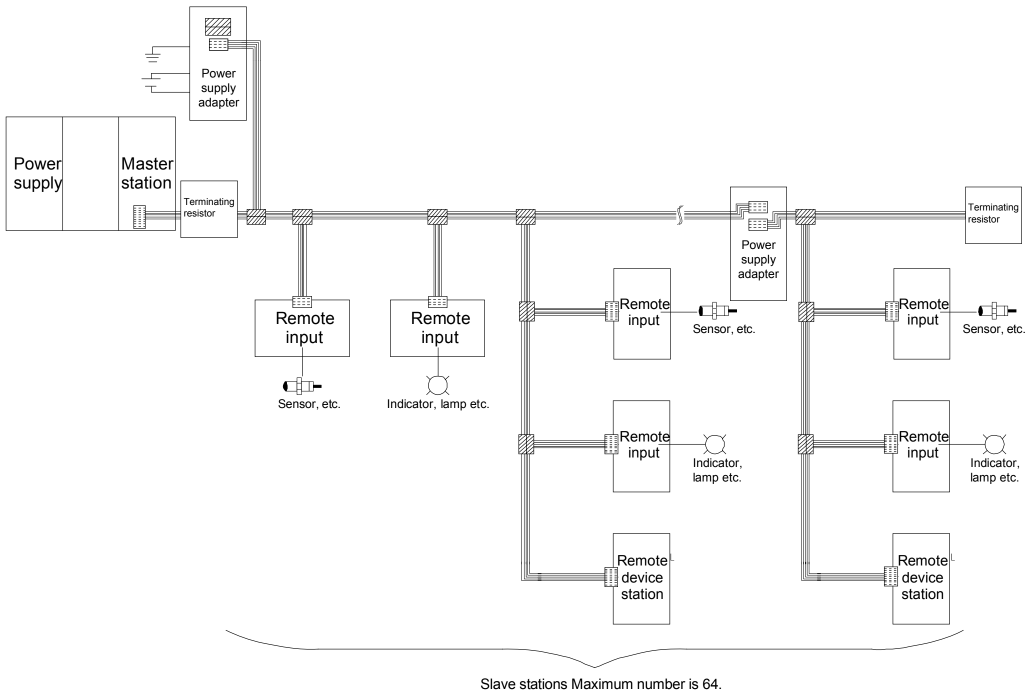


Figure 142 — Flat cable topology

32.5.2.2 Pass-through topology

A dedicated cable is configured with a pass-through type connector for each device as shown in Figure 143.

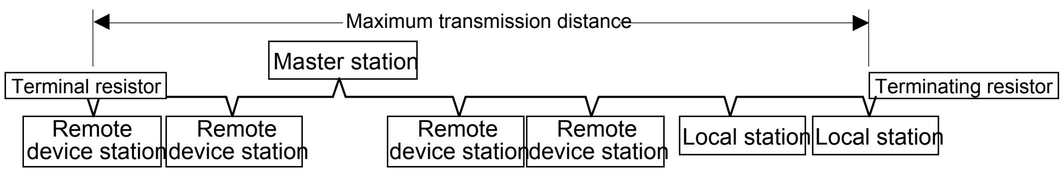


Figure 143 — Dedicated cable topology

32.5.2.3 T-branch topology

A T-branch topology is shown in Figure 144. The cable types can be mixed in the network, but must remain consistent for a given branch of trunk segment.

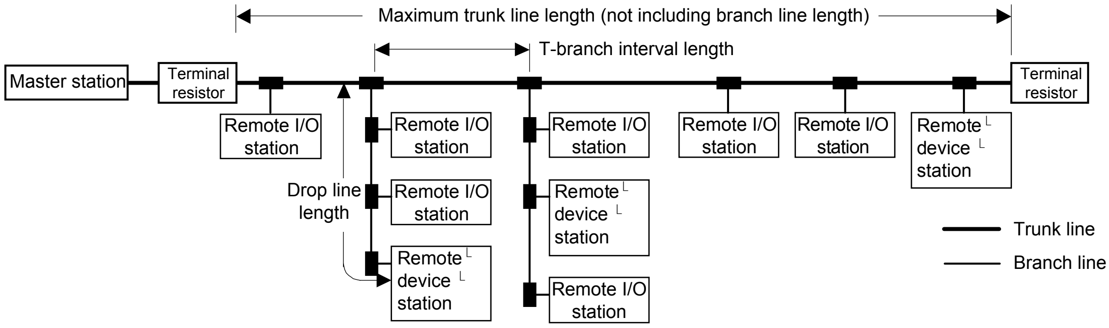


Figure 144 — T-branch topology

32.5.3 Topology requirements

32.5.3.1 Pass-through topology

The maximum cable length, as a function of bit-rate, is specified in Table 158. The minimum cable distance device-to-device is 20 cm.

Table 158 — Pass-through topology limits

Bit rate (kbit/s)	Max. cable length (m)
2 500	35
625	100
156	500

32.5.3.2 T-branch topology

The type 18-PhL-P topological implementation is restricted in that the trunk segment shall be constructed using only one type of cable (flat, round preferred, or round alternate). Similarly, each branch (spur) shall be self-consistent, that is, constructed of only one type of cable. However, branch cable types need not match the trunk cable type or that of other branches in the PhL-segment bus.

The only allowable bit rates for the T-branch topology are 156 kbit/s, 625 kbit/s and 2,5 Mbit/s.

The maximum cable lengths as a function of bit-rate and other topology limitation are specified in Table 159.

Table 159 — T-branch topology limits

Parameter	Value			Comment
	156 kbit/s	625 kbit/s	2 500 kbit/s	
Max. trunk segment length	500 m	100 m	35 m	Not including branch line length
Max. branch length	60 m	16 m	4 m	Cable length per branch (spur)
Max. overall branch length	200 m	50 m	15 m	Total length of all branch lines combined
Max. cable length between connected devices	500 m	100 m	35 m	
Max. cable length between T-branches	No limit			This distance measured on trunk line
Max. number of devices connected per branch	8			

32.5.4 Signal cable specifications

32.5.4.1 Flat cable

The 4-core unshielded flat cable Type-18-PhL-P medium is specified in Annex R.2.1.

32.5.4.2 Round cable - preferred

The preferred 4-core unshielded round cable for the Type-18-PhL-P medium is specified in Annex R.2.2. This cable type is also known as VCTF cord and is compliant with IEC 60227-5.

32.5.4.3 Round cable - alternate

The alternate 4-core unshielded round cable for the Type-18-PhL-P medium is specified in R.2.3.

32.5.5 Media termination

The trunk line segment shall be terminated at each end with its characteristic impedance. Requirements for these two transmission line terminating resistors are specified in Table 160 for flat cable and Table 161 for round cable.

Table 160 — Terminating resistor requirements – flat cable

Parameter	Value
Resistance	130 Ω
Power	0,5 W
Tolerance	<10 %

Table 161 — Terminating resistor requirements – round cable

Parameter	Value
Resistance	90 Ω
Power	0,5 W
Tolerance	<10 %

32.6 Endpoint and branch trunk cable connectors

32.6.1 Device connector

The required dimensions of the Type 18-PhL-P device connector are specified in Annex Q.2.

32.6.2 Flat-cable connector

The required dimensions of the Type 18-PhL-P flat cable connector are specified in Annex Q.3.

32.6.3 Round cable connector

The required dimensions of the Type 18-PhL-P round cable connector are specified in Annex Q.4. This connector is applicable to both styles of Type 18-PhL-P round cable.

32.6.4 Round cable alternate connector

The required dimensions of the Type 18-PhL-P round cable alternate connector is specified in Annex Q.5.

32.6.5 T-branch coupler

There are no required dimensions for the Type 18-PhL-P T-branch coupler. Any suitable commercially available terminal block can be used.

32.7 Embedded power distribution

32.7.1 General

Type 18-PhL-P includes specifications for network embedded power distribution. The power component of a PhL-segment can be either a single interconnected power distribution system or partitioned into more than one power allocation segments. The example block diagram in Figure 145 demonstrates a PhL-segment with two power allocation segments.

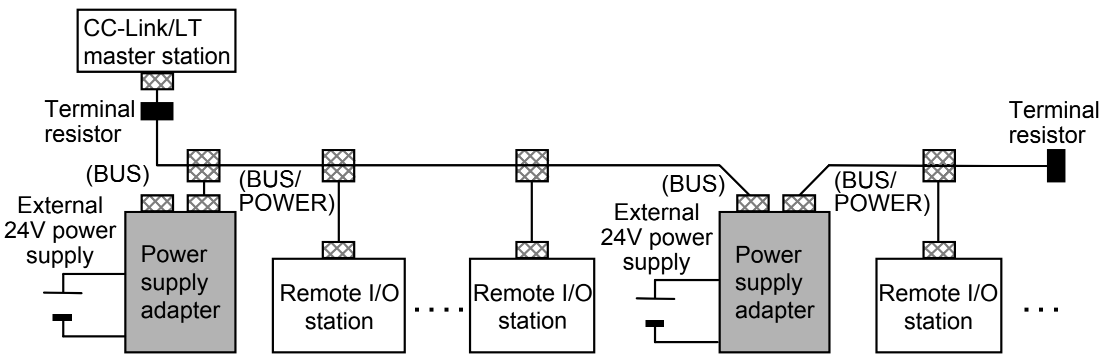


Figure 145 — Type 18-PhL-P power distribution

32.7.2 Power source

Power supply devices shall be implemented with two device bus connectors that provide pass-through connectivity for the data signals but power sourced to only one connector. The circuit diagram in Figure 146 shows the interconnection for the power source.

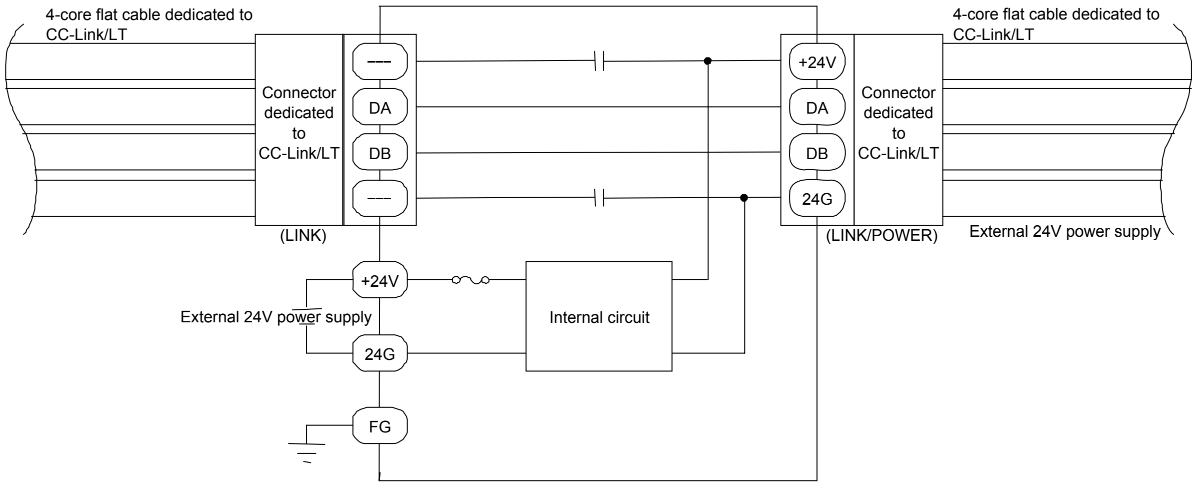


Figure 146 — Type 18-PhL-P power distribution

The 24 V power supply for the Type 18-PhL-P shall comply with the specifications given in Table 162.

Table 162 — 24 V Power supply specifications

Parameter	Specification
Max. operating voltage	28,8 V
Min. operating voltage	20,4 V
Max. current	5 A
Isolation – power to data signals	500 Vrms
Reverse over voltage protection	95 V
Current surge tolerance	Output voltage within 19,2 V to 30,0 V for ±5 A/1 mS pulse

32.7.3 Power loading

Each device connected to the Type 18-PhL-P bus that also consumes power shall comply with the requirements specified in Table 163.

Table 163 — 24V Power consumption specifications

Parameter	Specification
Max. operating voltage	30,0 V
Min. operating voltage	19,2 V
Max. current	5 A (see note 1)
Start current	1,33 times operating current (see note 2)
Reverse current protection	no damage to device or network from reverse wired power

NOTE 1 For full transmission distances, it is necessary to limit power consumption to 0,1 A per device.

NOTE 2 This does not include the inrush current required to charge the input bypass capacitors. When these are included, it is necessary to limit the overall inrush current such that the bus power shall not droop to less than 19,2 V for more than 1 ms when a device is plugged into an operating network.

The specifications for start current and inrush current (Table 163, Note 2) are required to support hot-pluggable devices, that is, devices that can be plugged into, or removed from, an operating network without harm to the network or the devices. Data errors may occur.

Filtering of the power input circuitry and protecting against reverse power connection is also required for stable performance at the higher bit rates. The filter parameters are not specified. A typical filter and protection circuit is shown in Figure 147 with critical components labeled.

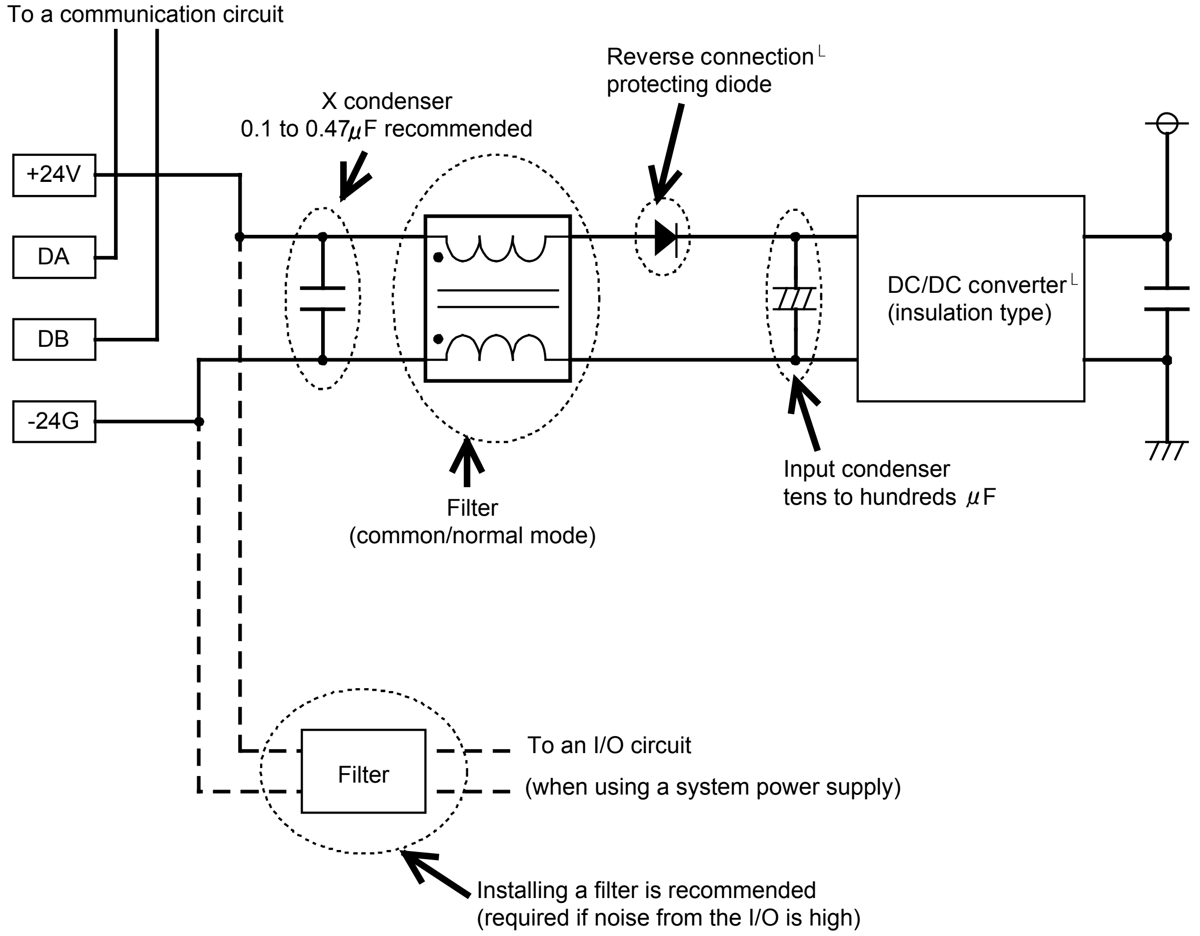


Figure 147 — Type 18-PhL-P power supply filtering and protection

32.8 Recommended type 18-PhL-P MAU circuitry

32.8.1 General

The circuit diagrams in the following two subclauses are included for informational purposes.

32.8.2 Communications element galvanic isolation

Galvanic isolation of the communications element is not required, but it is recommended and strongly encouraged for stable performance. It is minimally recommended that the communications element be configured with galvanic isolation as shown in Figure 148. It is further recommended that the input/output element be configured with its own galvanic isolation as shown in Figure 149.

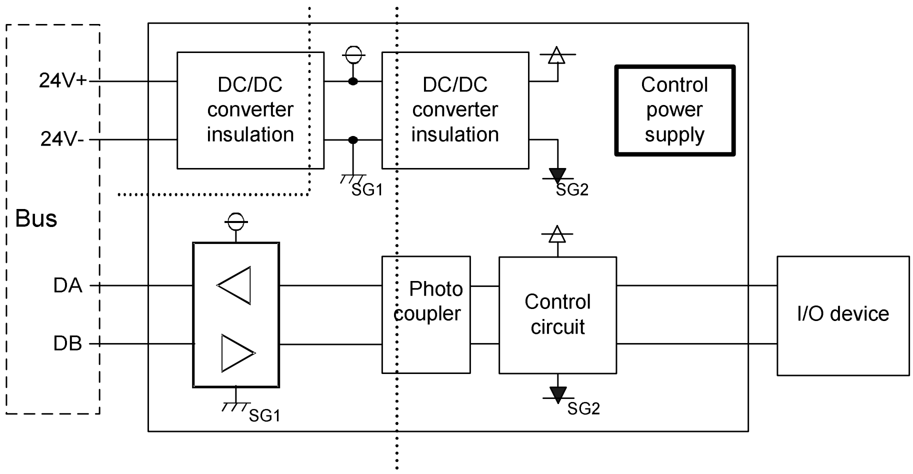


Figure 148 — Communication element isolation

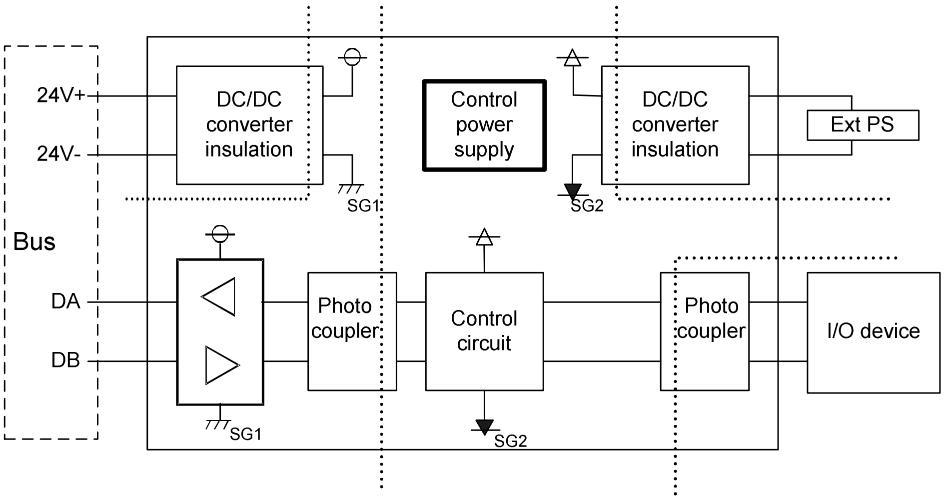


Figure 149 — Communication element and i/o isolation

32.8.3 Power

A complete power conditioning circuit is shown in Figure 150. This diagram serves as an informative guide for a recommended implementation of Type 18-PhL-P power supply components.

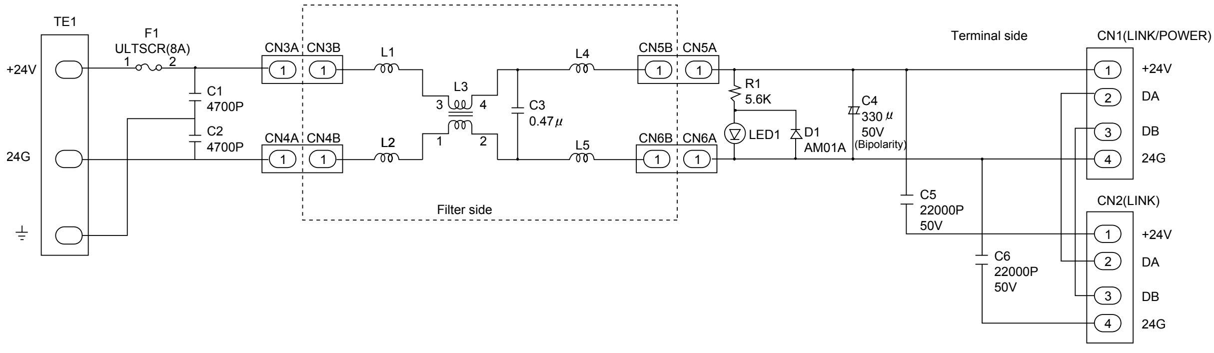


Figure 150 — PhL-P power supply circuit

Annex A
(normative)

Type 1: Connector specification

A.1 Internal connector for wire medium

A fieldbus connector that is inside the enclosure of the fieldbus device and therefore requires no protection against the electromagnetic and physical environment shall be specified as an internal connector. An internal connector shall meet the following functional requirements:

a) distinctly marked to avoid conductors being interchanged;
b) positive locking with a minimum of 50 N extraction force locked;
c) field installation with hand tools shall be possible;
d) the fixed (device) side shall be 4,8 mm × 0,8 mm male tabs with hole as shown in Figure A.1, Table A.1, and specified in IEC 60760;
e) each conductor of the cable shall be terminated with a locking female connector with an insulating sleeve or housing;
f) the female connector with insulating sleeve or housing shall fit through a 9,5 mm diameter hole.

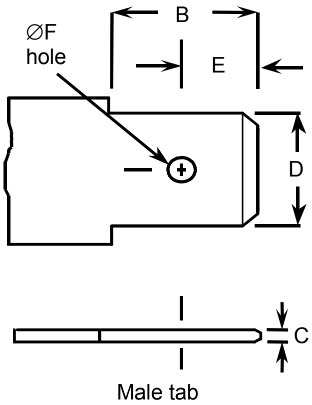


Figure A.1 — Internal fieldbus connector

Table A.1 — Internal connector dimensions

4,8 mm (0,187 in) Male tab				
	Millimetres		Inches	
	max.	min.	max.	min.
B	6,5	6,2	0,256	0,244
C	0,84	0,77	0,033	0,030
D	4,9	4,7	0,193	0,185
E	3,4	3,0	0,134	0,117
∅ F	1,5	1,3	0,060	0,050

A.2 External connectors for wire medium

A fieldbus connector that is outside the enclosure of the fieldbus device and therefore requires protection against the electromagnetic and physical environment shall be specified as an external connector.

Two external connectors are specified in accordance with the environment of the installation.

A.2.1 External connector for harsh industrial environments

An external connector for harsh industrial environments shall meet the following functional requirements:

a) polarized to avoid conductors being interchanged, both mated and unmated;
b) available with sealing to IEC 60529: IP65 when mated or fitted with protective caps;
c) the free (cable) side shall be available with a cable clamp which secures the cable but does not subject the cable conductors to damaging stress;
d) the conductors shall be completely surrounded by a conductive shell which maintains the electrical continuity of the shield;
e) the conductive shell of the free (cable) side shall be covered by insulating material;
f) the conductive shell of the fixed (device) side shall be insulated from its mounting surface;
g) the fixed (device) side shall provide a connection to the shield, other than the shell;
h) the contacts shall accommodate wire sizes of 0,20 mm^2 to 0,64 mm^2;
i) provided with positive locking to prevent disconnection by cable strain;
j) provided with four pins (two signal pins and two power pins);
k) available with crimped conductors;
l) provided with male contacts on the fixed (device) side;
m) a cable connector with male pins shall be available for in-line connection;
n) dielectric strength from contacts to shell and from shell to ground shall be at least as high as specified under isolation for the appropriate MAU;
o) contacts shall be assigned to functions as shown in Table A.2 and Figure A.2;
p) connector dimensions (mating face) shall be as shown in Figure A.3, Figure A.4 and Figure A.5.

Table A.2 — Contact assignments for the external connector for harsh industrial environments

Contact No.	Function
A	DATA + with the option of power +
B	DATA – with the option of power –
C	Reserved for option of power +
D	Reserved for option of power –

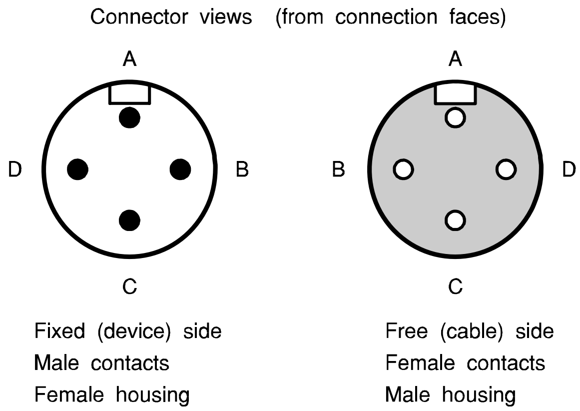


Figure A.2 — Contact designations for the external connector for harsh industrial environments

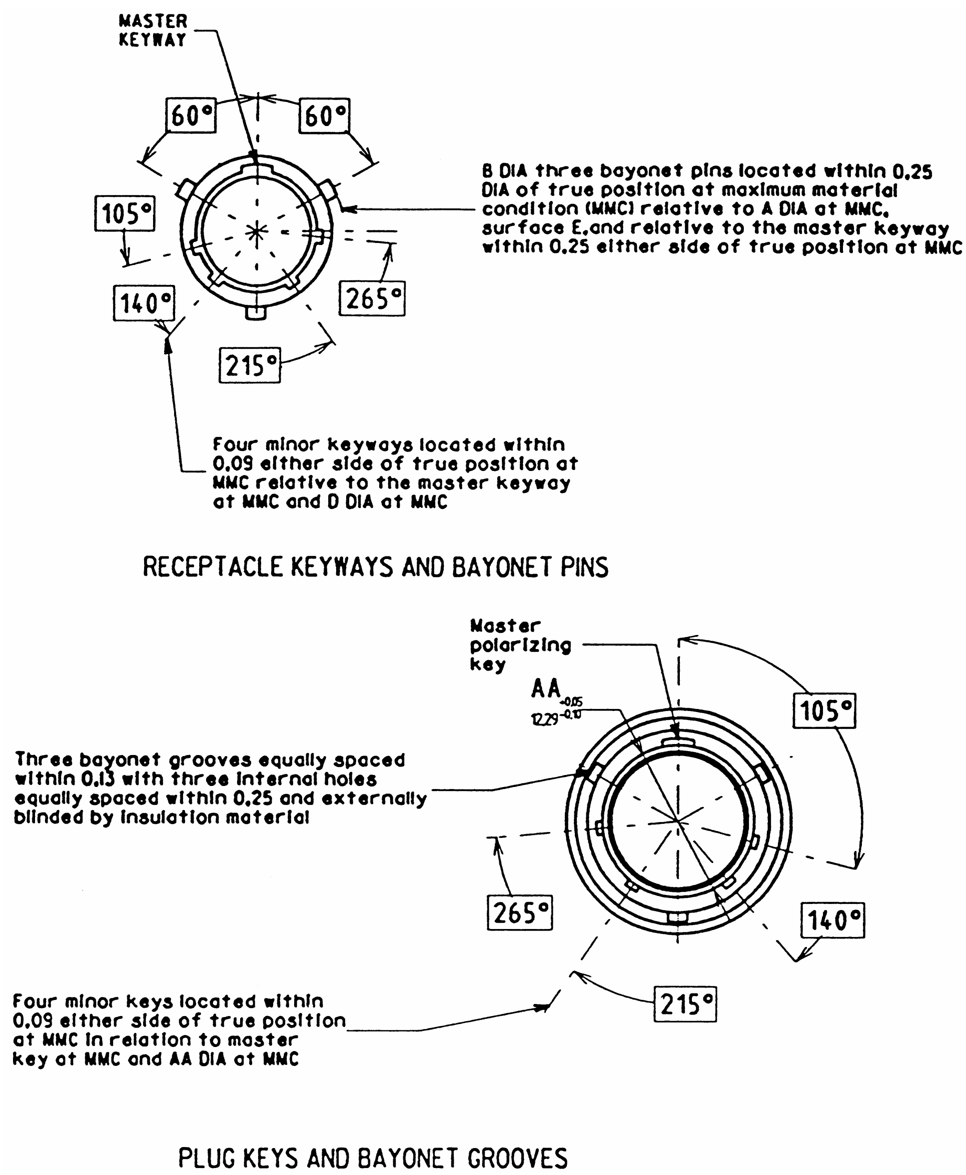
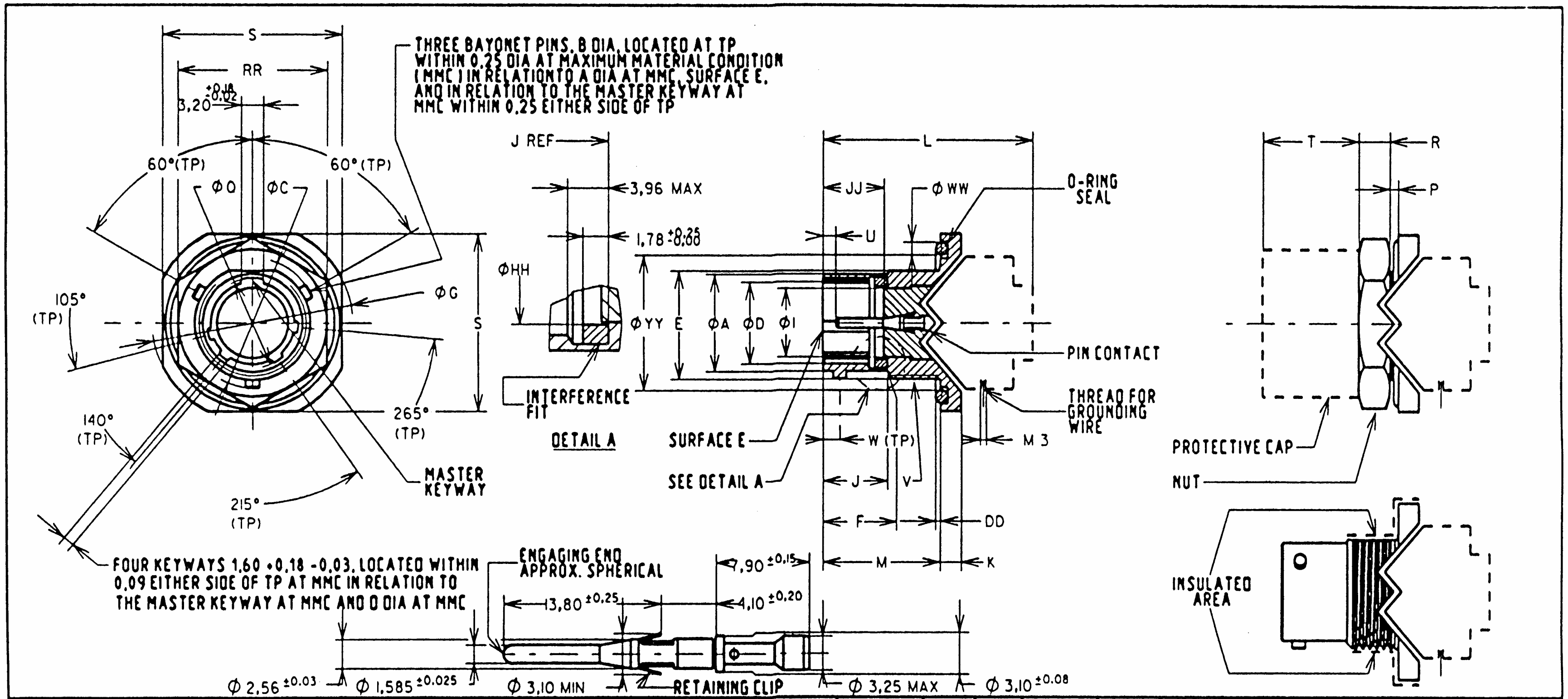


Figure A.3 — External fieldbus connector keyways, keys, and bayonet pins and grooves



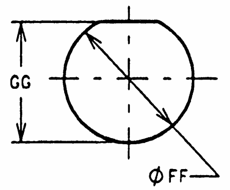
SIZE	ΦA	ΦB	ΦC	ΦD	E	F	ΦG	ΦI	J	JJ	K	L	M	P PANEL THK REF MIN	P PANEL THK REF MAX	ΦO	R	RR	S	T	U	V	W	ΦWW	ΦYY
	+0,03 -0,12 EXT. DIA.	+0,15 -0,05 BAY PIN	+0,00 -0,04 OVER BAY PINS	+0,13 -0,02 INT.DIA	+0,00 -0,25 MTG FLAT	MIN MTG THD LOC	+0,00 -0,82 ACROSS FLANGE COR	MAX INSERT	±0,25 PACK ING LOC	+0,00 -0,50 PIN INSERT LOC	± 0,51 THK MTG FLANGE	MAX OVER-ALL LENGTH	+0,79 -0,00 MTG FLANGE LOC	MIN	MAX	+0,13 -0,15 OVER KEY-WAYS	+0,25 -1,79 NUT THK	±0,43 HEXAGON DIM	MAX LENGTH SIDE	MAX PROTEC-TIVE CAP LENGTH	+0,25 -0,51 PIN CONTACT LOC	CLASS 2A MOUNT-ING THREAD	(TP) BAY PIN LOC	±0,08 O-RING CROSS SECTION	± 0,15 O-RING SEAL INT.DIA.
10	14,98	1,98	17,27	12,44	16,64	9,75	30,55	10,55	9,70	9,40	2,97	39,30	17,55	1,57	3,17	13,71	4,52	22,22	27,38	15,30	2,16	11/16-24	2,54	1,78	20,35

NOTE 1 Dimensions are in millimetres

NOTE 2 True position (TP) tolerances

NOTE 3 Typical material: shell - aluminium alloy
bayonet pins (ΦB) - stainless, passivated
nut - glass filled thermoplastic

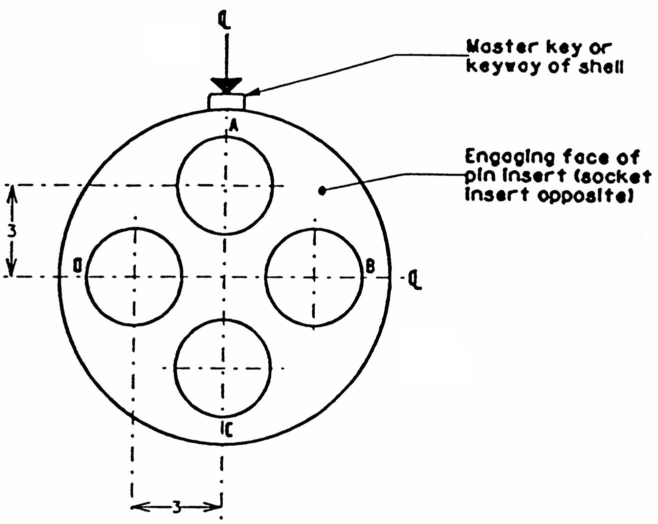
NOTE 4 Nut: thread size: 11/16 - 24 UNEF - 28
Slot dimension shall provide sufficient clearance for mounting on applicable receptacle
Slots shall be 120° apart



PANEL MTG DIMS REF
REFERENCE DIMENSIONS

SIZE	DD	ΦHH			ΦFF	GG
	±0,28 O-RING PROTEC-TION	MAX INT.DIA. GASKET			+0,25 -0,13 PANEL MTG HOLE	+0,25 -0,13 PANEL FLAT LOC
10	0,58	11,60			17,71	16,89

Figure A.4 — External fieldbus connector intermateability dimensions



Shell size	Number of contacts	Size contacts
10	4	16

NOTE 1 Dimensions are in millimetres.

NOTE 2 Insert arrangement is shown in the normal position in the shell with the A cavity in front of the master key or keyway of the shell. Only this "normal position" shall be used.

NOTE 3 Four keys or keyways (MMC) and insert shall be located within 0,09 either side of (TP) relative to master key or keyway (MMC) and shall DD or ID (MMC).

Figure A.5 — External fieldbus connector contact arrangement

A.2.2 External connector for typical industrial environments

A connector for typical industrial environments shall meet the following functional requirements:

a) polarized to avoid conductors being interchanged, both mated and unmated;
b) completely surrounded by a conductive shell;
c) provided with male contacts on the fixed (device) side, and with female threaded stand-offs for screw type locking (4-40NC-2B thread);
d) provided with female contacts on the free (cable) side, and with locking screws (4-40 NC-2A thread);
e) provided with nine pins (two signal pins, two power pins, and five reserved pins)
f) contacts shall be assigned to functions as shown in Figure A.6 and Table A.3;
g) connector dimensions (mating face) shall be as shown in Figure A.7 and Figure A.8, Table A.4 and Table A.5, and specified in IEC 60807-3.

Table A.3 — Contact assignments for the external connector for typical industrial environments

PIN number	Function
1	Reserved
2	Reserved
3	Reserved
4	Reserved
5	Reserved
6	DATA + with the option of power +
7	DATA – with the option of power –
8	Reserved for option of power +
9	Reserved for option of power –

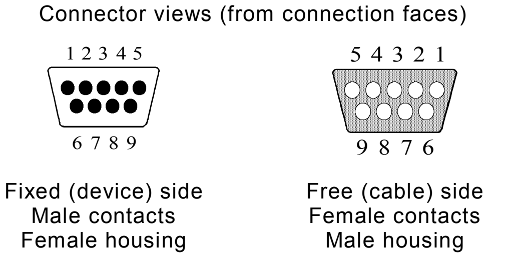


Figure A.6 — Contact designations for the external connector for typical industrial environments

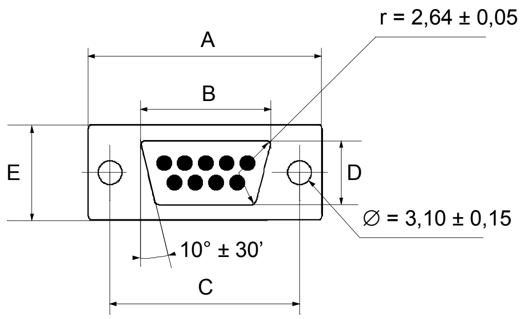


Figure A.7 — External fixed (device) side connector for typical industrial environments: dimensions

Table A.4 — Fixed (device) side connector dimensions

Fixed (device) side connector (male contacts, female housing)				
	Millimetres		Inches	
	max.	min.	max.	min.
A	31,19	30,43	1,23	1,20
B	17,04	16,79	0,67	0,66
C	25,12	24,87	0,99	0,98
D	8,48	8,23	0,33	0,32
E	12,93	12,17	0,51	0,48

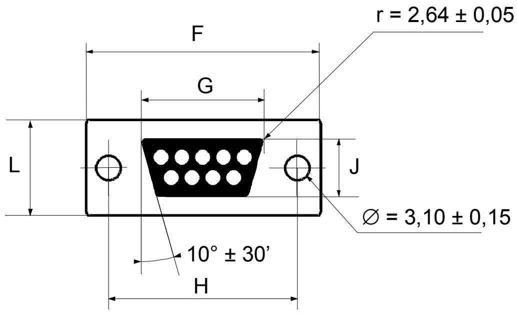


Figure A.8 — External free (cable) side connector for typical industrial environments: dimensions

Table A.5 — Free (cable) side connector dimensions

Free (cable) side connector (female contacts, male housing)				
	Millimetres		**Inches**	
	max.	min.	max.	min.
F	31,19	30,43	1,23	1,20
G	16,46	16,21	0,65	0,64
H	25,12	24,87	0,99	0,98
J	8,03	7,77	0,32	0,31
L	12,93	12,17	0,51	0,48

External connectors for optical medium

A fieldbus connector that is outside the enclosure of the fieldbus device and therefore requires protection against the electromagnetic and physical environment shall be specified as an external connector.

Two types of external connectors are specified in accordance with the environment of the installation.

A.2.3 External connector for typical industrial environments

A.2.3.1 External connector for typical industrial environments (1)

For the CPIC interface at the level of a fieldbus device, or an optical active star or an optical passive star, the connector used shall be compatible with the connector shown in Figure A.9 and Table A.6. (See IEC 61754-13.)

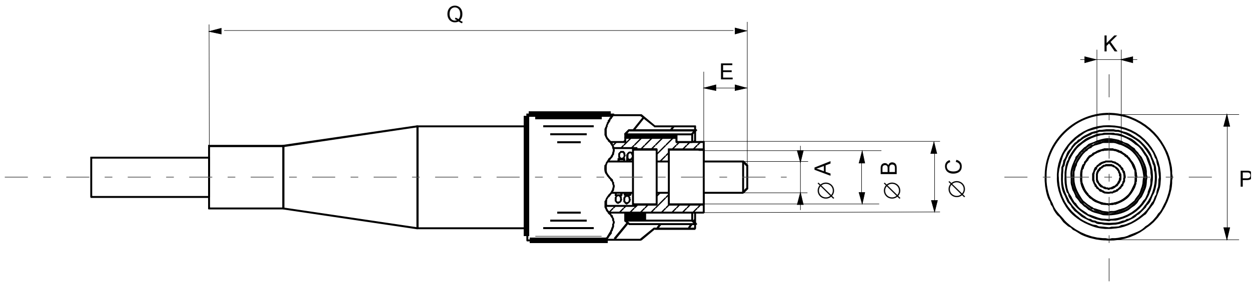


Figure A.9 — Optical connector for typical industrial environments (FC connector)

Table A.6 — Connector dimensions

Reference	Millimetres	
	min.	max.
∅ A	2,498	2,500
∅ B	4,40	4,42
∅ C	5,95	6,00
E	3,75	4,05
K	1,85	2,14
P	–	10,5
Q	–	45

A.2.3.2 External connector for typical industrial environments (2)

For the CPIC interface at the level of a fieldbus device, or an optical active star or an optical passive star, the connector used shall be compatible with the connector shown in Figure A.10.

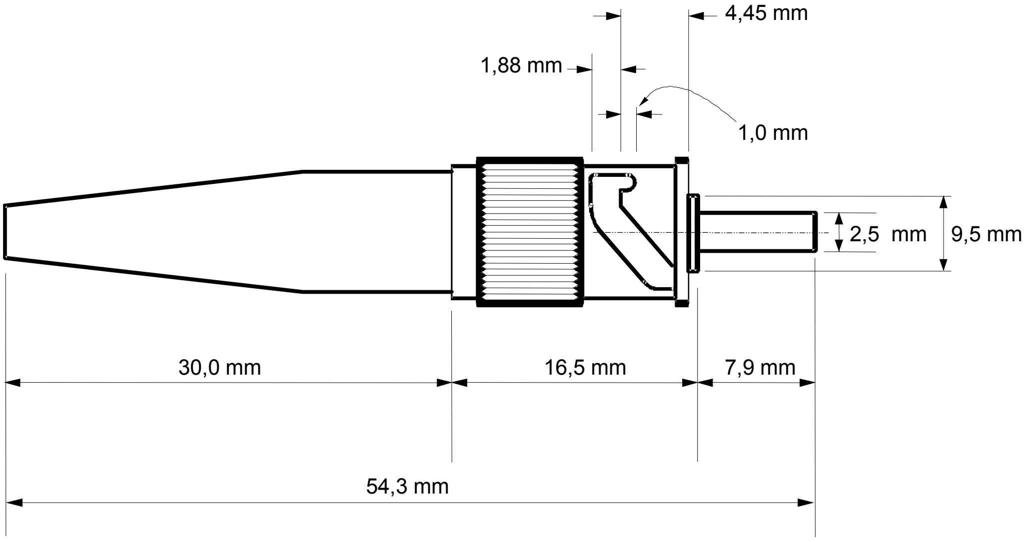


Figure A.10 — Optical connector for typical industrial environments (ST connector)

Annex B
(informative)

Types 1 and 3: Cable specifications and trunk and spur lengths for the 31,25 kbit/s voltage-mode MAU

B.1 Cable description and specifications

The preferred fieldbus cable is specified in 12.8.2 for conformance testing, and it is referred to as type "A" fieldbus cable.

NOTE 1 This cable will probably be used in new installations.

Other types of cables can be used for fieldbus wiring, other than for conformance testing. The alternate preferred fieldbus cable is a multiple, twisted pair cable with an overall shield, hereinafter referred to as type "B" fieldbus cable.

NOTE 2 This cable will probably be used in both new and retrofit installations where multiple fieldbuses are run in the same area of the user's plant.

A less preferred fieldbus cable is a single or multiple, twisted pair cable without any shield, hereinafter referred to as type "C" fieldbus cable. The least preferred fieldbus cable is a multiple conductor cable without twisted pairs but with an overall shield, hereinafter referred to as type "D" fieldbus cable.

NOTE 3 Type "C" and "D" cables will mainly be used in retrofit applications. They will have some limitations in fieldbus distance and S/N ratios that the type "A" and "B" cables do not have. This may preclude the use of type "C" and "D" cables in certain applications.

Typical cable specifications at 25 °C are listed in Table B.1.

Table B.1 — Typical cable specifications

Parameter	Conditions	Type "B"	Type "C"	Type "D"
Impedance, Ω	f_r (31,25 kHz)	100 ± 30	Not specified	Not specified
Max. d.c. resistance, Ω/km	Per conductor	56	132	20
Max. attenuation, dB/km	1,25 f_r (39 kHz)	5,0	8,0	8,0
Nominal conductor cross-sectional area, mm^2 (wire size)		0,32	0,13	1,25
Max. capacitive unbalance, nF/km	≥30 m length	6	Not specified	Not specified

B.2 Typical trunk and spur lengths

Using the network configuration rules specified in 12.3.3, the maximum lengths for type "B", "C" and "D" cables, including all spurs, typically will be:

– type "B" – 1 200 m;

– type "C" – 400 m;

– type "D" – 200 m.

NOTE These typical guidelines do not supersede the network configuration rules of 12.3.3.

Allowable spur lengths for either bus or tree topology are dependent on the number of communication elements on the fieldbus. Table B.2 relates the recommended number of communication elements to spur length. Maximum spur lengths are the same for type "A", "B", "C", and "D" cables. The table assumes one communication element per spur. When a spur with passive trunk coupler has more than one communication element, the length of that spur should be reduced by 30 m per communication element. As the recommended maximum total spur length is 120 m, the maximum number of communication elements per spur should be four.

Table B.2 — Recommended maximum spur lengths versus number of communication elements

Total number of communication elements	Recommended maximum spur length (m)
25 to 32	0
19 to 24	30
15 to 18	60
13 to 14	90
1 to 12	120

Spurs of length less than 1 m should be regarded as splices.

Annex C
(informative)

Types 1 and 7: Optical passive stars

C.1 Definition

A passive device in which the signal from input optical fibers is distributed among a larger number of output optical fibers (input and output optical fibers may be the same).

a) Optical reflective passive star

A device whose purpose is to reflect optical power input at any output port (see Figure C.1). This device can only be used with a single fiber mode MAU.

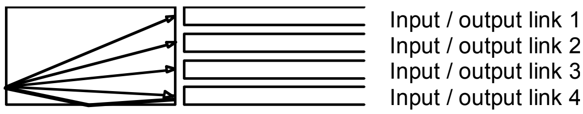


Figure C.1 — Example of an optical passive reflective star

b) Optical transmitive passive star

A device whose purpose is to divide optical power input at any output port (see Figure C.2). This device allows a broadcasting of information only over one direction. It can only be used with a dual fiber mode MAU.

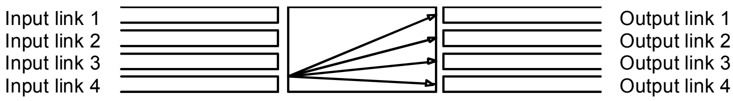


Figure C.2 — Example of an optical passive transmitive star

C.2 Example of attenuations

For a wavelength included between 700 nm and 900 nm, Table C.1 gives an example of minimal and maximal attenuations of optical passive star (these specifications are equally available for 62,5/125 fiber or 100/140 fiber).

Table C.1 — Optical passive star specification summary: example

700 nm ≤ λ_p ≤ 900 nm	Star 4/4	Star 8/8	Star 16/16	Star 32/32	Unit
Min. attenuation	–6,0	–9,0	–12,0	–16,0	dB
Max. attenuation	–9,0	–12,0	–16,0	–20,0	dB

Annex D
(informative)

Types 1 and 7: Star topology

D.1 Examples of topology

This subclause illustrates some of the network topologies that can be constructed in accordance with this standard. This subclause does not imply that these are the only possible topologies.

The physical size of a network, both in geographic length and the number of desired fieldbus devices, will have a significant impact on the choice of network topology. When a limited number of fieldbus devices are required, almost any topology can be used. Figure D.1 illustrates a possible topology.

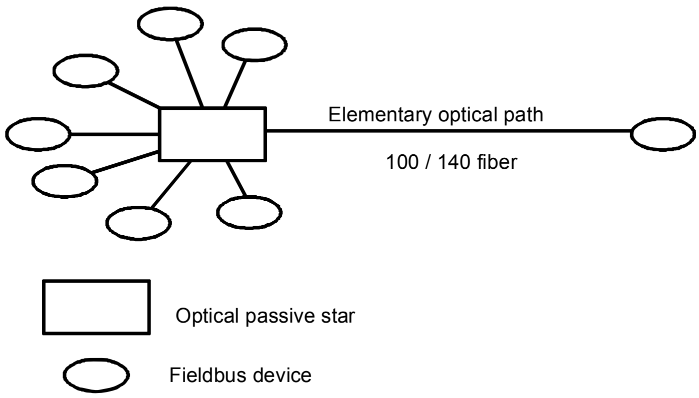


Figure D.1 — Example of star topology with 31,25 kbit/s, single fiber mode, optical MAU

For situations that require a large number of fieldbus devices located in widely separated geographic locations, a multi-star topology may be required. Topologies of this type may grow to very large numbers of communicating devices (see Figure D.2).

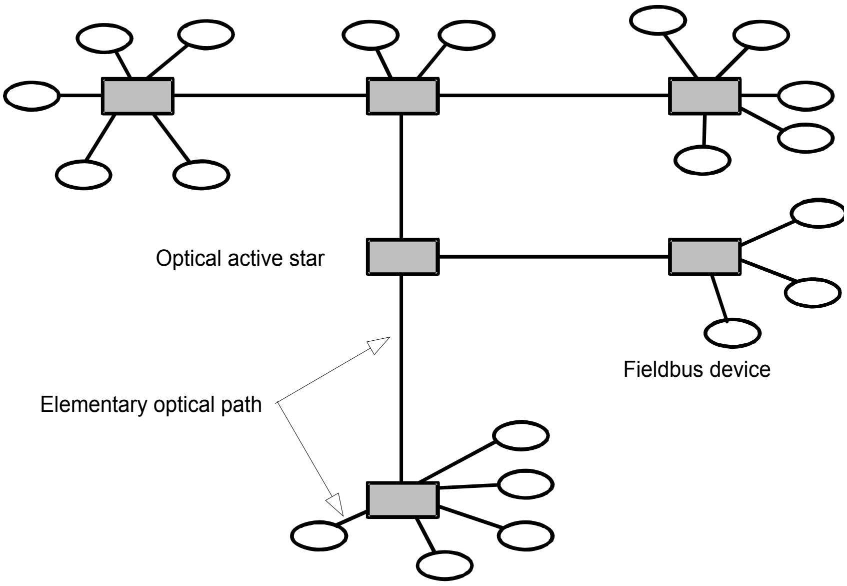


Figure D.2 — Multi-star topology with an optical MAU

D.2 Optical power budget

An optical power budget allows anticipation of the distribution of different losses and attenuations of the optical signal along an optical link.

From the transmitter effective launch power levels and the receiver operating range, it is possible to establish the minimum and maximum length of the link.

Two cases are considered.

– Minimum power case: corresponds to the minimum transmitter effective launch power, maximum losses, maximum penalties and maximum margin system, and the lower limit of the receiver operating range. This case gives the maximum guaranteed length.
– Maximum power case: corresponds to the maximum transmitter effective launch power, minimum losses, minimum penalties and minimum margin system, and the upper limit of the receiver operating range. This case gives the minimum guaranteed length.

Two examples are given. The first corresponds to the topology shown in Figure D.1 and the second, to the topology given in Figure D.2.

D.2.1 Passive star topology (31,25 kbit/s, single fiber mode, optical MAU)

For this example the transmission between high sensitivity modems is considered. Table D.1 summarizes the passive star topology specifications.

Parameters that will be considered are the following:

– typical fiber 100/140 attenuation: 4,0 dB/km
– optical passive star 8/8 attenuation: 9,0 dBm to 12,0 dB
– effective launch power (100/140 µm fiber): –14,5 dBm to –12,5 dBm
– high sensitivity receiver operating range: –40,0 dBm to –20,0 dBm

Table D.1 — Passive star topology

Parameters	max.	min.	Units
Receiver operating range (high sensitivity)	–40,0	–20,0	dBm
Effective launch power	–14,5	–12,5	dBm
Dynamics for all losses and attenuations	25,5	7,5	dB
Margin system	3,0	0,0	dB
Losses due to two connectors	2,0	0,0	dB
Reflective optical passive star (8/8)	12,0	9,0	dB
Max. and min. attenuations due to fiber	8,5	–	dB
Length of fiber between modems (fiber attenuation: 4,0 dB/km)	2 125	0	m

D.2.2 Active star topology (optical MAU)

For this example, the transmission between low sensitivity modems is considered. Table D.2 summarizes the passive star topology specifications.

Parameters that will be considered are the following:

– typical fiber 62,5/125 attenuation: 3,0 dB/km
– transmitter (effective launch power): (–11,5 ± 1,5) dBm
– low sensitivity receiver (receiver operating range): (–30,0 to –10,0) dBm.

Table D.2 — Active star topology

Parameters	max.	min.	Unit
Receiver operating range (high sensitivity) Transmitter effective launch power	–30,0 –13,0	–10,0 –10,0	dBm dBm
Dynamics for all losses and attenuations	17,0	0,0	dB
Margin system Losses due to two connectors Max. and min. attenuations due to fiber	3,0 2,0 12,0	0,0 0,0 0,0	dB dB dB
Length of fiber between modems (fiber attenuation 3,0 dB/km)	4 000	0	m

D.3 Mixed with wire media

The mixing of wire and optical media is achieved with an electro-optical converter. This element presents one or several wire medium accesses and one or several optical accesses. Each access, wire or optical, shall respect the transmit and receive circuit specifications.

This element regenerates the signal to their nominal optical power levels or electrical levels and to nominal timing characteristics (jitter, rise and fall times, slew rate, etc.).

Two examples are shown in Figure D.3 and Figure D.4.

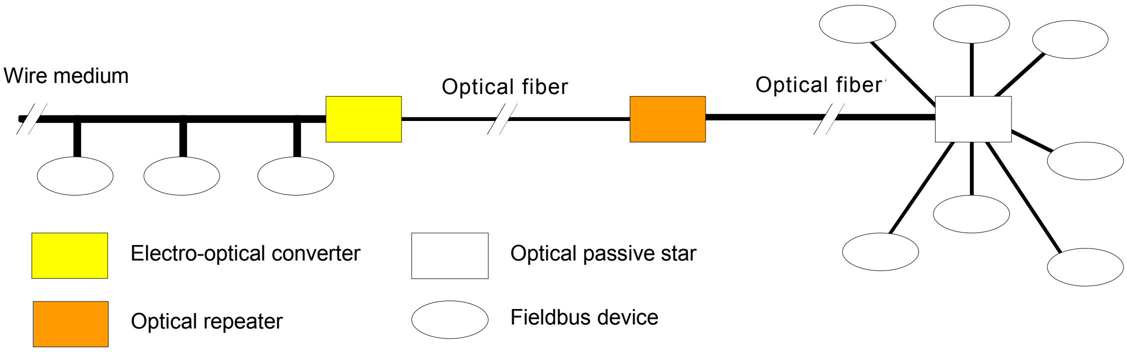


Figure D.3 — Example of mixture between wire and optical media for a 31,25 kbit/s bit rate

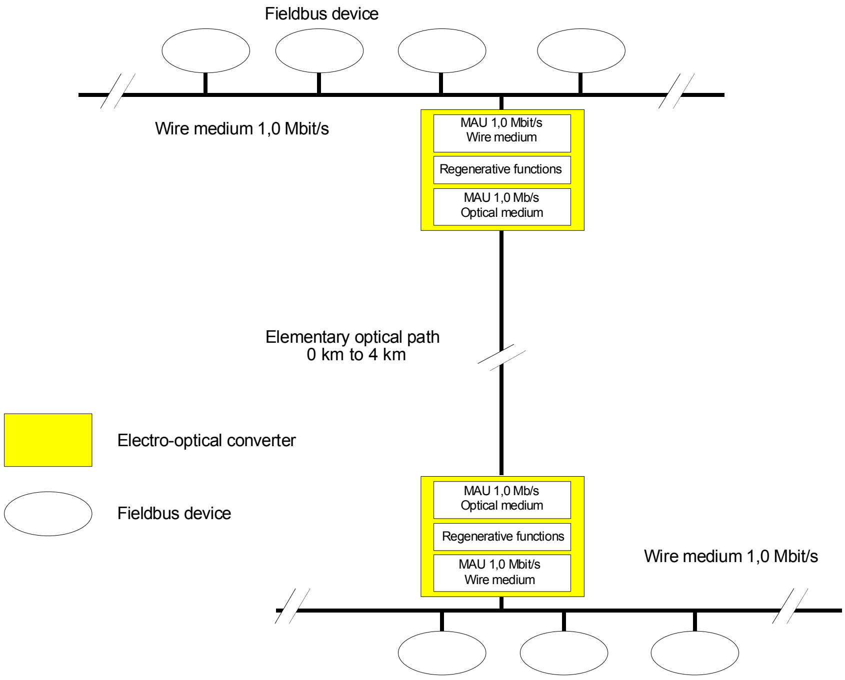


Figure D.4 — Example of mixture between wire and optical media

Annex E
(informative)

Type 1: Alternate fibers

E.1 Alternate fibers for dual-fiber mode

It is possible to use other fibers than the fiber A1d specified as standard test fiber. Depending on the characteristics of these fibers, effective launch power levels differ. On the other hand, receiver operating ranges for low and high sensitivities are identical.

Table E.1 allows a comparison between these different fibers.

Table E.1 — Alternate fibers for dual-fiber mode

Parameters	Subclause	Specified fiber test standard	Specified alternate fiber	Specified alternate fiber
Fiber	15.7.2	A1b (62,5/125)	A1a (50/125)	A1d (100/140)
Effective launch power	15.4.2	(–11,5 ± 1,5) dBm	(–14,5 ± 1,5) dBm	(–7,5 ± 1,0) dBm
Receiver operating range low sensitivity	15.5.2	–30,0 dBm to –10,0 dBm	–30,0 dBm to –10,0 dBm	–30,0 dBm to –10,0 dBm
Receiver operating range high sensitivity	15.5.2	–40,0 dBm to –20,0 dBm	–40,0 dBm to –20,0 dBm	–40,0 dBm to –20,0 dBm

E.2 Alternate fibers for single-fiber mode

It is possible to use other fibers than the fiber A1d specified as standard test fiber. Depending on the characteristics of these fibers, effective launch power levels differ. On the other hand, receiver operating ranges for low and high sensitivities are identical.

Table E.2 allows a comparison between these different fibers.

Table E.2 — Alternate fibers for single-fiber mode

Parameters	Subclause	Specified fiber test standard	Specified alternate fiber	Specified alternate fiber
Fiber	16.7.2	A1d (100/140)	A1a (50/125)	A1b (62,5/125)
Effective launch power	16.4.2	(–13,5 ± 1,0) dBm	(–21,0 ± 1,0) dBm	(–17,5 ± 1,0) dBm
Receiver operating range low sensitivity	16.5.2	–30,0 dBm to –12,5 dBm	–30,0 dBm to –12,5 dBm	–30,0 dBm to –12,5 dBm
Receiver operating range high sensitivity	16.5.2	–40,0 dBm to –20,0 dBm	–40,0 dBm to –20,0 dBm	–40,0 dBm to –20,0 dBm

Annex F
(normative)

Type 2: Connector specification

F.1 Connector for coaxial wire medium

Attachment to the coaxial medium shall be via BNC (see IEC 60169-8, Annex A) or TNC (see IEC 60169-17, 75 Ω variant) plug and jack connectors.

The TNC variant shall be sealed to IP67 minimum. Where sealing is required, the node shall also meet IP67 requirements.

NOTE It is possible to achieve sealing up to IP65 with the BNC.

The characteristic impedance shall be between 45 Ω and 80 Ω.

The center conductor contact shall be plated in conformance with one of the following specifications:

a) 0,75 µm gold minimum over 1,25 µm nickel minimum over base metal;
b) 0,05 µm to 0,2 µm gold flash over 1,25 µm palladium nickel minimum over 1,25 µm nickel minimum over base metal.

F.2 Connector for optical medium

F.2.1 General requirements

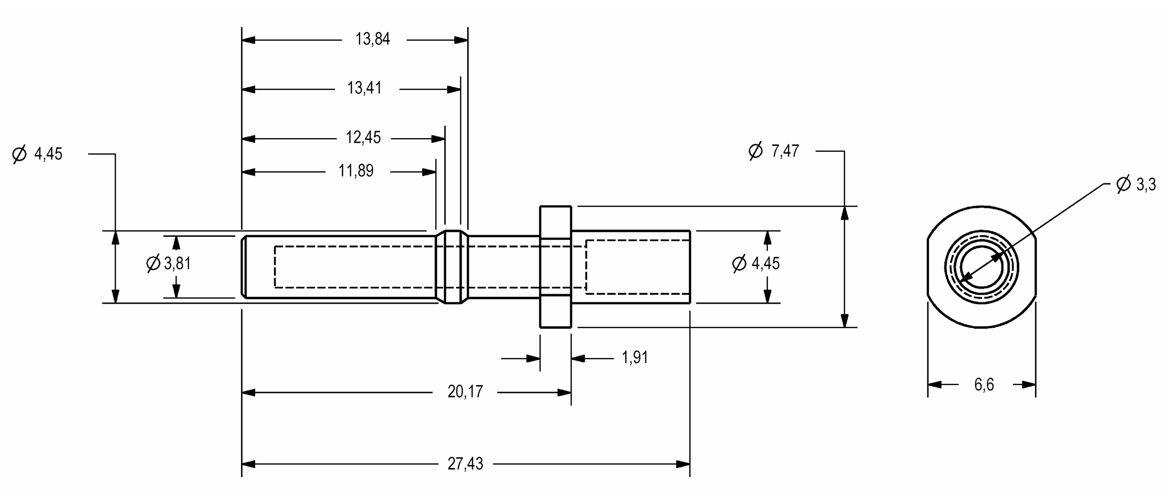
Connectors for optical medium shall meet the requirements specified in Table F.1.

Table F.1 — Connector requirements

Specification	Short range	Medium and long range
Connector Insertion Loss (nominal value)	1,5 dB	1,0 dB

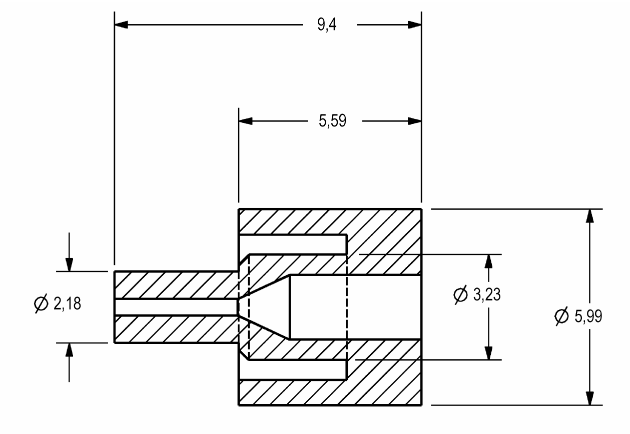
F.2.2 Connector for short range optical medium

This variant shall use a two-part connector, composed of a pin connector (as specified in Figure F.1, and a crimp ring that crimps the cable to the pin connector (as specified in Figure F.2).



NOTE Dimensions are in mm.

Figure F.1 — Pin connector for short range optical medium



NOTE Dimensions are in mm.

Figure F.2 — Crimp ring for short range optical medium

F.2.3 Connector for medium and long range optical medium

These variants shall use an ST type connector, as specified in IEC 61754-2.

F.3 Connector for NAP medium

The connector used at both ends of a NAP connection shall be a shielded 8-pin RJ-45 type connector (see IEC 60603-7).

The NAP connector pins shall be as shown in Table F.2. This pin definition shall apply to both ends of the cable. The connector shall be installed on the cable to meet the requirements shown in Figure 91.

Table F.2 — NAP connector pin definition

Pin number	Signal name
1	GND REF
2	N/C (no connection)
3	Tx_H
4	Tx_L
5	Rx_L
6	Rx_H
7	N/C (no connection)
8	GND REF

Annex G
(normative)

Type 2: Repeater machine sublayers (RM, RRM) and redundant PhLs

G.1 General

A PhL repeater device (bus or ring) shall be used to increase trunk lengths and number of nodes by connecting full length and/or fully loaded sections of medium. Repeaters may also be used to connect between different PhL variants, for example between fiber and coaxial wire. In addition, a ring repeater device shall support media redundancy through the use of a ring topology.

Repeater devices shall conform to all applicable clauses concerning the MAU sublayer and the MDS-MAU interface. A PhL bus repeater device shall consist of two (or more) complete PhL interfaces (MDS/MAU, from the same or different variants) connected together by a Repeater Machine (RM) sublayer. A PhL ring repeater device shall consist of two or more complete PhL interfaces connected together by a Ring Repeater Machine (RRM) sublayer.

A PhL repeater (bus or ring) need not have a MAC ID. A PhL repeater device is not the source of network traffic and shall not support layers above the RM or RRM sublayers. Rather, it shall only be responsible for retransmitting network traffic from one segment to one or more other segments, and for the correct implementation of the RM or RRM sublayer.

Optionally, a node may include the RM or RRM sublayer functionality as part of that node's MAC sublayer to allow a network node to function as both a network node and a repeater between PhL variants. This type of node shall be considered a network node and shall have a MAC ID.

A node that supports multiple PhL variants and an RM sublayer shall function as both a node (that is the source of network traffic) with redundant PhL entities (see G.3) and a PhL bus repeater device. A node that supports multiple PhL variants and a RRM sublayer shall function as both a node and a PhL ring repeater device.

G.2 Repeater machine (RM) sublayer

G.2.1 Requirements

Figure G.1 shows the reference model for a PhL bus repeater device.

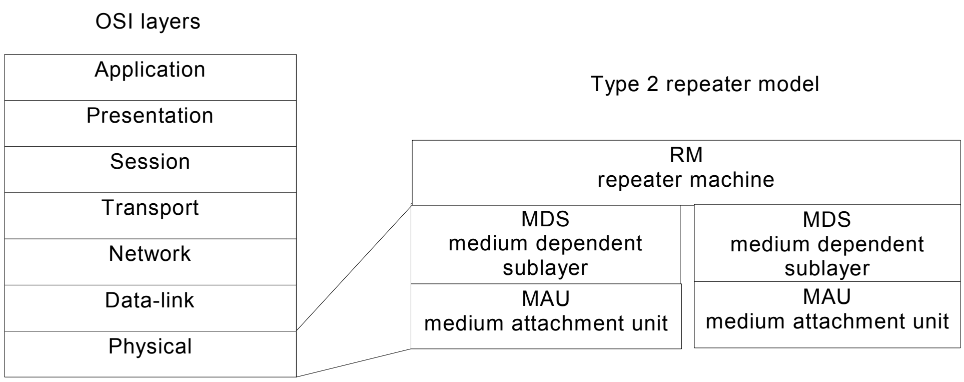


Figure G.1 — PhL repeater device reference model

Each of the two (or more) PhL entities connected by the RM sublayer shall follow the specifications shown for a given PhL variant.

A RM sublayer shall be used as a connection between segments to form a link as shown in Figure 84. Any MAC ID used on one PhL variant that is connected to another PhL variant using the RM sublayer shall be unique as the two sides share a common link.

The RM sublayer shall be completely transparent to network traffic. All valid MAC symbols between the start and end delimiters (inclusive) that are received by one PhL entity in the RM shall be passed unaltered to all of the others for transmission. The preamble shall be regenerated by the RM sublayer to correct any discrepancies introduced by the MDS or MAU. Preamble regeneration shall recreate the original preamble of 16 consecutive {1} M_symbols and may introduce up to an additional 4 consecutive {1} M_symbols. Following the retransmission of the end delimiter, the RM sublayer may introduce up to 4 additional consecutive M_symbols of any value.

The RM shall be a half-duplex sublayer. Only one PhL entity connected to the RM shall receive data at any one time while all the other PhL entities are retransmitting the received data.

The RM sublayer shall not be the cause of collisions on any medium. At any point in time, only one PhL entity shall be selected for reception while all others shall be selected for transmission. The PhL entity that is selected for reception shall be based on the state of the PLS_CARRIER_INDICATION from the PhL entity that indicates PLS_CARRIER_INDICATION (true) first. All other PhL entities connected to the RM sublayer shall be set for transmission while the PhL entity is receiving PLS_CARRIER_INDICATION (true) and PLS_FRAME_INDICATION (true). While that PhL entity is selected for reception, any PLS_CARRIER_INDICATION (true) from other PhL entities shall be ignored. A new PhL entity shall be selected for reception after the completion of the previous frame (PLS_FRAME_INDICATION = false).

The RM sublayer shall be designed to minimize the length of time delay that is added to the PLS_DATA_INDICATION retransmission. The RM sublayer time delay shall be defined as the time delay from the end of the received start delimiter to the end of the retransmitted start delimiter as measured at the MDS-MAU interface. Any delay added by the RM sublayer shall be included in the calculation of slot time used by the MAC sublayer. The total amount of delay that is added by the RM sublayer shall be made available for use by network configuration tools and users.

NOTE Any delay in the RM sublayer reduces the total amount of medium that can be supported and reduces the efficiency of the network by increasing the slot time required by the DLL protocol (see IEC 61158-4-2).

The RM sublayer shall be designed to reconstruct the data as transmitted from the originating node. This requirement shall allow an unlimited number of repeaters to be cascaded (in series) with no distortion being added to the original data by the repeaters. The only limit to the total number of RM sublayers that can be cascaded shall be the ability of the slot time to be adjusted to compensate for the total amount of delay on the medium. The maximum slot time is defined in the DLL protocol (see IEC 61158-4-2).

G.2.2 RM sublayer state machine (informative)

NOTE 1 This subclause describes an example implementation. There are no normative requirements.

The RM sublayer consists of two interconnected state machines. The first machine dictates which channel is receiving while all other channels are transmitting. The second state machine controls when the transmitting channel transmits data.

The first state machine consists of one state per channel to be arbitrated. When the second machine is in its idle state and a PLS_CARRIER_INDICATION arrives on any channel, this state machine moves to the state corresponding to the indication. If the second machine is in any state other than idle, this machine is locked and does not move, independent of PLS_CARRIER_INDICATION. The simultaneous first arrivals of two or more PLS_CARRIER_INDICATIONS is not a normal operating condition of the PhL and this machine's state transitions are unspecified.

The second state machine consists of 4 states: RM_IDLE, RM_CARRIER, RM_FRAME, RM_WAIT. If the node MAC sublayer is transmitting data, the RM should be forced to RM_WAIT:

– RM_Idle indicates that no activity is present on any channel. Other states move to RM_Idle when pls_carrier_indication is false for every channel. The presence of pls_carrier_indication on any channel causes the machine to move to the state RM_Carrier. While in RM_Idle, the pls_frame_request on all channels is false. The simultaneous first arrivals of two or more pls_carrier_indication is not a normal operating condition of the network and this machine should transition to RM_Wait;
– RM_Carrier indicates receive activity, but the MDS sublayer has not yet achieved lock (pls_lock_indication = false). This state should activate pls_frame_request on all channel's except the one indicated by the first machine as being the receive channel. The pls_data_request is preamble. If preamble regeneration is not used, this state serves as a placeholder to lock the first machine from transitioning. The presence of pls_lock_indication on the channel selected by the first machine causes the machine to move to the state RM_Frame;
– RM_Frame indicates the active repeating of data. This state activates pls_frame_request on all channels except the one indicated by the first machine as being the receive channel. It moves M_symbols from the receiving PhL entity to the transmitting channels, pls_data_indication => pls_data_request. At the point where the start delimiter of the repeated data is transmitted, it is required that at least 16 M_symbols of preamble have already been transmitted. The loss of pls_lock_indication on the channel selected by the first machine causes the machine to move to state RM_Wait;
– RM_Wait indicates the closing period of the repeated data. It holds off both state machines from moving to any other state to prevent repeating of echoes and end of packet noise. The machine remains in RM_Wait until pls_carrier_indication is false for all channels and the end of the blanking timer has occurred (see DLL protocol, IEC 61158-4-2). At that point, the machine moves to RM_Idle. While in RM_Wait, the pls_frame_request on all channels is false.

The PLS_FRAME_INDICATION of the receiving channel is not directly used by the repeater machines. Indirectly, the condition causing the end of frame should also force the receiver clock recovery to immediately unlock (PLS_LOCK_INDICATION = false) to eliminate repetition of noise after the end delimiter is repeated.

NOTE 2 Failure to maintain PLS_LOCK_INDICATION or failure to detect a valid start delimiter probably indicates a corrupted data frame or a burst of noise on the medium. The RM should be designed to minimize the possibility of repeating a corrupted frame or noise.

G.3 Redundant PhL

Figure G.2 shows a reference model for a node that contains multiple MDS and MAU entities to achieve PhL redundancy.

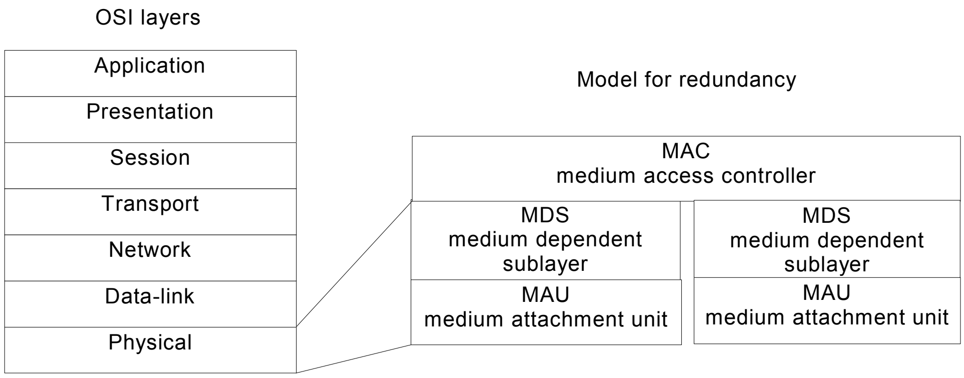


Figure G.2 — Reference model for redundancy

NOTE 1 The basic model is very similar to that used for the PhL Repeater devices specified in G.2.

The redundant PhL entities (‘channels’) in a single node shall transmit the same information on all channels at all times. The PLS_FRAME_REQUEST and PLS_DATA_REQUEST shall be common to all redundant channels.

PLS_DATA_INDICATION, PLS_CARRIER_INDICATION, PLS_FRAME_INDICATION, PLS_LOCK_INDICATION and PLS_STATUS_INDICATION shall be independent for each channel. At any point in time, some nodes may listen to one channel while other nodes listen to the other channel. Since both channels are considered independent and identical, neither channel shall be considered to be primary or preferred even though they are generally referred to as channel A and channel B.

NOTE 2 The MAC sublayer on each node determines which channel to select for use by the upper layers of its node. This determination is made independently on each node.

As the same data is transmitted on both channels, the same data shall be received on both channels. If PLS_FRAME_INDICATION of a channel has not yet been true for a MAC frame when PLS_STATUS_INDICATION of the other channel signals Normal, an error shall be declared on the channel that did not detect the MAC frame. Because the smallest MAC frame has 64 Ph-symbols from the end of the start delimiter to the end of the end delimiter, the two channels shall be designed and installed such that the difference in MAC frame arrival times at the DLL is ≤ 64 Ph-symbol times.

NOTE 3 If one channel detects a Normal frame and the other channel does not, the DLL raises either DLL_EV_ERRA or DLL_EV_ERRB (see IEC 61158-4-2).

In the example of a node with redundant PhL entities and a NAP shown in Figure G.3, the MAC sublayer shall support the RM sublayer functionality to allow the data on the selected channel to be retransmitted onto the NAP port. At the same time, the data received on the NAP shall be transmitted onto both of the redundant channels. Any data sourced from this node shall be transmitted on both channels and the NAP at the same time.

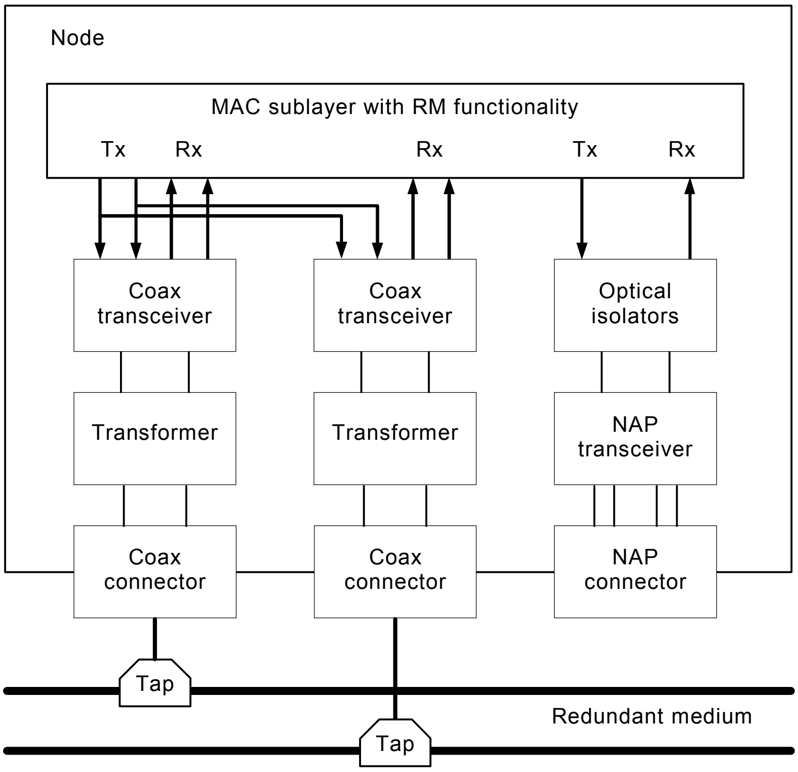
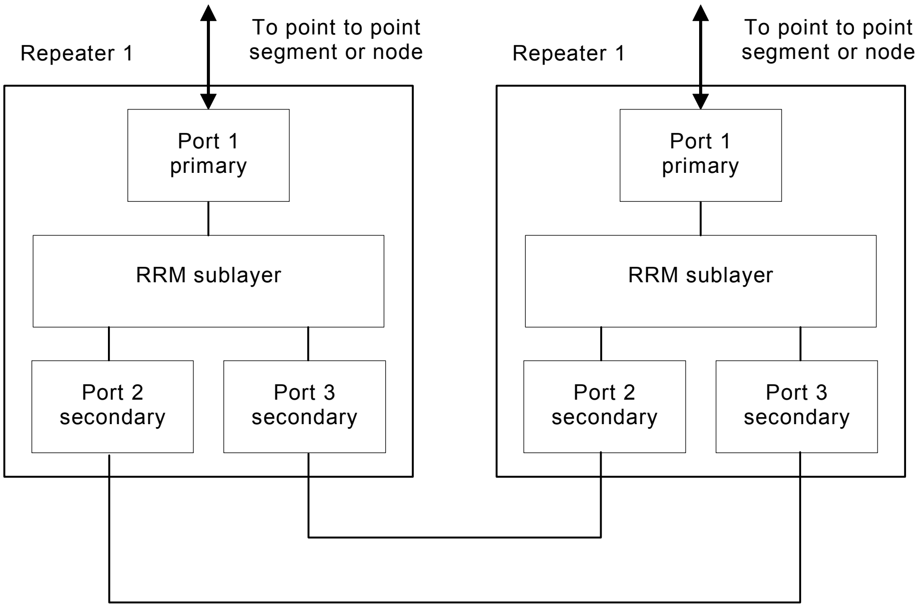


Figure G.3 — Block diagram showing redundant coaxial medium and NAP

G.4 Ring repeater machine (RRM) sublayer

G.4.1 Requirements

The minimum RRM shall be a three-port packet based switch (see Figure G.4). Port 1, the primary port, shall see a given data packet only once, and may be used as an interface to point to point network segments or to a node. The two secondary ports, port 2 and 3, shall be equal and shall participate in the ring. The RRM shall decide which port to repeat data packets from and shall prevent data packets from endlessly circling the ring.



NOTE If one connection fails, the other may still be active.

Figure G.4 — Block diagram showing ring repeaters

G.4.2 RRM sublayer operation

G.4.2.1 RRM requirements

To support RRM operation, the ports in each ring repeater shall meet the following requirements:

a) The secondary ports in each repeater shall have the ability to send and receive data at the same time. Each secondary port shall be independent of the other port, and each secondary port shall also have the ability to operate in a duplex fashion with a separate receiver and transmitter for each port.
b) The RRM shall have the ability to detect the network slot time, either by deciphering the moderator packet or by monitoring network activity, or by some other means.
c) Each secondary port shall have its own fiber port stack counter, called `fps_portx`, where x is the port number.

RRM operation shall start in an idle state when there is no network activity and `fps_port2` and `fps_port3` are both zero.

G.4.2.2 Port segmentation

The segmentation process shall be used by the RRM to reset counters for the synchronization purpose. At power up ports 2 and 3 shall begin in segmentation mode. The ports shall return to segmentation mode any time that communication is lost between adjacent fiber connected repeater ports. A port in segmentation mode shall block all messages from the other ports within the same module/node. Further a port in segmentation mode shall not rebroadcast segmentation frames from other ports within the same module.

NOTE For example, a node will enter segmentation mode during power up, when a fiber cable is disconnected from one of the fiber ports, or when traffic stops for one second or more.

In addition, the RRM shall force segmentation mode at any time the RRM detects that the counters are out of sync with traffic. Counter synchronization/resynchronization can be performed by determining the correct NUT boundaries.

A node shall enter segmentation mode based on the following conditions :

– upon power up,

– an echo of message is not received from an adjacent connected node,

– fiber link between two ports is quiet for more than one second, indicating no traffic (idle).

This method uses two special segmentation frames to acquire counter synchronization. The segmentations frames consist of M_symbols, as defined in 5.3.2. The segmentation frames are use for RRM handshaking during the segmentation process.

During segmentation, the affected port will broadcast as a query a preamble of 32 consecutive {1} M_symbols, as shown in Figure G.5. A port that is connected to a port broadcasting 32 consecutive {1} M_symbols that is in segmentation shall respond upon hearing this preamble with a (16 M_symbols preamble, start delimiter, 16 M_symbols preamble) sequence as shown in Figure G.6. A module transmitting preamble who is soliciting a response shall listen for a (preamble, start delimiter, preamble) sequence. Upon hearing a response it shall then reset the appropriate fps_portx counters, switch from port segmentation mode to port active mode. The port shall only be switched from segmentation mode to port active mode during a NUT boundary (quiet time). The segmentation process shall be used by the RRM to reset counters for the synchronization purpose. A port in segmentation mode and broadcasting queries shall continue until a response has been received back from a connected node. Upon receiving a response and during the NUT quiet time, the port may be put in service for transmission of data packets.

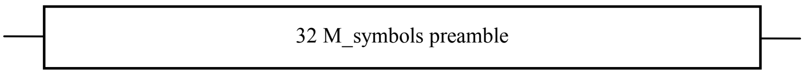


Figure G.5 — Segmentation query

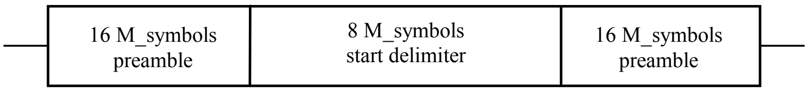


Figure G.6 — Segmentation response

G.4.2.3 Main operation

The port that sees network activity first shall define where the data shall be repeated to. If port 2 sees network activity first, data shall be repeated from port 2 to port 1 and port 3 (see details in G.4.2.4). Similarly, if port 1 sees network activity first, data shall be repeated from port 1 to port 2 and port 3 (see details in G.4.2.5). Port 2 and 3 are equal, so the behaviour of the RRM when port 2 sees activity first shall be identical to its behaviour when port 3 sees activity first.

For correct power up operation and to recover from a media failure, the RRM requires a timeout with no network activity equal to the slot time.

NOTE 1 It may be required that SMAX be set to one greater than the actual number of nodes on the network to get this timeout. This method will guarantee at least one quiet time per NUT. There is no problem with multiple quiet times per NUT.

NOTE 2 The RRM does not store parts of the frame to determine whether or not echoes are actually the same data packet that was sent transmitted. The order of data packets is guaranteed by the Type 2 DLL that specifies that nodes shall transmit sequentially. It is not possible for the order of the echoed frames to become garbled, unless a media or module malfunction occurs. At the instant of media malfunction a frame may be lost. However, the network will continue to function normally since the other message path still exists.

NOTE 3 The maximum value of `fps_portx` can be calculated as follows. The shortest possible data packet length is 56 bits, or 11,2 µs. The minimum time between frames is the node turn around time of 11,2 µs. At a maximum distance between the repeaters of 22,5 km, no more than 10 data packets can be travelling between neighbouring modules.

The corresponding main switch state machine for RRM operation is shown in G.4.2.6.

G.4.2.4 RRM operation when port 2 (or port 3) is active first

In the case where port 2 is active first, the RRM operation shall be as follows.

Port 2 receives the data packet. Since `fps_port2` is zero, the RRM shall repeat the data to port 1, port 2 and port 3 and shall increment `fps_port3`.

NOTE 1 The data is repeated out of the receive port, port 2, because the neighbouring RRM expects this to occur. This action generates an echo packet.

The RRM shall then wait for either:

1) Network activity on port 1.
   See G.4.2.5 for resulting behaviour.
2) New network activity on port 2.
   The RRM shall simply behave as it did previously.

NOTE 2 This requires that `fps_port3` be allowed to be greater than one and less than 11, since the worst-case timeout will have occurred by the time `fps_port3` reaches 11 (see case 4 below).

3) Reception of a data packet on port 3.
   This data packet should be the echo of the packet that was originally transmitted out of port 3 and is returned by the neighbouring module. Upon reception of this packet, `fps_port3` shall be decremented and the RRM shall return to the original idle state. Reception of this data packet shall not cause the RRM to repeat the packet to ports 1 and 2.

NOTE 3 This is because the `fps_port3` counter is non-zero, which indicates to the RRM that the received packet is an echo and is not a new data packet. Using this mechanism, the RRM prevents packets from endlessly circling the ring.

4) A timeout with no network activity equal to the slot time occurs.
   In this case, the neighbouring module has not returned the data packet transmitted out of port 3. This may have occurred due to a module malfunction or a media failure. If this occurs, `fps_port2` and `fps_port3` shall be reset to zero.

Port 2 and 3 are equal, so the behaviour of the RRM when port 3 sees activity first shall be identical to its behaviour when port 2 sees activity first (roles for port 2 and 3 shall be inverted in sequence above).

The corresponding state machine for port 2 (and 3) is shown in G.4.2.6.

G.4.2.5 RRM operation when port 1 is active first

In the case where port 1 is active first, the RRM operation shall be as follows.

Port 1 receives the data packet. The RMM shall repeat this packet by transmitting it out of port 2 and 3. When the port 2 and 3 transmit this data packet, they shall both increment their respective `fps_portx` counters.

The RRM shall then wait for either:

a) Network activity on port 1.
   The RRM shall simply behave as it did previously, namely transmitting the packet out of port 2 and port 3 and incrementing `fps_port2` and `fps_port3`.
b) Network activity on port 2 or port 3.
   Similar to case 3 in G.4.2.4: in this situation the next data packet that port 2 or port 3 receives should be an echo from a neighbouring module. Upon reception of this data packet, the port shall decrement its fps_portx counter. It shall not repeat this echoed packet.

c) A timeout with no network activity equal to the slot time occurs.
   Again, this means that echoes were not received (for whatever reason). In this case, `fps_port2` and `fps_port3` shall be reset to zero.

The corresponding state machine for port 1 is shown in G.4.2.6.

G.4.2.6 State machines

Figure G.7 shows the main switch state machine for RRM operation.

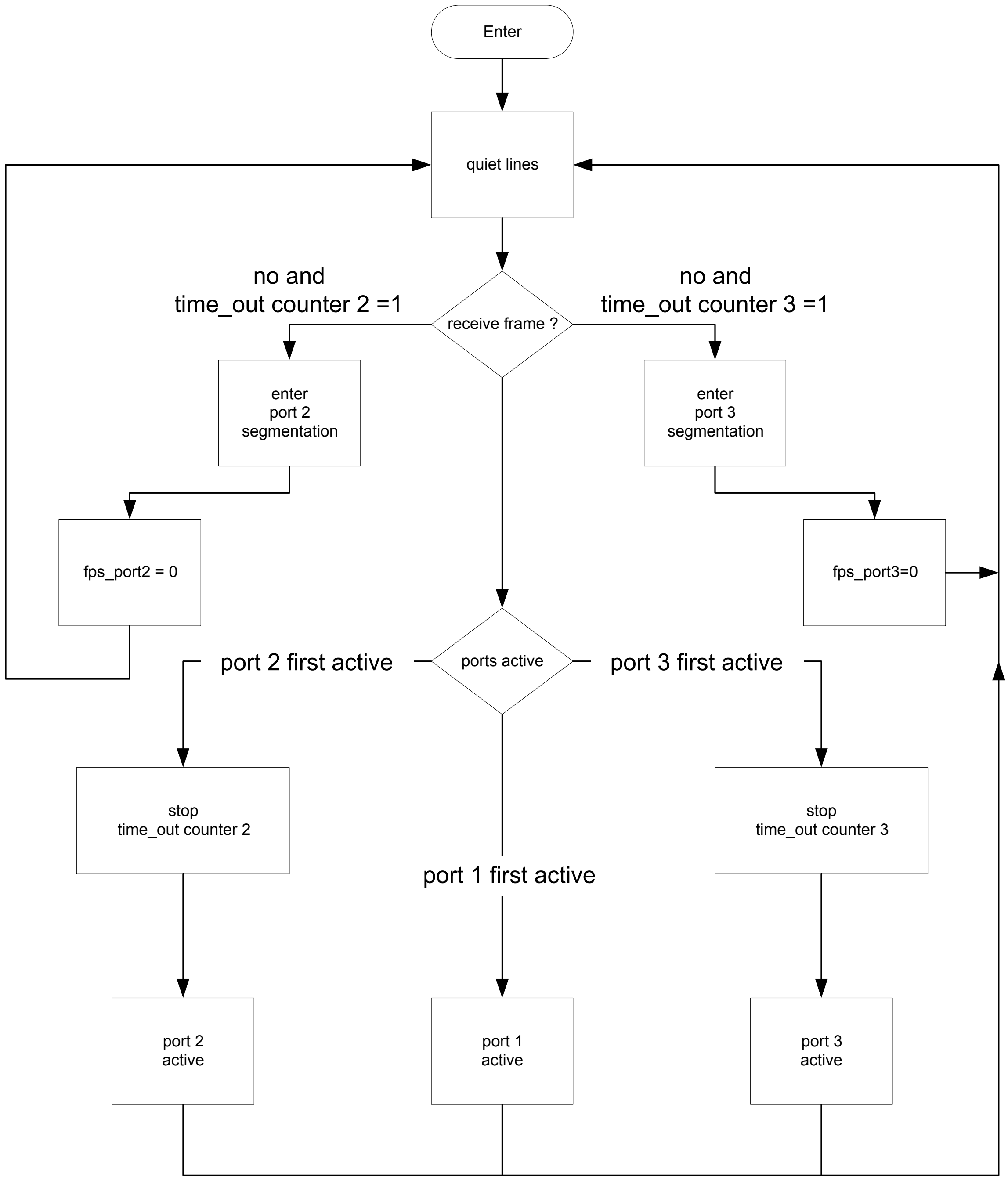


Figure G.7 — Main switch state machine

Figure G.8 shows the RRM behaviour when port 1 is active first.

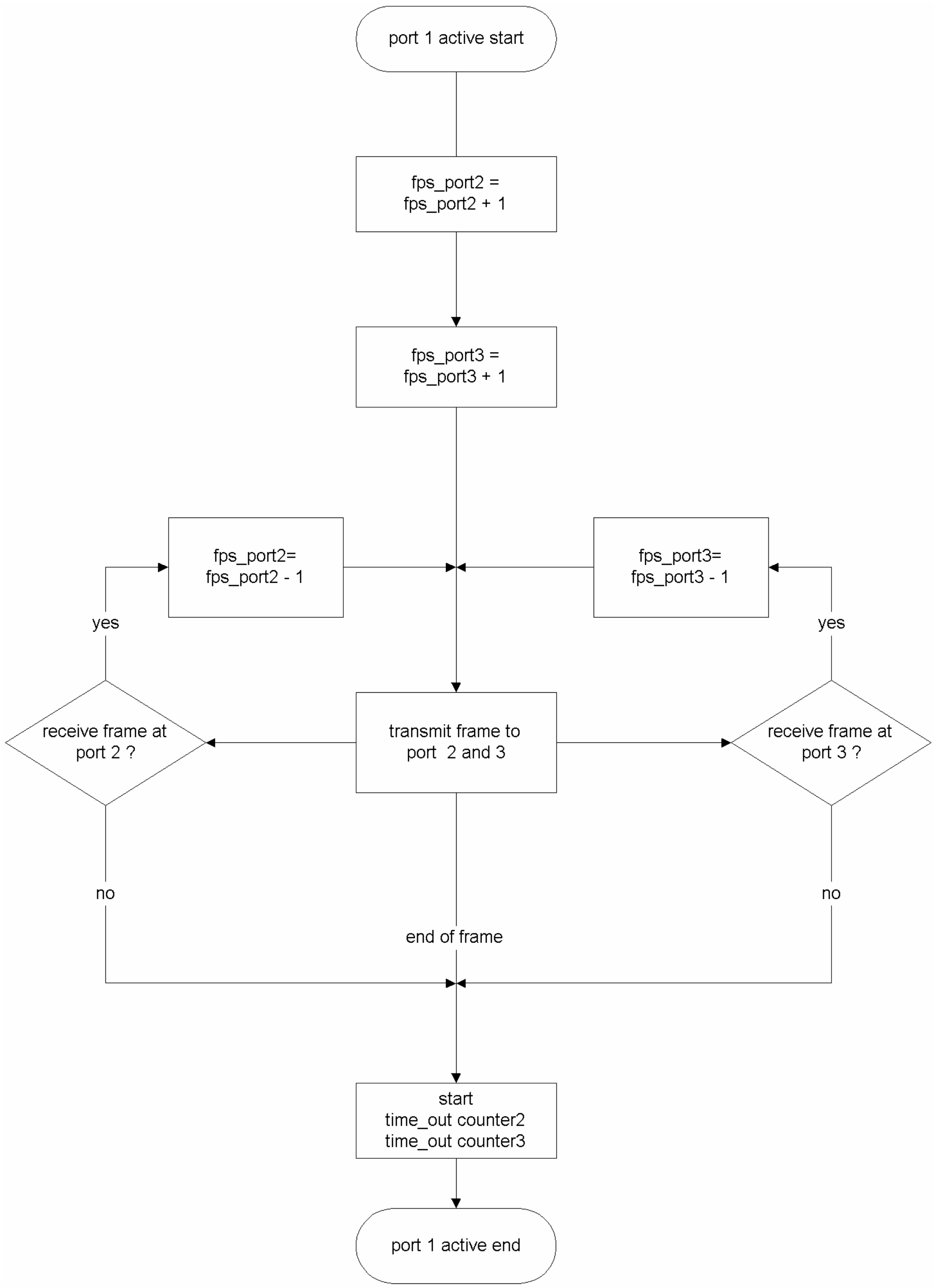


Figure G.8 — Port 1 sees network activity first

Figure G.5 shows the RRM behaviour when port 2 is active first. RRM behaviour when port 3 is active first shall be identical, with "2" and "3" being exchanged in Figure G.9.

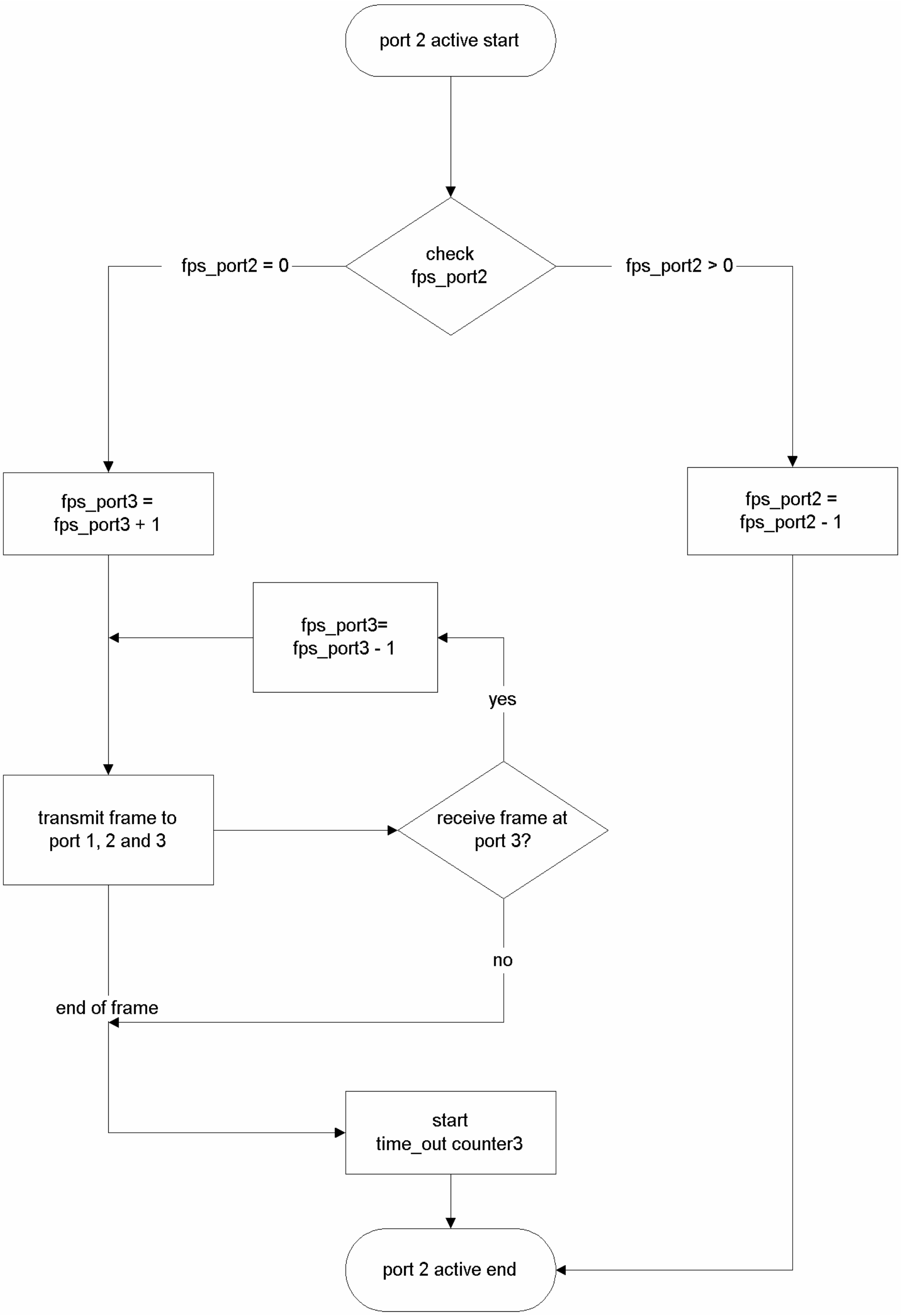


Figure G.9 — Port 2 sees network activity first

Annex H
(informative)

Type 2: Reference design examples

H.1 MAU: 5 Mbit/s, voltage mode, coaxial wire

H.1.1 Transceiver reference design example

The transmitter, shown in Figure H.3 and Figure H.4 is made up of a CMOS pre-transmitter pair, transistor transmitter pair, and the transformer. The series Schottky diodes and over voltage diodes are discussed later in this subclause.

The pre-transmitter is a 74AC08. This device allows the combination of the data and enables signals and provides the base drive for the drive transistors

The transistor driver uses a pair of MMBT2369 transistors. These are high-speed switches selected for important performance factors including the following

- collector current capability of at least 150 mA;
- fast switching characteristics typically better than 10 ns;
- small size SOT-23;
- low V_{ce} sat at I_c about 0,5 V;
- low output capacitance 4,0 pF nom.

The series base resistors define the required base drive and the shunt base resistors reduce turn off time. The base capacitors provide slew rate limiting that improves radiated emissions slightly.

The transformer (1:1:1) couples the transmit signal to the medium. Each side of the driver pair controls one side of the center tapped transformer, such that the driver operates in a push pull configuration. The voltage presented to each side of the driver is 4,2 V typical (at V_{cc} = 5 V) and 4,7 V maximum (at V_{cc} = 5,5 V). This corresponds to a peak driver output current (into 37,5 Ω) of about 110 mA typical and about 125 mA maximum. The total peak supply current including the base drive is about 140 mA.

The receiver circuitry is conceptually simple. The complexity arises in controlling the detection thresholds. Figure H.1 is a schematic reduced to include just the important components of the RXDATA detector.

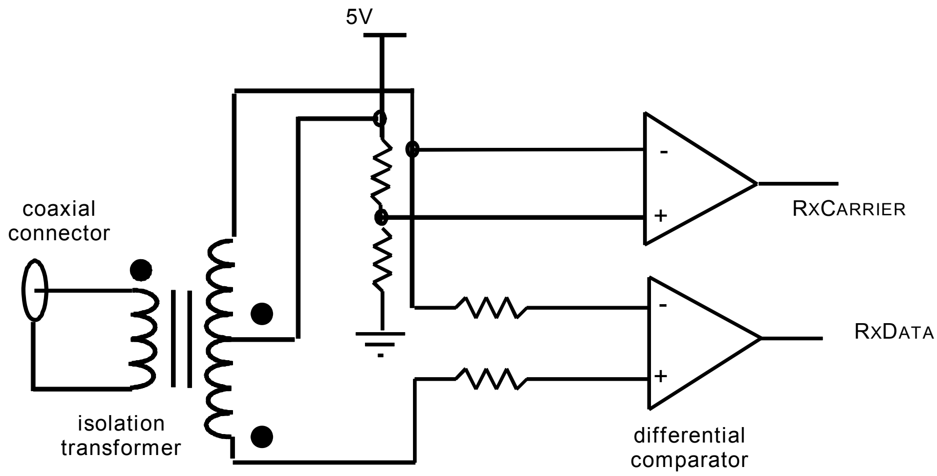


Figure H.1 — Coaxial wire MAU RxData detector

The detector example uses a 26LS32A (quad receiver) selected for high input impedance. Many devices of this class offer a minimum input impedance spec of 6 kΩ, whereas one supplier has a specification of 12 kΩ minimum. A special screening is required for this part, in the reference design, to allow an improved sensitivity over a smaller common-mode range. The important specifications for this device are the following:

a) high input impedance (this is required to meet the node input impedance requirements): 15 kΩ typical, 12 kΩ minimum;
b) low worst case threshold voltages: ± 100 mV over a common-mode range of 0 V to 5,5 V;
c) 0 °C to 85 °C temperature range;
d) single 5 V supply;
e) ±10 % supply tolerance;
f) fast enough to handle the Manchester encoded 5 Mbit/s bit rate.

For the Rx detector shown in Figure H.1 and in the schematic diagrams shown in Figure H.3 and Figure H.4, Table H.1 shows the input voltage levels for transition of RxData and RxCarrier.

Table H.1 — 5 Mbit/s, voltage-mode, coaxial wire receiver output definitions

Input voltage at medium	RxData	RxCarrier
V_{in} <–140 mV	false (0)	false(0)
-140 mV < V_{in} < 23 mV	undefined	false(0)
23 mV < V_{in} < 140 mV	undefined	undefined
140 mV < V_{in} < 255 mV	true(1)	undefined
255 mV < V_{in}	true(1)	true(1)

The series resistors on the input to the 26LS32A are different in value to counteract the threshold offset caused by the 26LS32A's fail-safe resistors.

Carrier detection uses another of the receivers in the 26LS32A. It performs a single ended comparison of the input signal to a DC threshold as shown in the simplified schematic of Figure H.2.

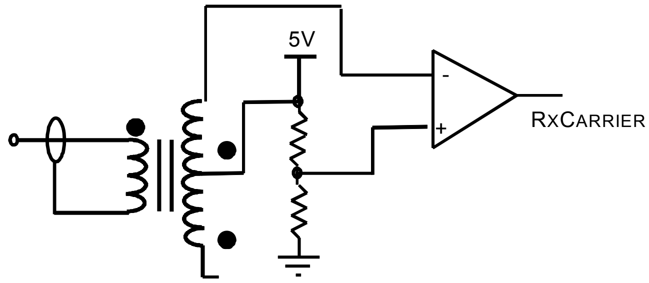


Figure H.2 — Coaxial wire MAU RXCARRIER detection

The RXCARRIER signal looks just like the RXDATA signal at high signals. At low signal levels it looks similar, except that the RXCARRIER 'one' pulse widths are narrower than those of the data are. When no signal is present the RXCARRIER output is always low, unlike the data, which is **undefined** and could be changing state with noise.

Figure H.3 shows an example of a redundant transceiver and Figure H.4 shows an example of a single channel transceiver.

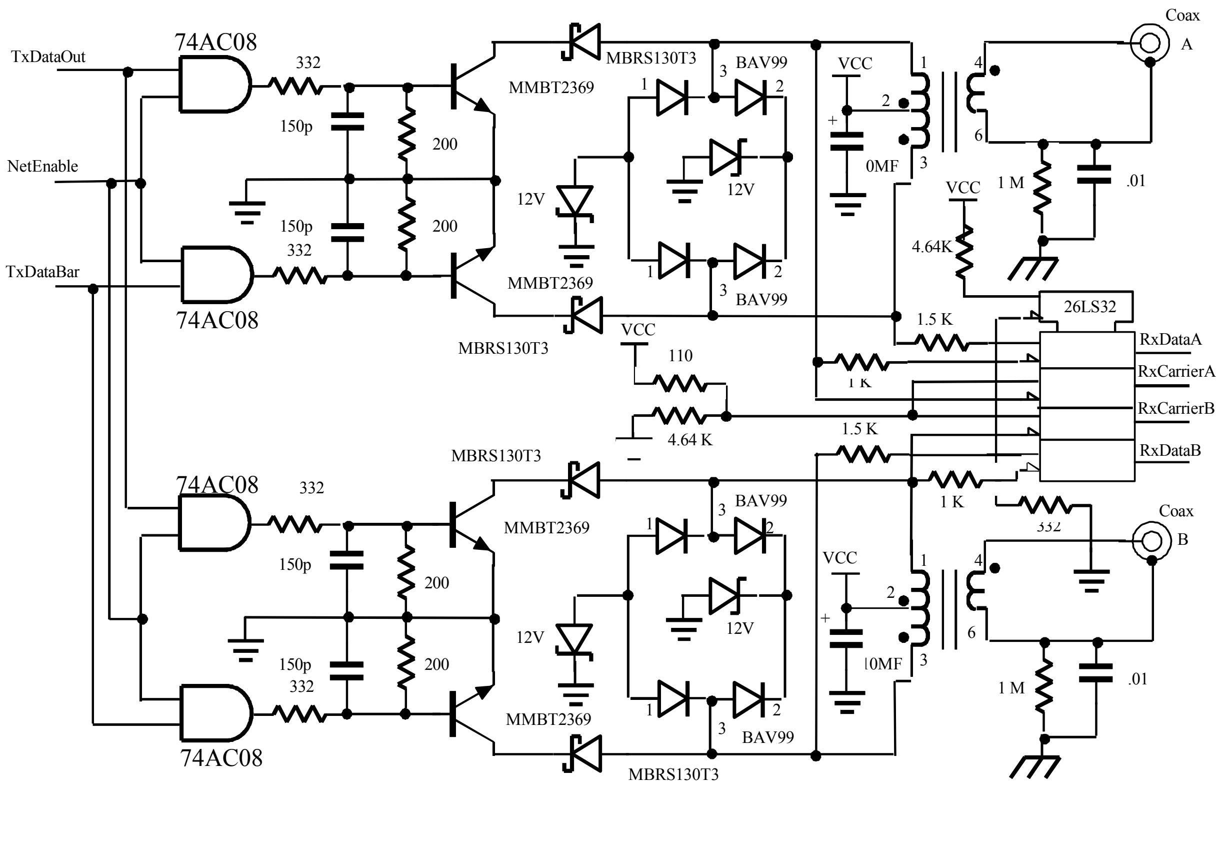


Figure H.3 — Redundant coaxial wire MAU transceiver

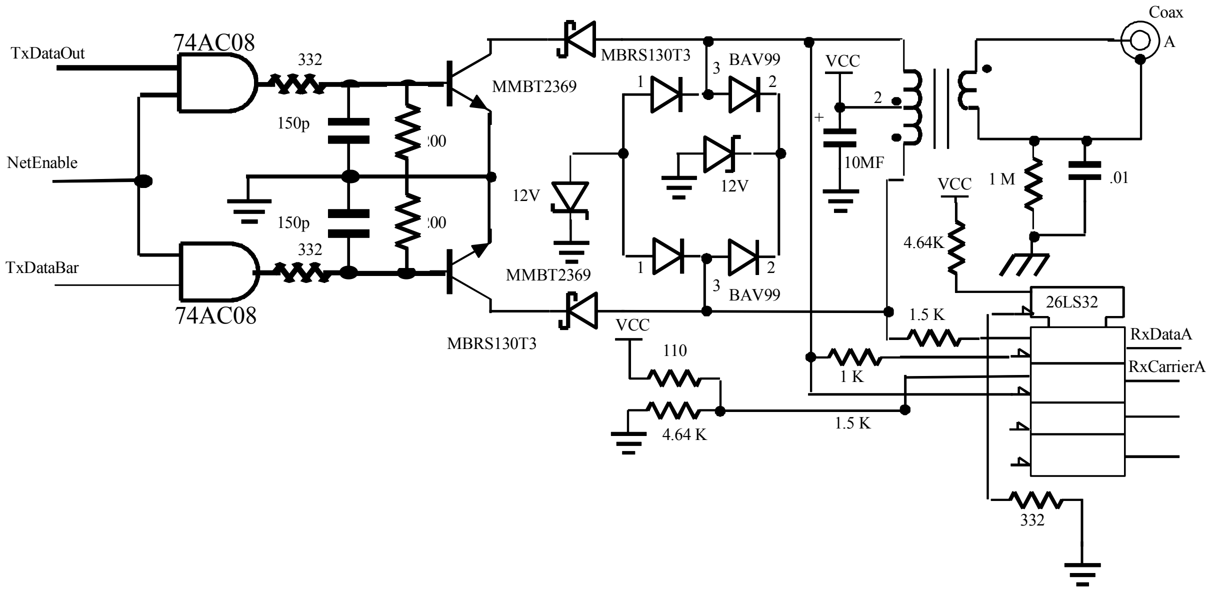


Figure H.4 — Single channel coaxial wire MAU transceiver

H.1.2 Transformer reference design example

Core is IEC 61596 type EP-7, ungapped, with minimum Al = 1 100 nH per turn^2. Construction sequence for the windings is as follows:

a) winding 1 between pins 3 and 2: diameter 0,127 mm, 18 turns;

b) 1 mil. tape;

c) winding 2 between pins 2 and 1: diameter 0,127 mm, 18 turns;

d) 1 mil. tape;

e) winding 3 between pins 4 and 6: diameter 0,127 mm, 18 turns;

f) outer wrap.

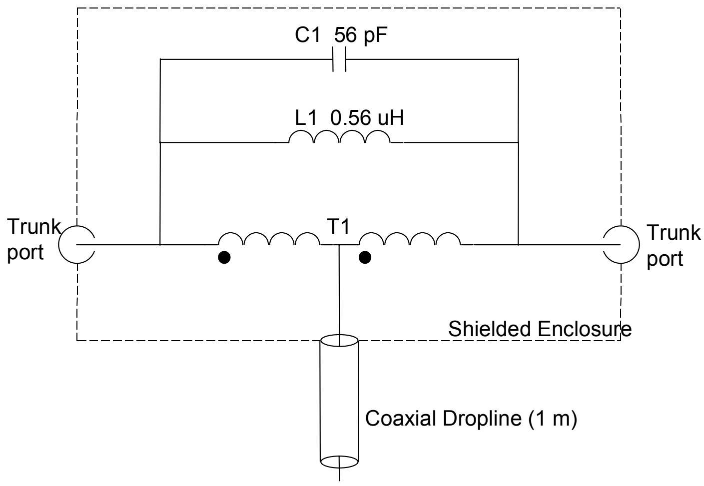
H.1.3 Tap reference design example

An example design of the Tap is shown in Figure H.5. The autotransformer (T1) is wound on a Ferronics 11-720B toroidal core. Winding is 18 turns bifilar, single strand, with minimum overlap of 0,254 mm diameter heavy poly-nylon magnet wire.

Measured electrical characteristics are as shown in Table H.2.

Table H.2 — Coaxial wire medium toroid specification

Parameter	Value
Leakage inductance	75 μH at 300 kHz
Magnetising inductance	890 μH at 300 kHz
Winding capacitance	20 pF at 25 MHz
Winding loss resistance	0,1 Ω at 300 kHz
Core loss resistance	16 kΩ at 1,3 MHz



NOTE Values shown are nominal. The actual values should be adjusted to meet the scattering parameter requirements detailed in Figure 86.

Figure H.5 — Coaxial wire medium tap

H.2 Network access port (NAP)

The design of the node NAP circuitry shown in the schematic in Figure H.6 is relatively simple. A single transmitter and receiver are used. The receiver has an internal offset voltage added to produce a zero data state for the fault conditions (medium removed, short circuited, etc.) listed in the requirements shown in Table 97. The polarity of the receive signal is high for data zero. Differential RS-422 transmitters and receivers are used to improve noise rejection.

Back biased diodes are provided on the NAP transmitter lines to prevent damage due to electrostatic discharge.

For the fiber medium option, the NAP circuitry is the same. The coaxial wire medium transceivers are simply replaced by optical fiber transceivers.

The schematic for a non-isolated permanent node uses a transceiver similar to the one shown in Figure H.6.

As in the node, a single transmitter / receiver is used for data. The same offset circuit is used to guarantee the correct disconnect and power off levels. In addition, the same transmitter protection diodes are used.

For a transient node that derives its power from a grounded source, opto-isolators are used. The design shown in Figure H.7 shows how opto-isolators and a DC-DC converter can be used to supply the required ground isolation.

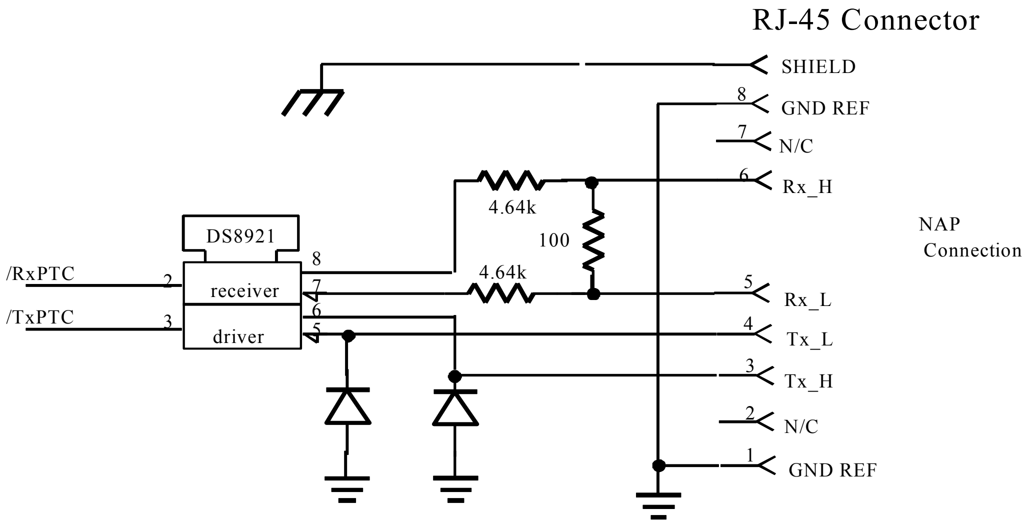


Figure H.6 — Non-isolated NAP transceiver

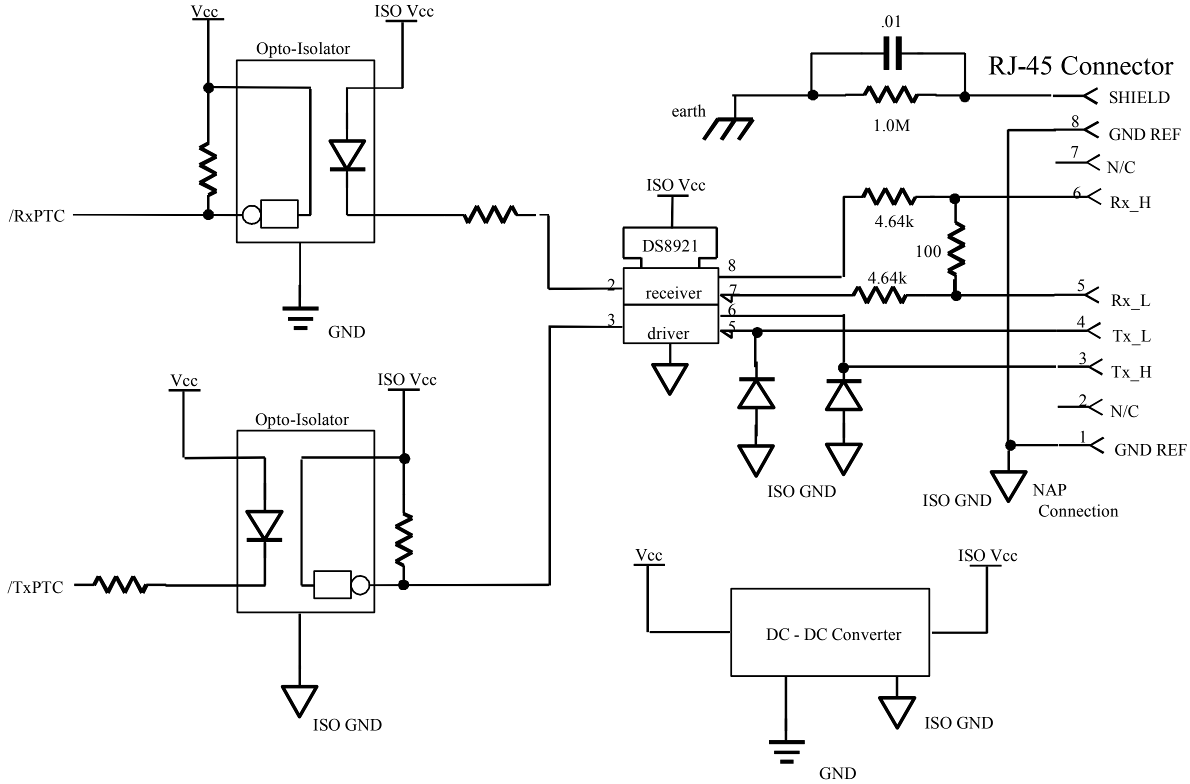


Figure H.7 — Isolated NAP transceiver

Annex I
(normative)

Type 3: Connector specification

I.1 Connector for synchronous transmission

I.1.1 General

The topology can be in the form of a tree, line or a combination of the two. The tees connect the stations (e.g. field devices) to the bus cable; they shall be have an IP 65 rating. The tee connect can be constructed in single T or multiple T, see Figure I.1. The tee function can also be integrated into the station.

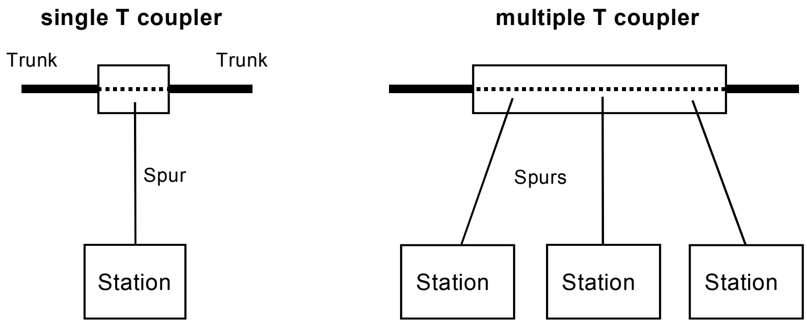


Figure I.1 — Schematic of the station coupler

I.1.2 Pin assignment of M12 circular connector

The contacts of the M12 circular connector shall be assigned to functions as shown in Table I.1 and Figure I.2.

Table I.1 — Contact assignments for the external connector for harsh industrial environments

Contact No.	Function
1	Data + with the option of power +
2	not connected
3	Data – with the option of power –
4	not connected
Thread	Shield

The shield shall be concentric around the thread. The shield potential shall be transmitted via the thread. Existing Type 3 devices with connected pin 4 are still conform to this International Standard. For new devices the pin 4 shall not be used. Existing pre-harnessed Type 3 cables with connected pin 4 are still conform to this International Standard. For new cables the pin 4 shall not be connected.

The M12 circular connector and the female connector shall be IP 65 or higher.

The male and female contacts shall be designed such that they maintain their transmission properties even in a corrosive atmosphere, e.g. chemical environment.

The centered hole of the female plug shall not be fitted because of the increased air and creepage distances in potentially explosive atmospheres, see Figure I.2.

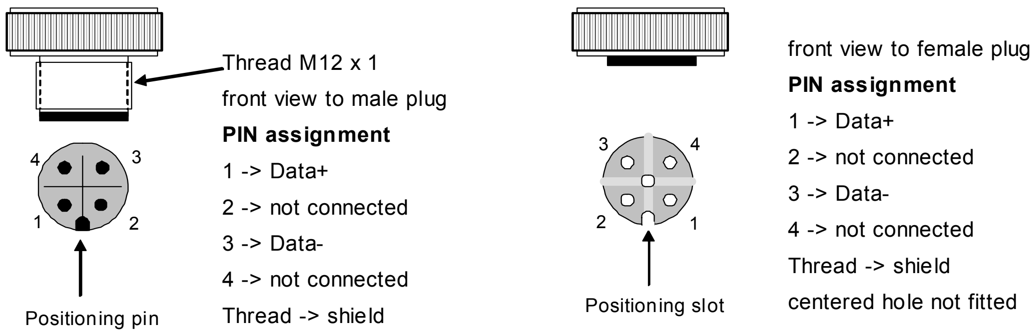


Figure I.2 — Pin assignment of the male and female connectors IEC 947-5-2 (A coding)

I.1.3 Connection between a tee and a station

The tees and the stations are connected using a shielded circular connector M12. The tee can be connected directly to the station or a branch using a shielded M12 connector.

Always make sure that the bus cable shield is applied over a large surface according to the grounding guidelines (for grounding and shielding, see 21.8.6 and 21.8.7).

Field termination techniques such as screw or blade terminals and permanent termination may also be used.

I.2 Connector for asynchronous transmission

I.2.1 Connector for non-intrinsic safe asynchronous transmission

Each station is connected to the medium via a 9-pin sub-D connector. The female side of the connector is located in the station, while the male side is mounted to the bus cable.

The mechanical and electrical characteristics are specified in IEC 60807-3.

Preferably a metal connector housing should be used. When put together both parts of the connector should be fixed by conducting screws. The connection between the cable sections and the stations should be realized as T-connectors, containing three 9-pin sub-D connectors (two male connectors and one female connector). Such T-connectors allow disconnection or replacement of stations without cutting the cable and without interrupting operation (on line disconnection).

The pin assignments for the connectors are shown in Table I.2 and Figure I.3.

Table I.2 — Contact designations

Pin number	RS-485 ref.	Signal name	Meaning
1		SHIELD (see notes 1, 2)	Shield, protective ground
2		M24V (see note 1)	Minus 24 V output voltage
3	**B/B'**	RxD/TxD-P	Receive/transmit-data-P
4		CNTR-P (see note 1)	Control-P
5	**C/C'**	DGND	Data ground
6		VP	Voltage-plus
7		P24V (see note 1)	Plus 24 V output voltage
8	**A/A'**	RxD/TxD-N	Receive/transmit-data-N
9		CNTR-N (see note 1)	Control-N
NOTE 1 Signals are optional. NOTE 2 Recommended to be not connected.			

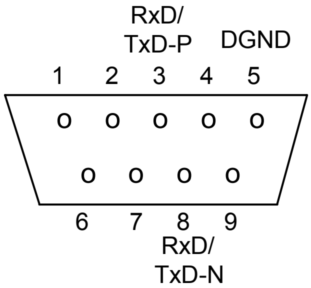


Figure I.3 — Connector pinout, front view of male and back view of female respectively

The Data Ground, connected to pin 5, and the Voltage-Plus, connected to pin 6, supply the Bus Terminator.

The control signals CNTR-P and CNTR-N, connected to pin 4 and pin 9, support direction control when repeaters without self control capability are used. ANSI TIA/EIA-485-A signaling is recommended. For simple devices the signal CNTR-P may be a TTL signal (1 TTL load) and the signal CNTR-N may be grounded (DGND). The definition of signaling is not a subject of this standard.

The 24 V output voltage, according to IEC 61131-2, Table 6, allows the connection of operator panels or service devices without integrated power supply. If a device offers 24 V output voltage it shall allow for a current load up to 100 mA.

I.2.2 Connector for intrinsic safe asynchronous transmission

I.2.2.1 IP20 connecting technique

For mechanical and electrical characteristics, see I.2.1.

The pin assignments for the connectors are shown in Table I.3.

Table I.3 — Contact designations

Pin number	RS-485 ref.	Signal name	Meaning
1		SHIELD (see note 1)	Shield
2		NC	(Not connected)
3	**B**	RxD/TxD-P	Receive/transmit-data-P
4		NC	(Not connected)
5		ISM (see note 2)	Bus termination minus
6		ISP (see note 2)	Bus termination plus
7		NC	(Not connected)
8	**A**	RxD/TxD-N	Receive/transmit-data-N
9		NC	(Not connected)
NOTE 1 Signal is optional and recommended to be not connected.			
NOTE 2 Signal is current-limited by resistors.			

The ISM, connected to pin 5, and the ISP, connected to pin 6, supply the Bus Terminator.

Series inductances in the data lines, as used in non-intrinsic safe connectors, shall not be used. The wiring from bus input to bus output in the connector shall be designed for a maximum current of 4,8 A. The trap to the communication device (A, B, ISM and ISP wire) must be designed for the maximum input current of 2 x Io (~300 mA). The appropriate values for the design of the connector (track widths, separation distances etc.) shall be according to IEC 60079-11.

The separation distances between A, B, ISM and ISP wire from the connector's trap to the current limiting resistors in the communication device shall be infallible in accordance IEC 60079-11.

I.2.2.2 IP65 connecting technique

The 4-pin M-12 connector according to IEC 947-5-2 is used for fieldbus systems where extreme industrial environments exist. Only shielded connectors are permitted. The connectors feature a mechanical key (B-coding).The pin assignments for the connectors are shown in Table I.4.

Table I.4 — Contact designations

Pin number	RS-485 ref.	Signal name	Meaning
1		ISP (see note)	Bus termination plus
2	**A**	RxD/TxD-N	Receive/Transmit-Data-N
3		ISM (see note)	Bus termination minus
4	**B**	RxD/TxD-P	Receive/Transmit-Data-P
Threaded joint		SHIELD	Shield
NOTE Signal is current-limited by resistors.			

The ISM, connected to pin 3, and the ISP, connected to pin 1, supply the Bus Terminator.

Series inductances in the data lines, as used in non-intrinsic safe connectors, shall not be used. The connector contacts shall be designed for the maximum current of 4,8 A.

The connector at the field device must be a female type M12 connector, as shown in Figure I.4.

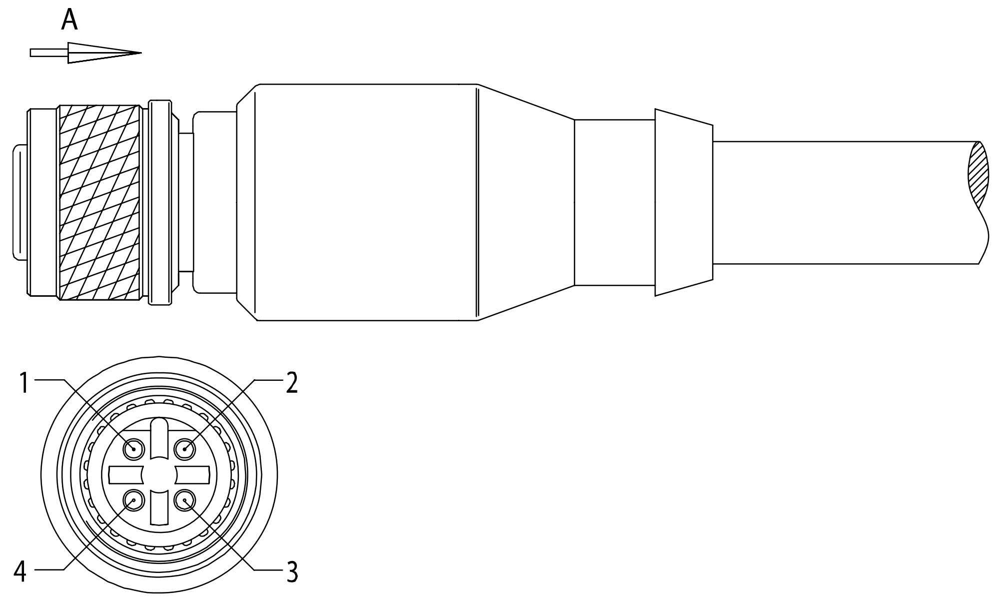


Figure I.4 — Connector pinout, front view of female M12 connector

The connector at the cable side must be a male type M12 connector, as shown in Figure I.5.

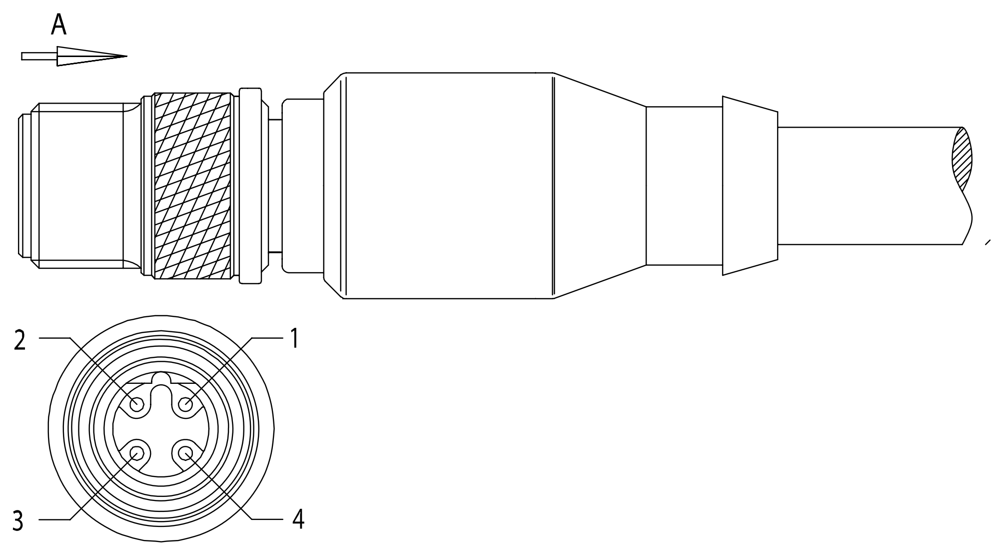


Figure I.5 — Connector pinout, front view of male M12 connector

The fieldbus topology has a linear structure. The junctions (tees), as shown in Figure I.6, connect the individual devices to the trunk cable. The stub length should be as short as possible. Series inductances in the data lines shall not be used.

The Tee shall be uniform and concentric all the way to the cap nut (Threaded joint), (metal connectors and similar).

The supply voltage provided by the devices for driving the termination resistance shall be passed on via the Tee.

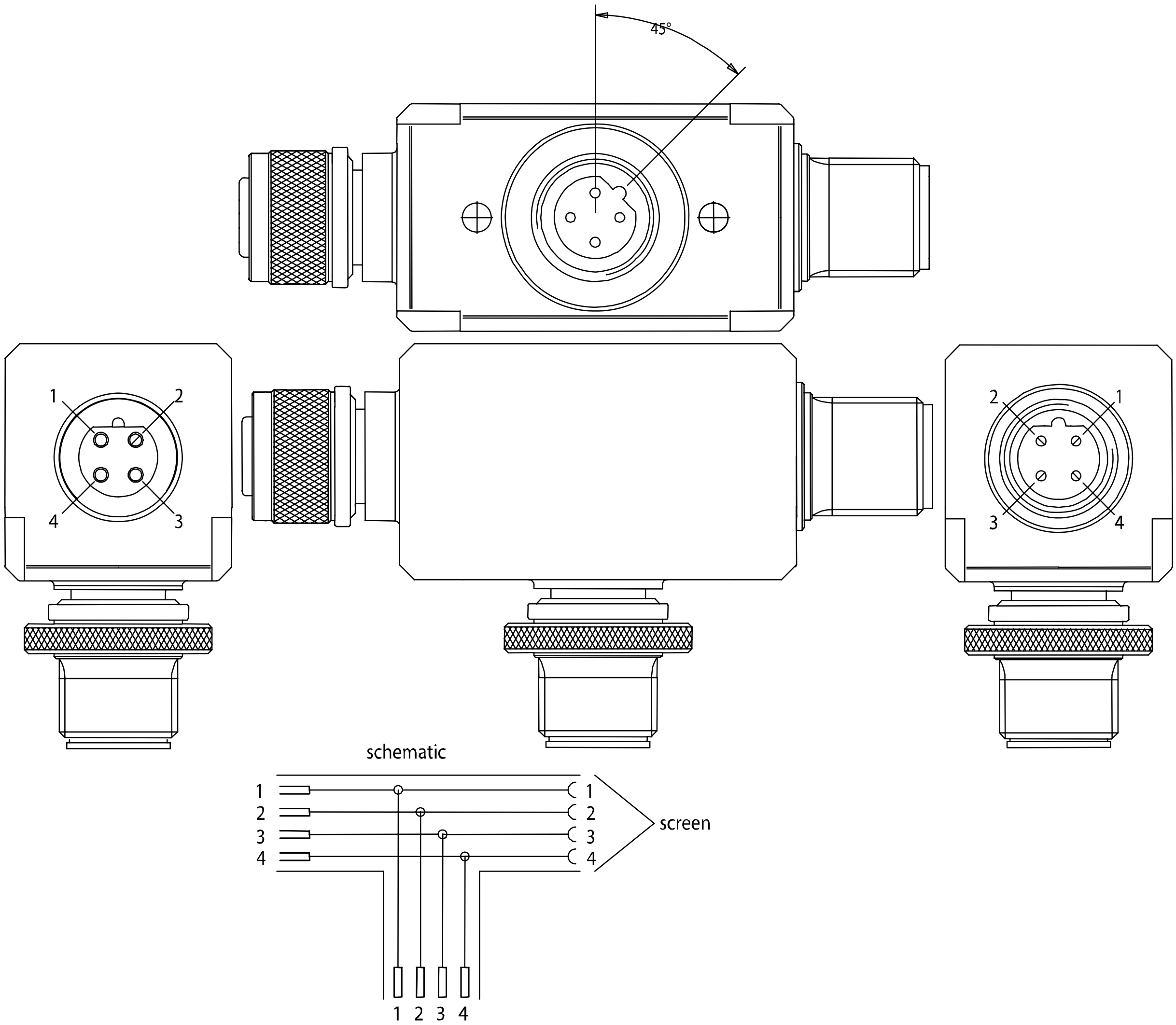


Figure I.6 — M12 Tee

Figure I.7 shows the pinout and schematic of the M12 bus termination.

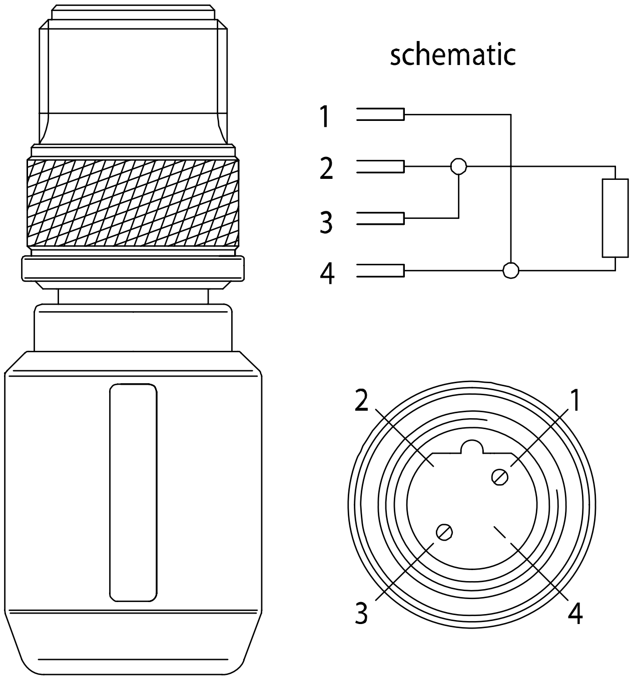


Figure I.7 — M12 Bus termination

I.2.2.3 Terminal connecting technique

The terminal connection shall provide the signals A, B, ISM and ISP. The terminal designation shall be according to the signal name. Alternatively, when internal bus termination is available, only the signals A and B may be provided. The communication device shall provide a suitable connection for cable shield.

The wiring from bus input to bus output in the terminal shall be designed for a maximum current of 4,8 A.

I.3 Connectors for fiber optic cable

I.3.1 Connectors for glass fiber optic cable (850 nm and 1 300 nm wavelength)

Glass fiber optic cables are connected or interconnected using type BFOC/2.5 connectors according to IEC 60874-10-1.

NOTE Butt joint contact of the fibers, so-called physical contact (PC), minimizes the attenuation and reflection for fiber-fiber connections.

I.3.2 Connectors for plastic and glass fiber optic cable (660 nm wavelength)

Plastic fiber optic cables are preferentially connected or interconnected using type BFOC/2.5 connectors.

Other connector elements are admissible if they are compatible to reference fiber 980/1 000 µm plastic fiber or 200/230 µm glass fiber.

Annex J
(normative)

Type 3: Redundancy of PhL and medium

The use of a redundant PhL improves the reliability of the fieldbus. When implemented, the redundant PhL contains two separately installed medium (bus cable "a" and bus cable "b") and two complete Medium Attachment Units (MAUs) per station. The redundancy architecture in principle is shown in Figure J.1.

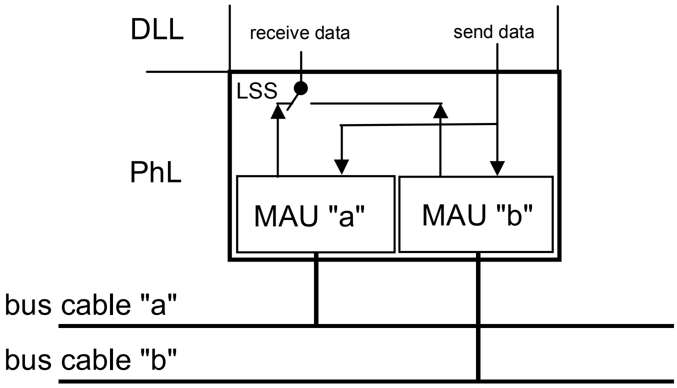


Figure J.1 — Redundancy of PhL MAU and Medium

The basic principle, shown in Figure J.1, assumes that data is sent out simultaneously by both MAUs (transceivers) onto both mediums (bus cable "a" and bus cable "b"). In contrast to this, each station receives from only one medium (either bus cable "a" or bus cable "b"). The receive channel is selected by a Line Selector Switch (LSS), which is located between both MAUs and the DLL. The Line Selector Switch is controlled by the Ph-management. For this the Medium Access Control (MAC) of each station's DLL monitors the medium activity, and gives corresponding information to DL-management (see IEC 61158-3-3 the DLMS Event and Get Value service) independently of any other station. The main switching conditions for masters and slaves are as follows:

- two or more successive invalid frames are received; invalid means frames with invalid format, invalid parity bit or invalid frame check sequence are detected;
- time out timer T_{TO} expires (see IEC 61158-4-3, "Timers and counters");
- no Syn. Time T_{SYN} (i.e. line idle for at least T_{SYN}) was detected during one Synchronization Interval Time T_{SYNI} (see IEC 61158-4-3, "Timer Operation").

NOTE 1 Dependent on the execution, further switch conditions may be selected.

The selected receive channel "a" (primary) or "b" (alternate) is notified to the Ph-management, see 6.3. The Ph-management then provides this information to the PHMS-user via the management interface.

NOTE 2 There is no preferred receive channel after the system initialisation is finished.

Annex K
(normative)

Type 3: Optical network topology

K.1 Signal flow in an optical network

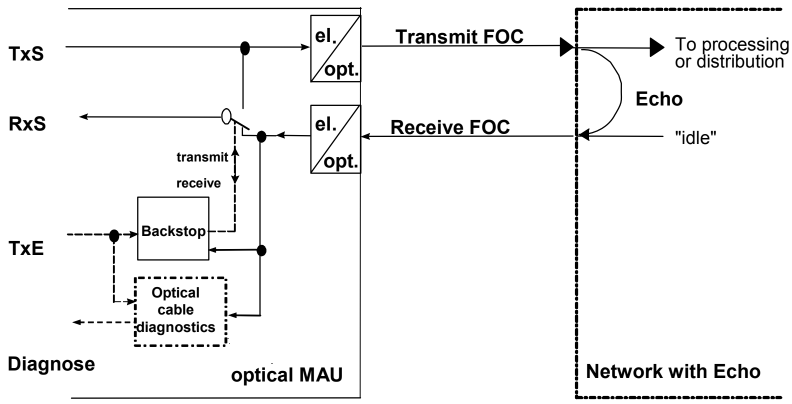
K.1.1 General

Connections to Master or Slave stations or coupling elements, such as star couplers, repeaters, etc. are the user's responsibility. However, the user must make sure that the various interfaces are compatible with each other.

This clause contains the description of optical Medium Attachment Units (MAU) to connect to a fiber optical network with or without echo.

K.1.2 Connection to a network with echo

After a delay, the optical MAU receives its own transmit signal from the network again as an echo. Echo signal detection can be used to confirm the status of the physical connection to the optical MAU at the other end of the line (see Figure K.1).



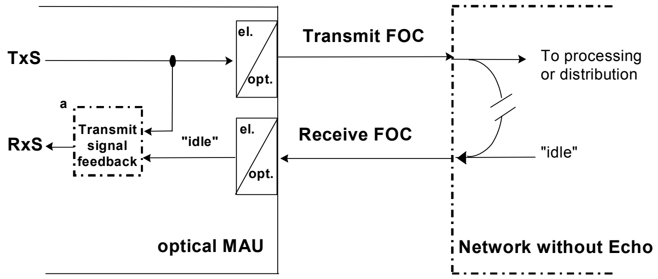
Key:
FOC = Fiber optic cable
TxE = Transmit enable
TxS = Transmit signal
RxS = Receive signal
MAU = Medium attachment unit

Figure K.1 — Optical MAU in a network with echo

The echo is returned with a delay equal to twice the signal delay to the coupling element (e.g. star coupler) that generates the echo. With a ring structure, the delay corresponds to one cycle of the ring. The receive signal delay, which does not occur in asynchronous transmission networks, shall not cause operating faults or error messages. The transmitting optical MAU shall remove the echo signal from the network. The echo signal shall not be returned to the network by the transmitter again and shall not lead to duplication of the message as a "new" message within a field device.

K.1.3 Connection to a network without echo

The optical MAU does not receive its own transmit signal from the network again as an echo in such a network. The receive line remains idle during the transmit procedure as shown in Figure K.2. No information is available on the status of the link.



Key:
FOC = Fiber optic cable
TxS = Transmit signal
RxS = Receive signal
MAU = Medium attachment unit

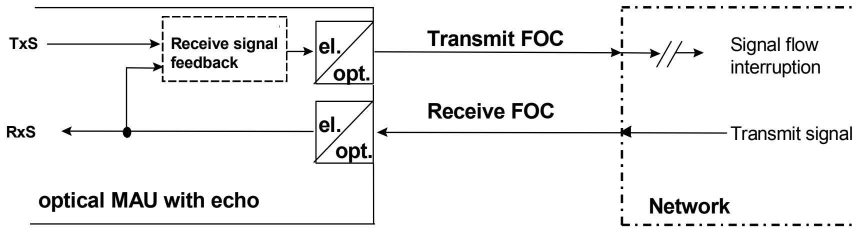
[a] mandatory for Master

Figure K.2 — Optical MAU in a network without echo

Masters shall fulfil the requirements of token acknowledgement locally, for example with hardware feedback (emulation) of the transmit signal.

K.1.4 Optical MAU with echo function

An optical MAU with echo function returns the signal received at an input gate to the associated return line as shown in Figure K.3. This allows an appropriate optical MAU at the other end of the optical line to check for its own message by monitoring for the echo.

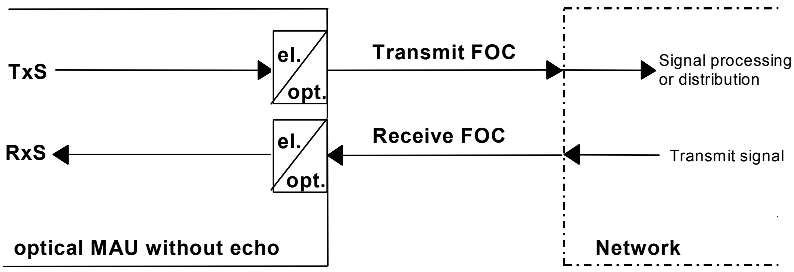


Key:
FOC = Fiber optic cable
TxS = Transmit signal
RxS = Receive signal
MAU = Medium attachment unit

Figure K.3 — Optical MAU with echo via internal electrical feedback of the receive signal

K.1.5 Optical MAU without echo function

An optical MAU without echo function does not return the signal received at an input gate to the associated return line. The output remains at the idle level (see Figure K.4).



Key:
FOC = Fiber optic cable
TxS = Transmit signal
RxS = Receive signal
MAU = Medium attachment unit

Figure K.4 — Optical MAU without echo function

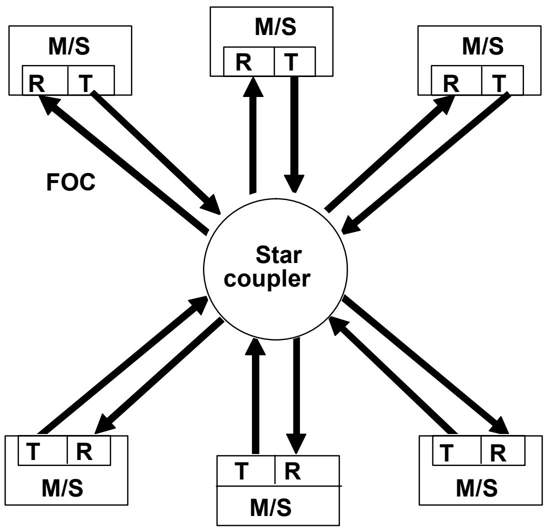
K.1.6 Examples of topology

K.1.6.1 General

The following subclauses illustrate some of the network topologies that can be constructed in accordance with this standard. This subclause does not imply that these are the only possible topologies.

K.1.6.2 Star topology

Central signal distribution using active star couplers results in a star-shaped structure for the optical network with the active star coupler as the central element (see Figure K.5)



Key:
R = Optical receiver
T = Optical transmitter
M/S = Master or slave station
FOC = Fibre optic cable

Figure K.5 — Optical network with star topology

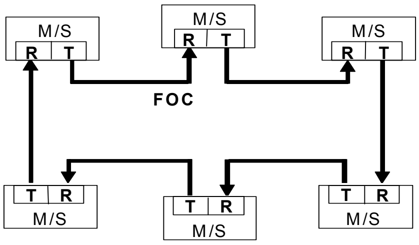
The active star coupler is used in optical networks as a central signal distributor with signal level restoration. Regeneration of the signal timing (re-timing) is available as an option. The active star coupler requires an electrical power supply. The active star coupler converts optical signals received at an input into electrical signals. Internal signal processing takes place electrically. Electro-optical converters at the output gates transmit an optical signal.

K.1.6.3 Ring topology

A ring structure, as shown in Figure K.6, requires additional control measures in the station. A transmitting station (Master/Slave) shall interrupt the ring logically and maintain the interruption after the end of the telegram until the telegram has passed around the ring once and returned to the transmitting station, where it is discarded.

Stations in receive mode shall output the received signal on the transmit side again.

Stations have to be provided with a protection, which prevents dropping the ring into a statically closed ring. This problem can occur if e.g. a fault spike occurs during an “idle” phase.

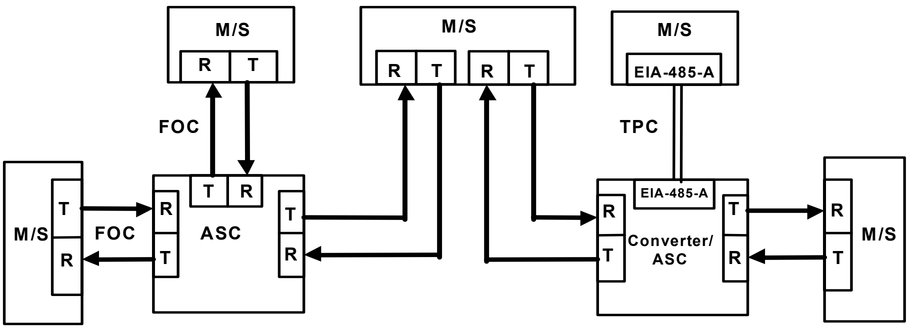


Key:
R = Optical receiver
T = Optical transmitter
M/S = Master or slave Station
FOC = Fiber optic cable

Figure K.6 — Optical network with ring topology

K.1.6.4 Bus topology

The bus topology is built with type 3x3 star couplers or stations with integrated optical interfaces (see Figure K.7).

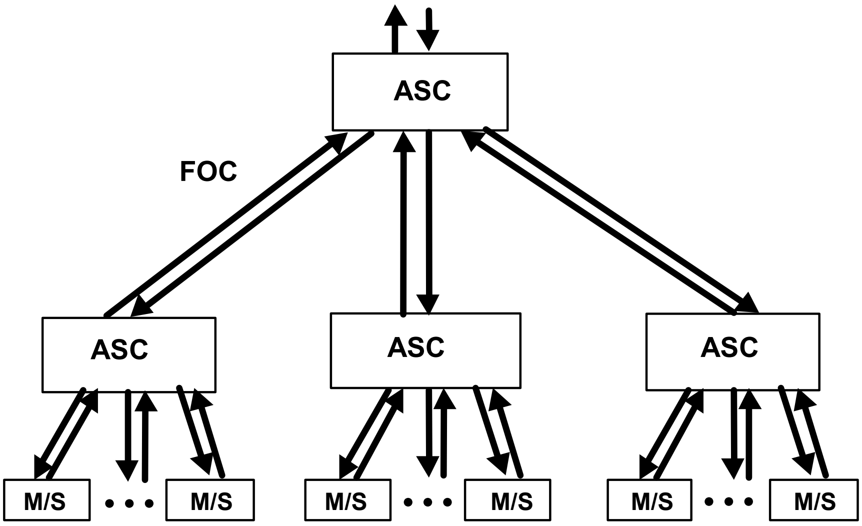


Key:
FOC = Fibre optic cable
TPC = Twisted-pair cable
ASC = Active star coupler
M/S = Master or slave Station
R - Optical receiver
T - Optical transmitter
EIA-485-A: - Transceiver

Figure K.7 — Optical network with bus topology

K.1.6.5 Tree topology

Several active star couplers can be combined to build networks with a tree structure as shown in Figure K.8.



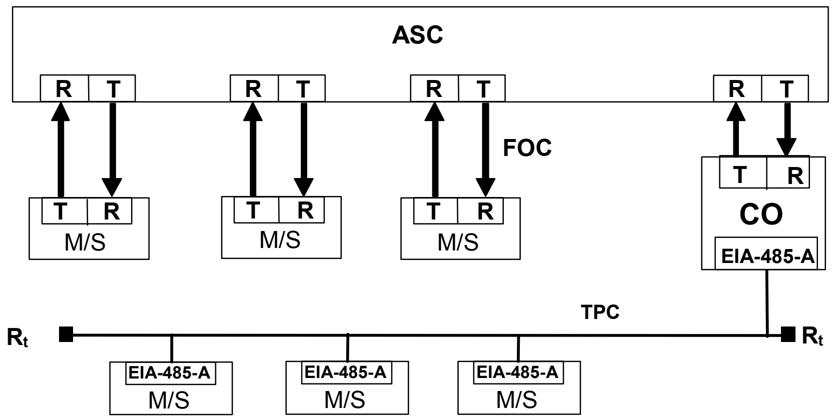
Key:
ASC = Active star coupler
M/S = Master or slave station
FOC = Fiber optic cable

Figure K.8 — Tree structure built from a combination of star structures

K.1.6.6 ANSI TIA/EIA-485-A / fibre optic converter

An ANSI TIA/EIA-485-A / fiber optic converter is used to connect a station or a subnet based on the ANSI TIA/EIA-485-A technology to an optical network segment or an optical Master/Slave station.

Figure K.9 illustrates an application example for an ANSI TIA/EIA-485-A / fiber optic converter.



Key:
ASC = Active star coupler
M/S = Master or slave station
CO = Converter
R_t: = Terminating resistor
FOC = Fiber optic cable
R = Optical receiver
T = Optical transmitter
TPC = Twisted-pair cable
EIA-485-A = Transceiver

Figure K.9 — Application example for an ANSI TIA/EIA-485-A / fiber optic converter

The ANSI TIA/EIA-485-A / fiber optic converter can also be implemented internally in a modular active star coupler.

K.1.7 Optical power budget

K.1.7.1 General

A fiber-specific optical signal level budget is available between two nodes that can be consumed in the form of attenuation along the optical link.

Specific budget calculations can be carried out using the specifications from the respective manufacturer.

Signal level budget refers to the difference between the output power from the optical transmitter and the input power required by an optical receiver for error-free signal detection. The overall attenuation must be between the level budgets for overload and sensitivity.

The following subclauses provide examples of which network extents can be implemented with various fiber types and transmitter power levels.

K.1.7.2 Limiting conditions

The following limiting conditions must be taken into consideration when interpreting the tables and dimensioning the optical links.

K.1.7.2.1 Numerical aperture (NA)

Numerical aperture (for description refer to IEC 60 793-2).

K.1.7.2.2 Output power

Output power is the power level in the fiber for a “0” signal for the specified fiber for the entire temperature range giving consideration to sample diffusion and to the losses that are caused by the fiber connection at the transmitter (connector element).

K.1.7.2.3 Receiver limits

These values identify the acceptable signal range (dynamic range) for a “0” signal (“light” ON), whereby “overload” refers to the highest acceptable signal level (= brightest “light”) and “sensitivity” refers to the lowest signal level. Moving outside the dynamic range does not necessarily cause interruption of the data transfer, but increases the deviation of signal timing beyond the specified limits that increases the likelihood of transmission errors.

K.1.7.2.4 Level budget

Level budget is the dynamic range resulting from the specified transmitter/receiver combination. The bit error rate (BER) is $<10^{-9}$ within these limits.

K.1.7.2.5 Overall attenuation

Overall attenuation refers to the minimum required attenuation required for overload protection of the receiver or to the maximum allowed attenuation needed to utilize the entire sensitivity of the receiver.

The overall attenuation is composed of:

– fibre attenuation for the fiber optic cable;

– coupling losses for inserted connectors and splices, if applicable;

– a system margin.

K.1.7.2.6 System reserve

System reserve takes account of the transmitter element's output power loss due to aging. The life expectancy of a transmitter element is usually defined by the time by which the transmitted power has fallen by 3dB compared to the value for a new element.

When determining the overload immunity of a receiver, it is assumed that this "system reserve" has not been consumed.

K.1.7.2.7 Fiber attenuation

Fiber attenuation refers to the maximum allowable attenuation or to the minimum required attenuation of the fiber optic cable.

K.1.7.2.8 Specific fiber attenuation

Specific fiber attenuation is the maximum or minimum attenuation of the fiber optic cable per length unit. It is dependent on the wavelength of the light.

Attenuation values for fibers are not stipulated in the specifications and must be obtained from the data sheet for the respective fiber. The values in the tables are typical values based on experience.

NOTE The peak wavelength of the emitted light shifts with the operating temperature of the transmitter element. This wavelength shift must be taken into consideration when determining the limiting values for the specific fiber attenuation.

K.1.7.2.9 Fiber length

The fiber length is calculated by dividing that part of the overall attenuation that is due to fiber attenuation by the specific fiber attenuation.

K.1.7.3 62,5/125 µm multi-mode glass fiber

The transmit power level is so chosen that the minimum optical link length is 0 m, i.e. receiver overload cannot occur with the 62,5/125 µm fiber. An example of a level budget calculation for this reference fiber is given in Table K.1.

Table K.1 — Example of a link budget calculation for 62,5/125 µm multi-mode glass fiber

Link budget for a 62,5/125 µm multi-mode glass fiber standard link (graded index profile) NA = 0,275			
Transmitter output power	–20 … –15		dBm
Receiver limits	**Overload** -10	**Sensitivity** -24	dBm
Level budget	0	9	dB
Overall attenuation	0	9	dB
System reserve	0	3	dB
Fiber attenuation	0	6	dB
Specific fiber attenuation	2,5	3,5	dB/km
Fiber length	min. 0	max. 1 700	m

K.1.7.4 9/125 µm single mode glass fiber

This fiber type has been included to be able to implement longer optical links.

The transmit power level is so chosen that the minimum optical link length is 0 m, i.e. receiver overload cannot occur with the 9/125 µm fiber.

The Table K.2 shows typical values in practice, which do not represent specifications.

Table K.2 — Example of a link budget calculation for 9/125 µm single mode glass fiber

Link budget for a 9/ 125 µm single mode glass fiber standard link (step index profile) NA = 0,13			
Transmitter output power	–20 … –10		dBm
Receiver limits	**Overload** -10	**Sensitivity** -27	dBm
Level budget	0	7	dB
Overall attenuation	0	7	dB
System reserve	0	2	dB
Fiber attenuation	0	5	dB
Specific fiber attenuation	0,3	0,5	dB/km
Fiber length	min. 0	max. 10 000	m

K.1.7.5 980/1 000 µm multi-mode plastic fiber

Due to its larger diameter, plastic fiber places lower demands on absolute mechanical tolerances during installation. This generally leads to reduced installation costs.

However, due to the much higher fiber attenuation compared to glass fiber, plastic fiber is generally only suitable for relatively short optical links. The wavelength range of the optical signal is chosen to match the minimum attenuation of the plastic material. Numerical example for the level budget is given in Table K.3.

Table K.3 — Example of a link budget calculation for 980/1 000 µm multi-mode plastic fiber

Link budget for a 980/1 000 µm plastic fiber standard link (step index profile) NA = 0,47					
Transmitter output power	**Standard**		**Increased**		
Output power	–11 … – 5,5		–6 … 0		dBm
Receiver limits	**Overload** -5,0	**Sensitivity** -20,0	**Overload** 0	**Sensitivity** -20,0	dBm
Level budget	-0,5	9,0	0	14,0	dB
Overall attenuation	0	9,0	0	14,0	dB
System reserve	0	3,0	0	3,0	dB
Fiber attenuation	0	6,0	0	11,0	dB
Specific fiber attenuation	0,15	0,25 (see note)	0,15	0,25 (see note)	dB/m
Fiber length	min. 0	max. 24	min. 0	max. 44	m
NOTE Increased attenuation due to the fiber material and the wavelength shift due to temperature changes in the transmitter element.					

K.1.7.6 Multi-mode glass fiber 200/230 µm fiber

This fiber type has been included to be able to implement longer optical links. The numerical example for the level budget is given in Table K.4.

Table K.4 — Example of a level budget calculation for 200/230 µm multi-mode glass fiber

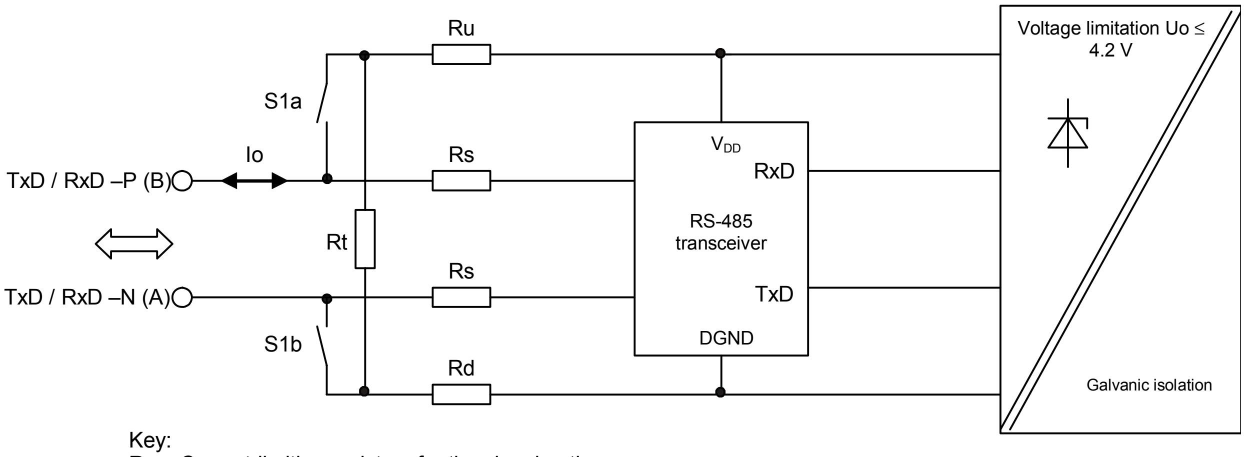
Link budget for an 200/230 µm fiber standard link (step index profile) NA = 0,37			
Transmitter output power	– 16,0 to -8,0		dBm
Receiver limits	**Overload** -8,0	**Sensitivity** -22,0	dBm
Level budget	0	6,0	dB
Overall attenuation	0	6,0	dB
System reserve	0	3,0	dB
Fiber attenuation	0	3,0	dB
Specific fiber attenuation	5	10	dB/km
Fiber length	min. 0	max. 300	m

Annex L
(informative)

Type 3: Reference design examples for asynchronous transmission, wire medium, intrinsically safe

L.1 Bus termination in the communication device

In this version, the bus termination is already in the device by means of the resistors Rt, Ru and Rd, as shown in Figure L.1. Activation is done via the switch S1 for the device which is installed at the end of the bus segment.



Key:
Rs =Current-limiting resistors for the signal path
Rt, Ru; Rd : Bus-termination resistors

Figure L.1 — Bus termination integrated in the communication device

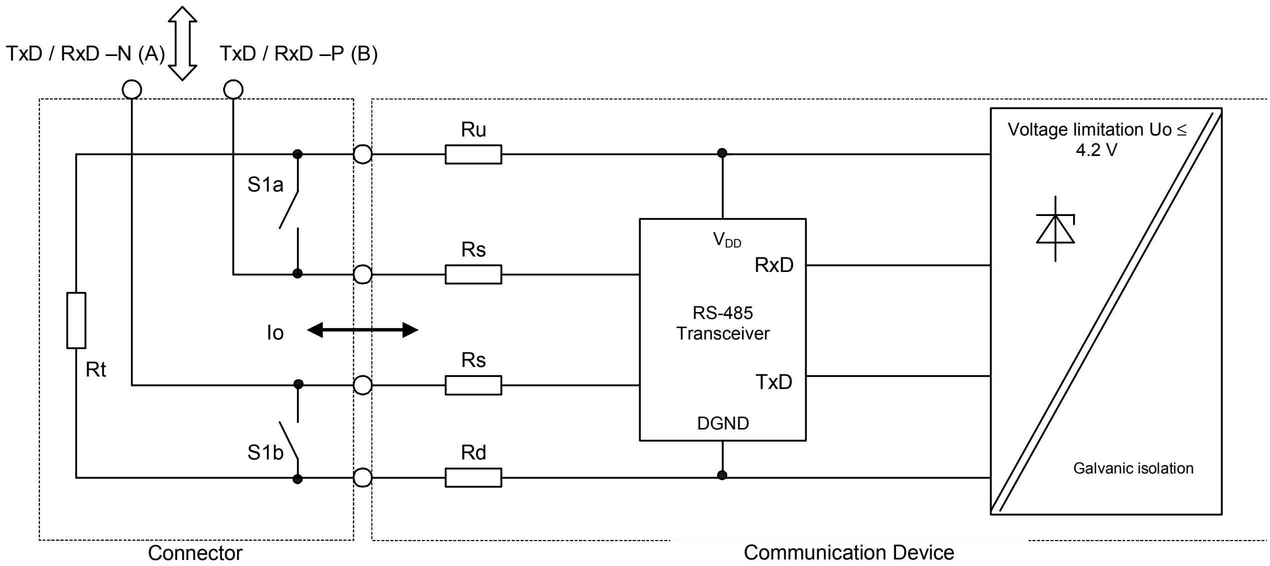
When determining the maximum output current Io, it shall be noted that, on account of the switch S1, the resistor R3 is connected in parallel to R1 and the resistor R4 is connected in parallel to R2.

NOTE Here, the safety-related limiting values as described in "PTB-Mitteilungen, 113 Jahrgang, Heft 2/2003, Die Bewertung der Zündfähigkeit eigensicherer Stromkreise anhand eines Rechenverfahrens. Abschnitt: Der eigensichere RS 485 Feldbus als Anwendungsbeispiel." shall also be adhered too.

For the design of the components and the required separation distances, the relevant applicable standard shall be met (e.g. IEC 60079-11).

L.2 Bus termination in the connector

In this version, the bus termination is realised in the connector, as shown in Figure L.2. For this, it is necessary that the communication devices provide the appropriate power supply. Activation is done via the switch S1 for the devices which are installed at the relevant end of the bus segment.



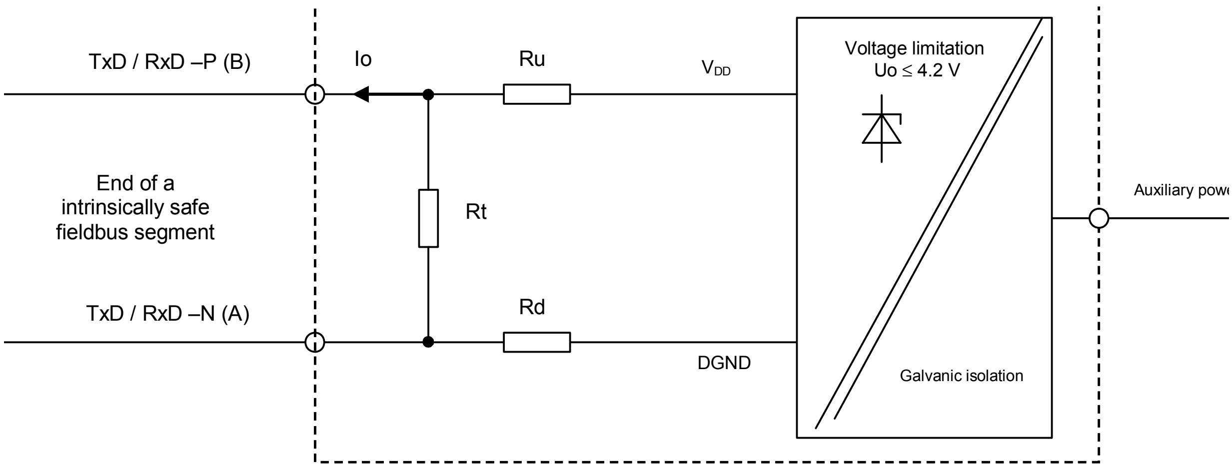
Key:
Rs : Current-limiting resistors for the signal path
R3, R4; R5 : Bus-termination resistors

Figure L.2 — Bus termination in the connector

L.3 External bus termination

The auxiliary power supply must be galvanically isolated from the field bus circuit, as shown in Figure 111. Details of this are provided in 22.2.4.3.

In this version, the bus termination is realised externally in a seperate device, as shown in Figure L.3.



Key:
Rt, Ru; Rd : Bus termination resistors

Figure L.3 — External bus termination

The auxiliary power supply must be galvanically isolated from the field bus circuit.

The resistors Ru and Rd are relevant for the calculation of the maximum output current I_o. In this context, the safety-related limiting values for external bus terminations shall be adhered too. Regarding to the design of the components and the necessary separation distances, the relevant applicable standard (e.g. IEC 60079-11) shall be applied.

Annex M
(normative)

Type 8: Connector specification

M.1 External connectors for wire medium

M.1.1 Subminiature D connector pin assignment

The connector pin assignment is shown in Figure M.1, Figure M.2 and Table M.1.

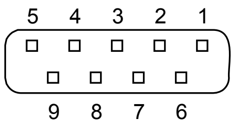


Figure M.1 — Outgoing interface 9-position female subminiature D connector at the device

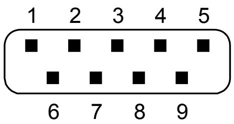


Figure M.2 — Incoming interface 9-position male subminiature D connector at the device

Table M.1 — Pin assignment of the 9-position subminiature D connector

Pin number	Signal line
1	DO
2	DI
3	GND
4	–
5	–
6	/DO
7	/DI
8	–
9	–

M.1.2 Terminal connector pin assignment

Figure M.3 shows the terminal connector position at the device and pin assignments of the terminal connector are shown in Table M.2.

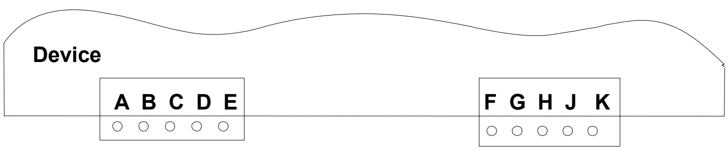


Figure M.3 — Terminal connector at the device

Table M.2 — Pin assignment of the terminal connector

Incoming interface			Outgoing interface	
Pin	Standard		Pin	Standard
A	/DO1		F	/DO2
B	DO1		G	DO2
C	/DI1		H	/DI2
D	DI1		J	DI2
E	GND1		K	GND

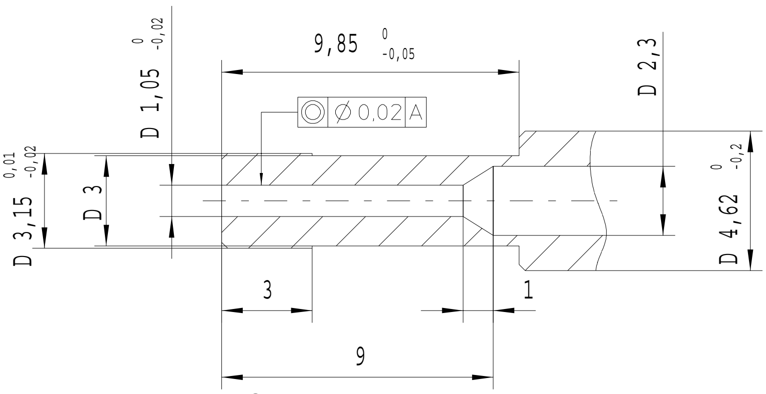
A separate terminal for protective earth shall be provided.

The sequence of terminal points should be observed.

M.2 External connectors for fiber optic medium

A network connector that is outside the enclosure of the device and therefore requires protection against the electromagnetic, chemical and physical environment shall be specified as an external connector.

If a degree of protection of IP20 or less is used for the device having an optical MAU implemented the connector used for the CPIC at the device level should be mechanically compatible with a F-SMA type connector as specified in IEC 61754-22. The ferrule of an optical F-SMA connector for polymer optical fiber (980/1 000 µm) is shown in Figure M.4.



NOTE All measures in mm.

Figure M.4 — Ferrule of an optical F-SMA connector for polymer optical fiber (980/1 000 µm)

M.3 External connectors for hybrid connectors for IP65 applications

If a hybrid connector for applications with a degree of protection of IP65 or higher is used for the device having an optical MAU implemented, this connector used for the CPIC at the device level should be as shown in Figure M.5 and Figure M.6 with the connector dimension specified in Table M.3.

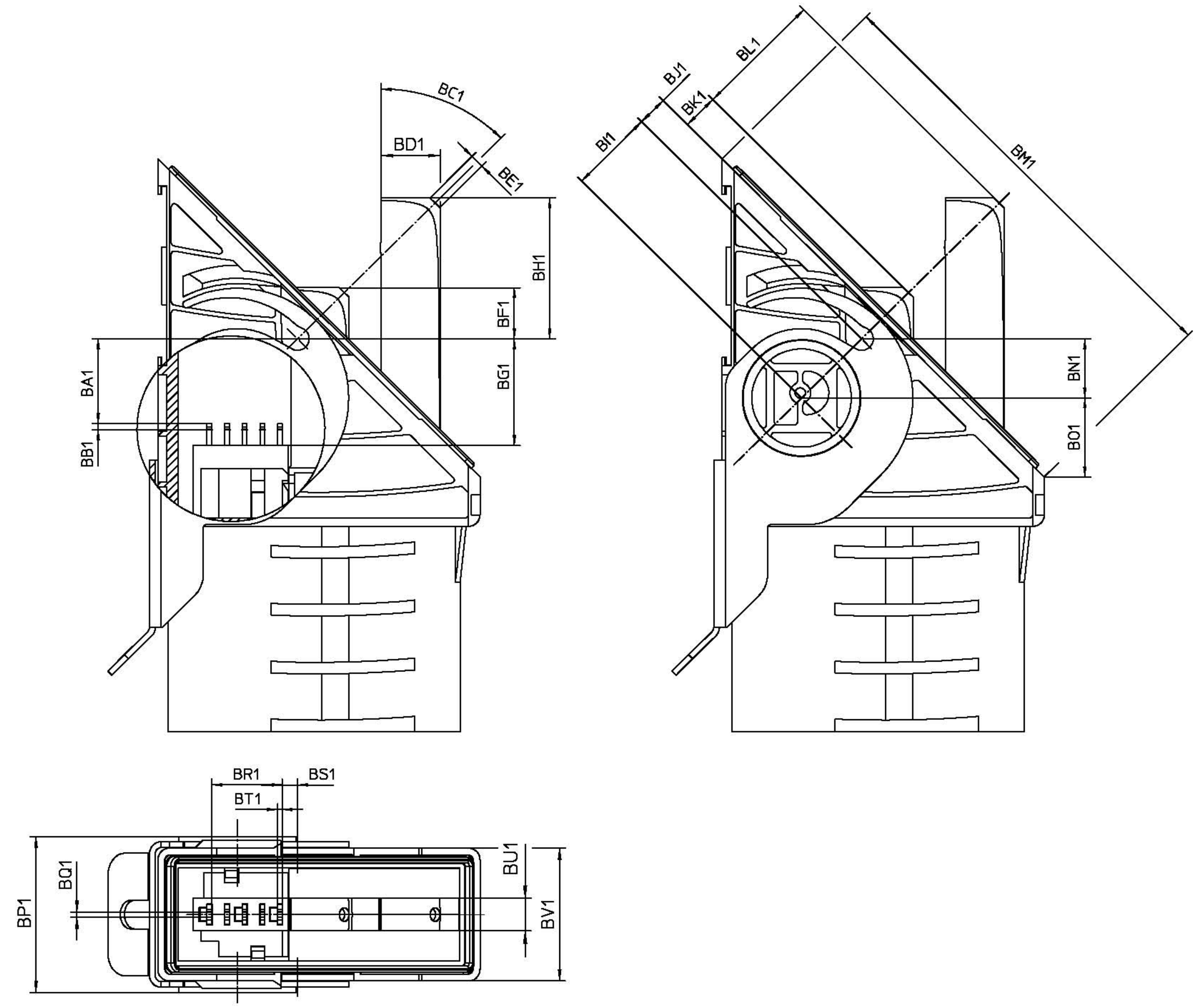
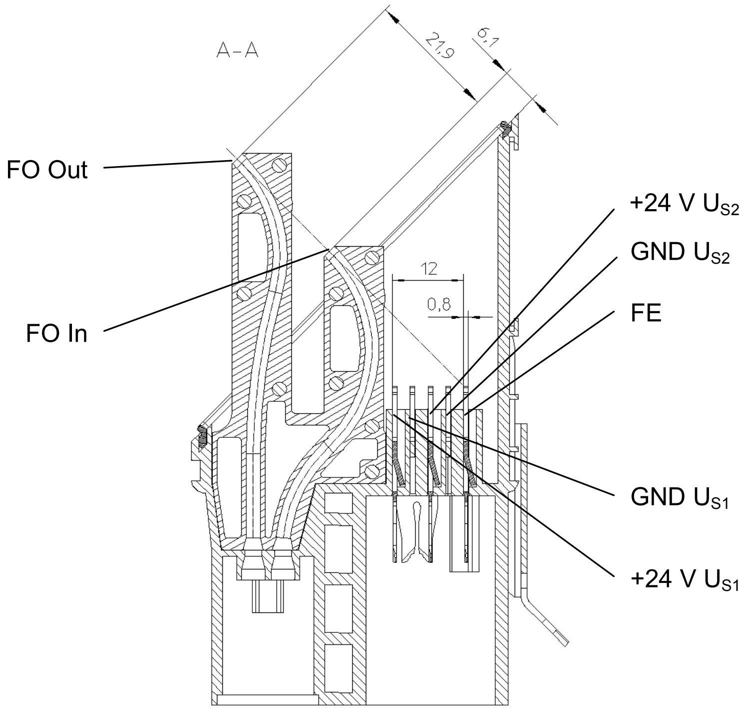


Figure M.5 — Type 8 fiber optic hybrid connector housing



Key:

U_{S1} = Sensor and bus module power supply

U_{S2} = Actuator power supply

FO in = connection to the FO transmitter

FO out = Connection to the FO receiver

Figure M.6 — Type 8 fiber optic hybrid connector assignment

The electrical contacts for the power supplies should be capable of supporting a continuous maximum current of 16 A at 24 V.

Table M.3 — Type 8 fiber optic hybrid connector dimensions

Letter	Max.	Min.	Nominal
	(millimetres)		
BA1	14,9	14,5	14,7
BB1	1,2	1	1,1
BC1	45,5	44,5	45
BD1	10,2	9,8	10
BE1	2,5	2,3	2,4
BF1	9	8,6	8,8
BG1	18,7	18,3	18,5
BH1	24,5	24,1	24,3
BI1	14,7	14,3	14,5
BJ1	5,3	5,1	5,2
BK1	6,3	5,9	6,1
BL1	22,1	21,7	21,9
BM1	78	77,6	77,8
BN1	10,45	10,05	10,25
BO1	13,85	13,45	13,65
BP1	27,2	26,8	27
BQ1	0,95	0,75	0,85
BR1	12,2	11,8	12
BS1	2,7	2,5	2,6
BT1	0,9	0,7	0,8
BU1	5,7	5,5	5,6
BV1	23,2	22,8	23

Annex N
(normative)

Type 16: Connector specification

Connectors for fiber optic cables shall

- correspond to F-SMA standard (see IEC 61754-22);
- have a quality level of at least 5;
- have a metallic connector ring.

The transmitter and receiver components shall be built into light-proof housings.

In addition, it is recommended that fiber optic cables have a strain relief.

Annex O
(normative)

Type 16: Optical network topology

O.1 Topology

The topology shall consist of optical point-to-point transmission lines and subscribers. A transmission line shall consist of fiber optic cables having no optical branches. Transmission shall take place in only one direction. The master and the slaves are part of the network (subscribers).

Figure O.1 shows the structure in connection with the control unit and the devices. The control unit may encompass one or more masters, as needed by the application. A master shall handle only one network on the physical layer as well as in the overlying protocol layers. Slaves shall be used to connect the devices to the optical fiber network. On the physical layer, a slave can represent the connection of one or more devices to the optical fiber network. Logically, one slave with several devices shall act the same as several slaves with one device each. Although the slaves are connected to each other physically through the optical fiber network, all transmission of information takes place directly between the master and the slaves. A star-shaped topology is created if every master has only one slave connected to itself.

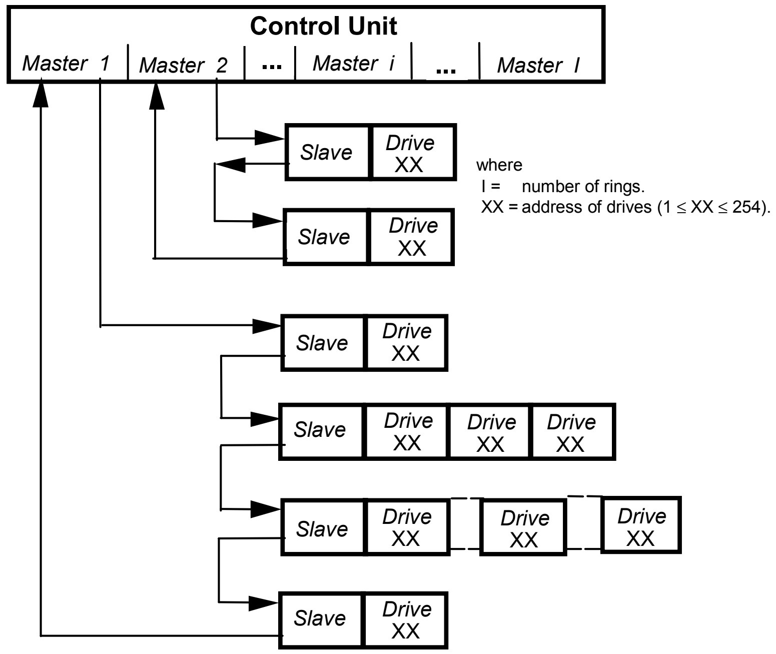


Figure O.1 — Topology

The physical arrangement of slaves in the network shall be independent from the device address set for the slave, as well as from the timing sequence of transmitting the acknowledge telegrams.

NOTE The number of devices in a network is M = K. The sequence of the AT is labeled as 1, 2, ..., M and the sequence of the device data records in the MDT is labeled as 1, 2, ... K.

The Types CP16/1 and CP16/2 interface determine any exchange of information within a network. Any cooperation of networks is controlled by the control unit and is not subject to this specification.

O.2 Optical power budget

O.2.1 Optical signals on the transmission line

Optical power levels on the transmission line have units of dB_m or µW which are related as follows:

– level [dBm] = 10 × log (level [µW] / 1 000 µW):

– level [µW] = 10 level [dBm] / 10 dBm x 1 000 µW.

The optical signals given in Table O.1, Table O.2 and Table O.4 for the transmitter, the receiver, and the transmission line are measured with a plastic fiber cable (POF) with a 1 mm core diameter and a length of 1 m or with a glass fiber cable (HCS) with 200 µm diameter and a length of 1 m as specified in Table O.3.

Optical levels and edges (status changes) along the transmission line are specified by means of the following parameters:

a) P_{TmaxL}, the maximum transmission power at an optically low level. If the optical signal falls below this level, it is at a logic low state;

b) P_{TminH}, the minimum transmission power at an optically high level. If the optical signal goes above this level, it is at a logic high state;

c) P_{TmaxH}, the maximum transmission power at an optically high level. Stationary signals shall never exceed this limit. A rising optical edge, however, may dynamically exceed the upper limit of the optically high level. This makes it possible to accent the rising edge (minimizing the rise time). Both the magnitude, as well as the duration of the excess signal level are limited;

d) k_{os}, factor for optical power overshoot. This parameter indicates the factor by which the maximum optical transmission power may be exceeded dynamically. The excess power level is only permissible during an optical status change from low to high (rising signal edge).

NOTE PRxxx is used to express the PTxxx equivalent for a receiver.

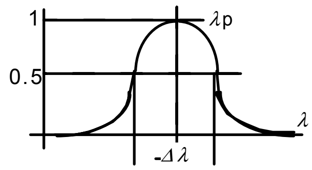
The optical signal shall pass through P_{TmaxL} to P_{TminH} in a monotonic manner (which means that the signal noise is less than 100 nW = –40 dB_m). Therefore, the logic high level between P_{RmaxL} and P_{RminH}, can be recognized definitely without generating additional signal changes.

O.2.2 Transmitter specifications

Unless stated otherwise, these specifications shall be valid throughout the temperature range from 0 °C to +70 °C.

A transmitter shall follow the specifications in Table O.1.

Table O.1 — Transmitter specifications

Position	**Attenuation at 650 nm**		
Fiber type	**POF**		**HCS**
Optical transmission power	**Low**	**High**	**High**
P_{TmaxL}	-31,2 dBm	-28,2 dBm	-33,2 dBm
	0,75 µW	1,5 µW	0,5 µW
P_{TminH}	-10,5 dBm	-7,5 dBm	-18 dBm
	90 µW	180 µW	16 µW
P_{TmaxH}	-5,5 dBm	-3,5 dBm	-10 dBm
	280 µW	450 µW	100 µW
Transmitting diode wavelength			
Peak wavelength	λ_{pk} = 640 nm to 675 nm		
Spectral bandwidth	$\Delta\lambda \leq$ 30 nm (25 °C)		
Optical spectrum			
k_{os}	120 %		
Temperature range	0 °C to 70 °C		
NOTE All data are for λ_{pk} (which is λ_p in the above inset drawing).			

O.2.3 Receiver specifications

Unless stated otherwise, these specifications are valid throughout the temperature range from 0 °C to +70 °C.

In order to process the data correctly, the receiver shall meet the requirements shown in Table O.2. Since the bandwidth of the fiber optic cable is relatively wide, distortion of the optical signals is insignificant.

Table O.2 — Receiver specifications

Wavelength	**650 nm**	
Fiber type	**Plastic fiber POF**	**Glass fiber HCS**
P_{RmaxL}	–31,2 dBm	–33,2 dBm
	0,75 µW	0,5 µW
P_{RminH}	–20 dBm	–22 dBm
	10 µW	6,3 µW
P_{RmaxH}	–5 dBm	–7 dBm
	316 µW	200 µW
Dynamic power (P_{RmaxH} to P_{RminH})	15 dB	
Bit error rate	$\leq 10^{-9}$	
Temperature range	0 °C to 70 °C	
NOTE All data are for λ_{pk}		

O.2.4 Fiber optic cable

The fiber optic cable can consist of plastic or glass with a step index profile or graded index profile. An example is shown in Figure O.2 and Table O.3.

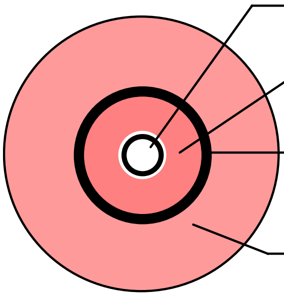


Figure O.2 — Structure of a single-core cable (example)

Table O.3 — Cable specifications (example)

	Plastic fiber POF	Glass fiber HCS
Core diameter	980 µm	200 µm
Cladding diameter	1 000 µm	230 µm
Numeric aperture	0,47	0,37
Bandwidth	≥5 MHz × 1 km	≥10 MHz × 1 km

O.2.5 System data of the optical transmission path

The optical power levels are shown in Figure O.3 and shall be in accordance with values in Table O.4.

Table O.4 — System data of the optical transmission line at 650 nm

Fiber type		POF		HCS
Optical transmission power (see 30.1)		Low	High	High
Transmission power	P_{TmaxL}	-31,2 dBm	-28,2 dBm	-33,2 dBm
		0,75 µW	1,5 µW	0,5 µW
	P_{TminH}	-10,5 dBm	-7,5 dBm	-18 dBm
		90 µW	180 µW	16 µW
	P_{TmaxH}	-5,5 dBm	-3,5 dBm	-10 dBm
		280 µW	450 µW	100 µW
Received power	P_{RmaxL}	-31,2 dBm		
		0,75 µW		
	P_{RminH}	-20 dBm		
		10 µW		
	P_{RmaxH}	-5 dBm		
		315 µW		
	Dynamic power (P_{RmaxH} to P_{RminH})	15 dB		
System value	P_{TminH} to P_{RminH}	9,5 dB	12,5 dB	4 dB
System reserve (including lifetime of transmitting diode)		≥ 5,1 dB		≥ 2 dB
Line attenuation (System value – System reserve)		≤ 4,4 dB	≤ 7,4 dB	≤ 2 dB
Measuring cable attenuation (typical)		0,2 dB/m	0,2 dB/m	10 dB/km
Cable length		≤ 22 m	≤ 37 m	≤ 200 m
Transmission rate (NRZI)		2 Mbit/s, 4 Mbit/s, 8 Mbit/s and 16 Mbit/s		
Bit error rate		≤ 10-9		
Temperature range		0 °C to 70 °C		

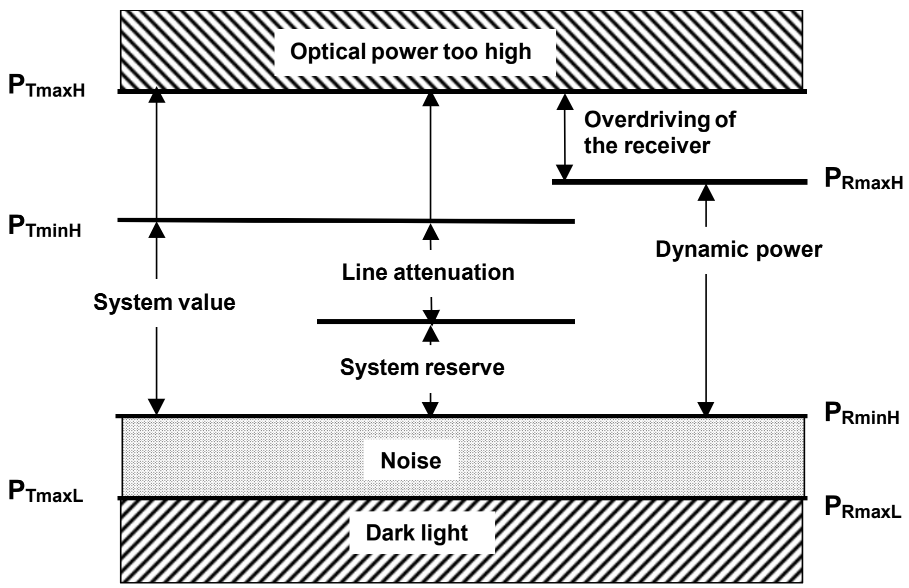


Figure O.3 — Optical power levels

Annex P
(informative)

Type 16: Reference design example

P.1 Functional principles of the repeater circuit

Figure P.1 shows an example of an implementation of the signal-regeneration function from the repeater circuit. The primary task of this circuit consists of retrieving the clock RCLK from the NRZI-coded input signal IN. This may be accomplished e.g., by means of a digital phase-locked loop (DPLL). In addition, by sampling the input signal IN at appropriate times, a regenerated received signal RxD can be generated. The NRZI-coded signal is especially useful in the network structure.

The circuit consists of eight flip-flops and a combinational logic PLA. The flip-flops are driven by a common clock CX. This clock signal is generated by a crystal oscillator having 16 times the frequency of the data rate, which is 32 MHz at 2 Mbit/s transmission rate.

It is also possible to implement DPLLs having different sampling rates. In order to match the following condition, a sampling rate of at least 12 times is needed:

$$0 \le t_{cadreal} \le \frac{t_{bitnom}}{11}$$

Flip-flop 1 is used to initially synchronize the input signal. Flip-flop 2 is used for edge detection; it is always the case that if IN1 = 1 and IN2 = 0, a positive edge has been found. Flip-flops 5-8 in conjunction with the combinatorial logic are used to implement a finite-state machine.

The status diagram of Figure P.2 illustrates the behavior of the DPLL. States Z = 0 through Z = 15 correspond to the binary values which are given by the output signals of the flip-flops 5-8.

Depending on the status number (Z = 0 ... 15) in which E (event: light-on edge detected) or E* (event: no light-on edge detected) is detected, the DPLL reacts by repeating or skipping a status. If E is found to be in the state Z = 0, the DPLL does not repeat or skip (i.e., the DPLL is synchronized). Input signals are not sampled at the theoretical mean of the bit cell but in their shifted position. This enables the system to operate even with relatively strong distorted signals. During the transition from Z = 3 to Z = 4, RCLK = 1 is set. During the transition from Z = 10 or Z = 11 to Z = 12 and from Z = 11 to Z = 13, RCLK = 0 is set and the output signal RxD is set equal to the synchronized input signal IN1.

Figure P.3 illustrates the timing of various signals.

In general, the signal becomes distorted mainly by electrical-to-optical conversion and vice versa. In Figure P.3, it is shown what the signal IN1 looks like ideally, and what its typical shape is during minimum and maximum transmission power. The assumption is made that a series of NRZI-coded zeros is transferred. This corresponds to a rectangular signal with the period 2 × tBIT.

Increasing transmission power eventually overdrives the receiver. The electrical signal level corresponding to the optical "light-on" remains at the receiver output longer than the generating electrical signal at the transmitter's input. Since the signal IN1 is not symmetric, it is useful to synchronize the phase lock loop on one signal edge only. For this purpose, the light-on edge seems to be more stable. Depending on the physical circumstances (i.e., inverted or non-inverted receiver) either the positive or the negative edge can be used as the input signal of the DPLL.

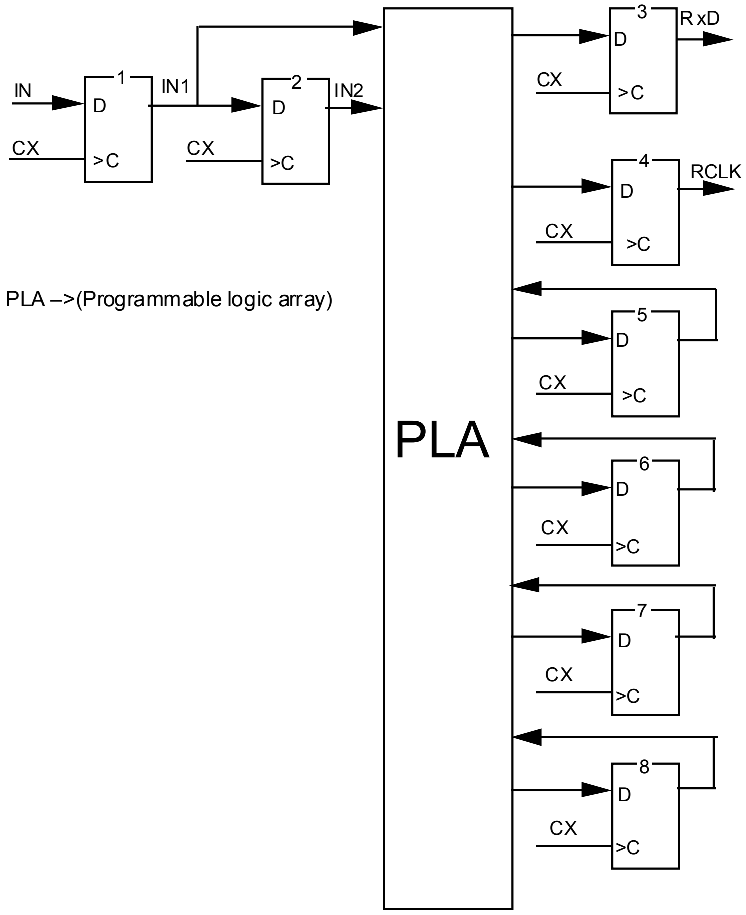
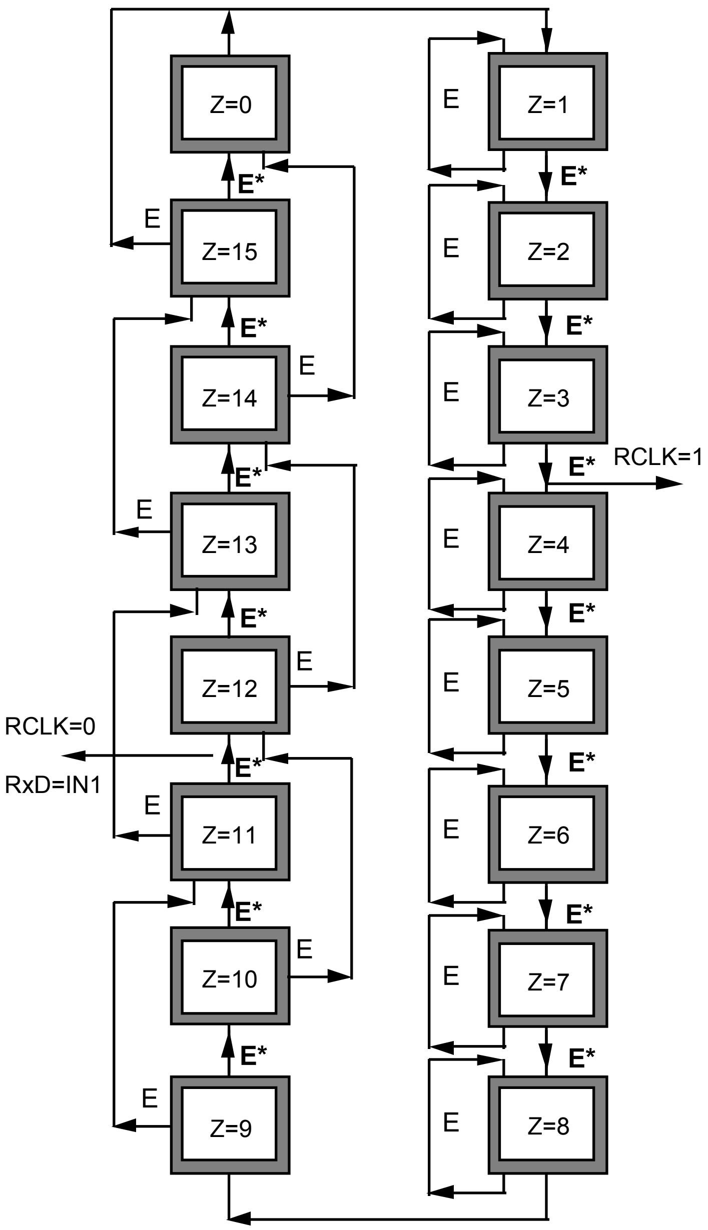


Figure P.1 — Example of an implemented DPLL



Key:

E = event that light-on edge is detected

E* = event that no light-on edge is detected.

Figure P.2 — DPLL status diagram

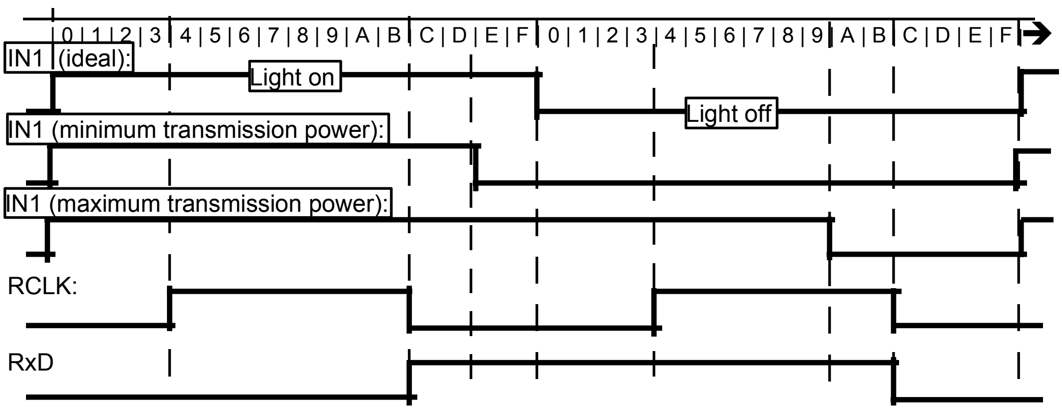


Figure P.3 — DPLL timing

P.2 Attenuation on the transmission line

This informative clause shows which factors contribute to the attenuation along the transmission line.

Two levels of maximum allowable attenuation along the line are specified. A transmitter can be switched to drive a transmission line with "low attenuation" or "high attenuation". This reduces the effects of the large attenuation range (0 dB to 7,4 dB).

The following factors contribute to attenuation:

- the fiber optic cable
- possible additional couplings (e.g. wall breakthroughs)

The additional variable couplings do not include inserted attenuation due to F-SMA plug connectors on the transmitter output and receiver input.

The transmission "low attenuation" should be selected for a short transmission line without additional couplings (e.g., 2 dB attenuation along the line) whereas "high attenuation" is selected for a long transmission line with additional couplings (e.g., 7 dB attenuation along the line). When designing the line, care shall be taken that the maximum attenuation along the line does not exceed the power levels as defined by high and low attenuation, i.e. the level of the transmission power shall eventually be adapted to the expected attenuation along the line.

Attenuation due to the couplings is often specified by technical data for the plugs. Attenuation due to the fiber optic cable cannot be determined so simply. The reason is that the specific attenuation of the fiber optic cable is not constant in the range of the specified wavelength range. For instance, a cable with a specified attenuation of 220 dB/km may in fact have this rating for only a narrow range of wavelengths, around 650 nm. This specific attenuation rating can easily increase to a value in excess of 350 dB/km (at wavelengths of approximately 635 nm and approximately 680 nm).

Consider that the wavelength radiated by the transmitting diode shifts to longer wavelengths at increasing temperatures (λp and $\Delta\lambda$ increase), significant portions of the emitted light become attenuated by the fiber optic cable.

In order to determine the exact attenuation due to the fiber optic cable, the product of attenuation and radiated light power has to be integrated over the wavelength.

A 30 m long fiber optic cable with a typical attenuation rating of 220 dB/km may have an attenuation interval of 6 dB to 9 dB over the entire temperature range of 0 °C to +55 °C (due to shifted wavelength).

Another uncertainty factor contributing to attenuation along the line is assembly. A cleanly mounted and polished plug has a very low inserted attenuation, compared to a poorly installed plug.

Annex Q
(normative)

Type 18: Connector specification

Q.1 Overview

Only Type 18-PhL-P defines specific connectors.

Q.2 Device connector

The required dimensions of the Type 18-PhL-P device connector are shown in Figure Q.1 for a right angle and Figure Q.2 for a straight board mount connector.

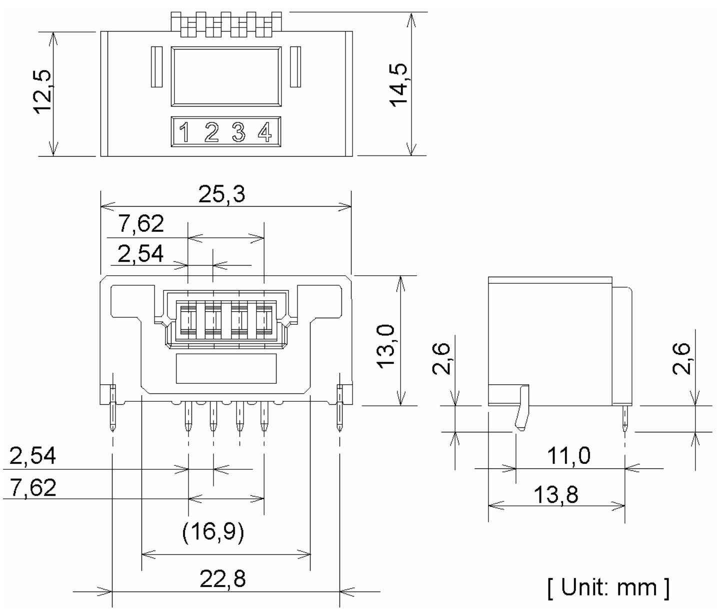


Figure Q.1 — PhL-P device connector r-a

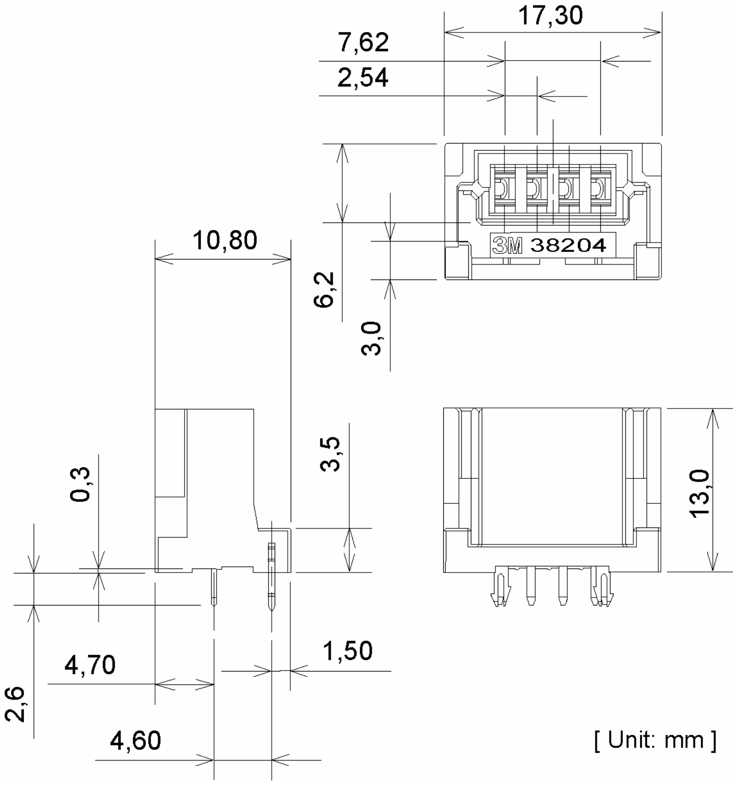


Figure Q.2 — PhL-P device connector straight

Q.3 Flat-cable connector

The required dimensions of the Type 18-PhL-P flat cable connector are shown in Figure Q.3 and Figure Q.4.

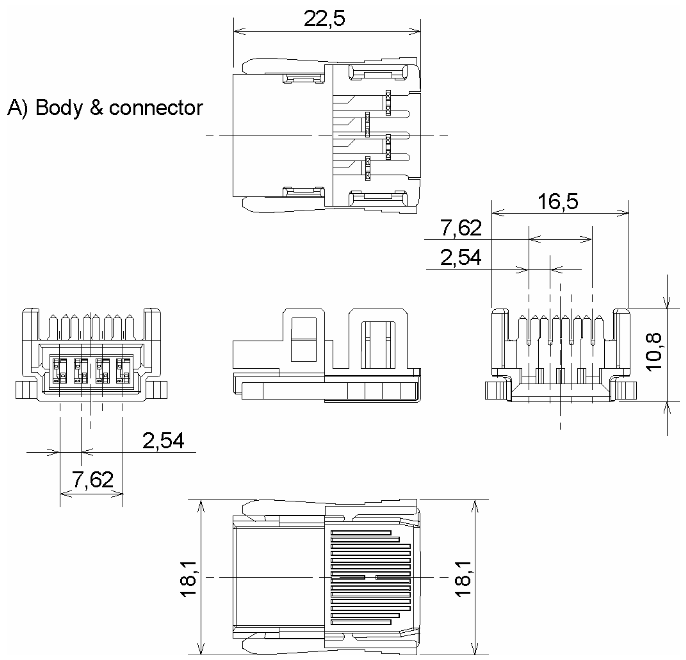


Figure Q.3 — PhL-P flat cable connector and terminal cover – body and connector

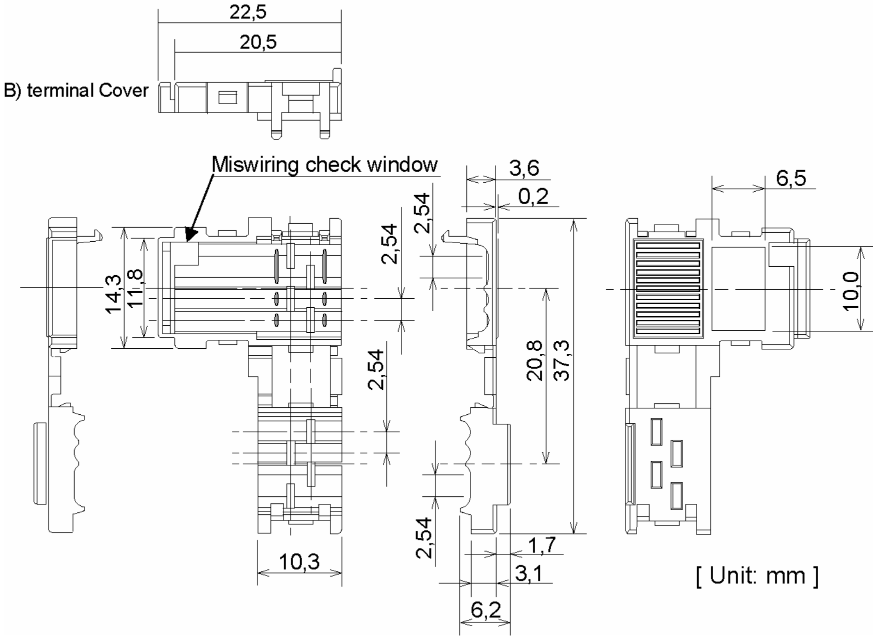


Figure Q.4 — PhL-P flat cable connector and terminal cover – terminal cover

Q.4 Round cable connector

The required dimensions of the Type 18-PhL-P round cable connector are shown in Figure Q.5 and Figure Q.6. This connector is applicable to both styles of Type 18-PhL-P round cable.

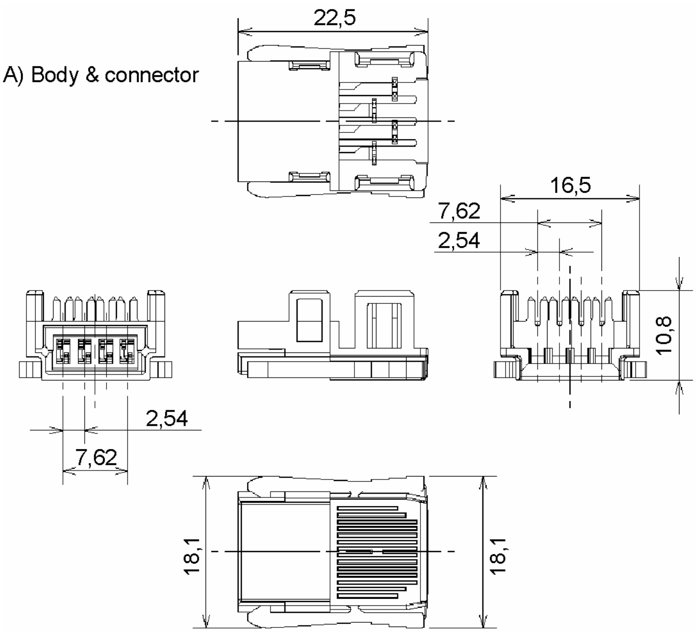


Figure Q.5 — Type 18-PhL-P round cable connector body

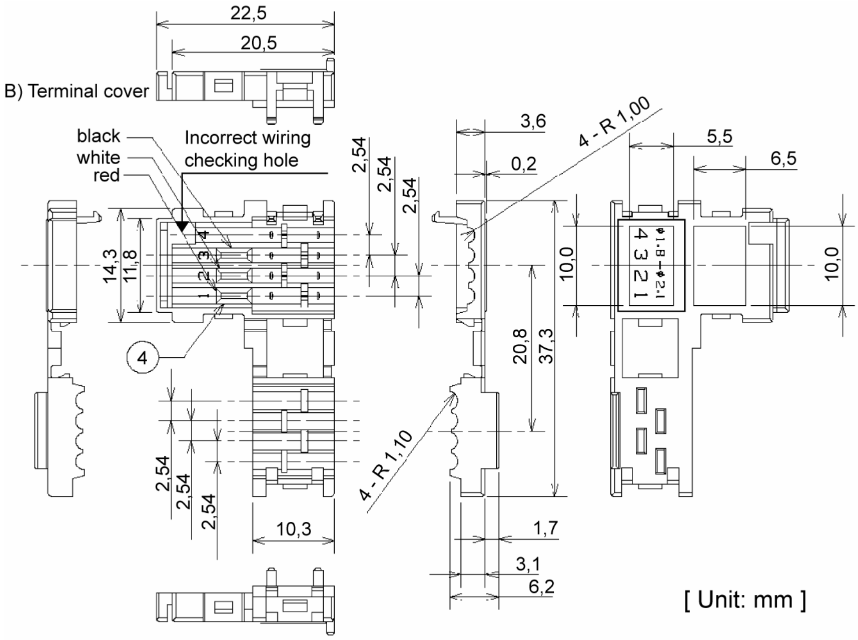


Figure Q.6 — Type 18-PhL-P round cable connector terminal cover

Q.5 Round cable alternate connector

The required dimensions of the Type 18-PhL-P round cable alternate connector is shown in Figure Q.7 and Figure Q.8.

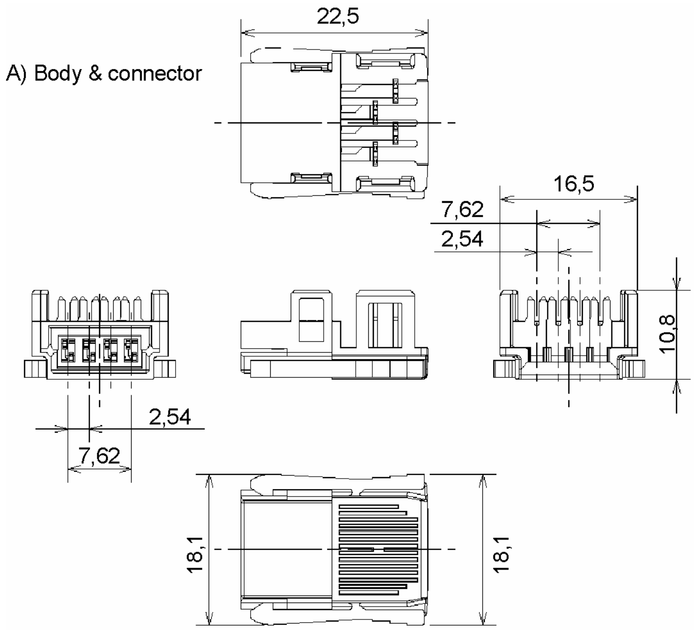


Figure Q.7 — Type 18-PhL-P round cable alternate connector and body

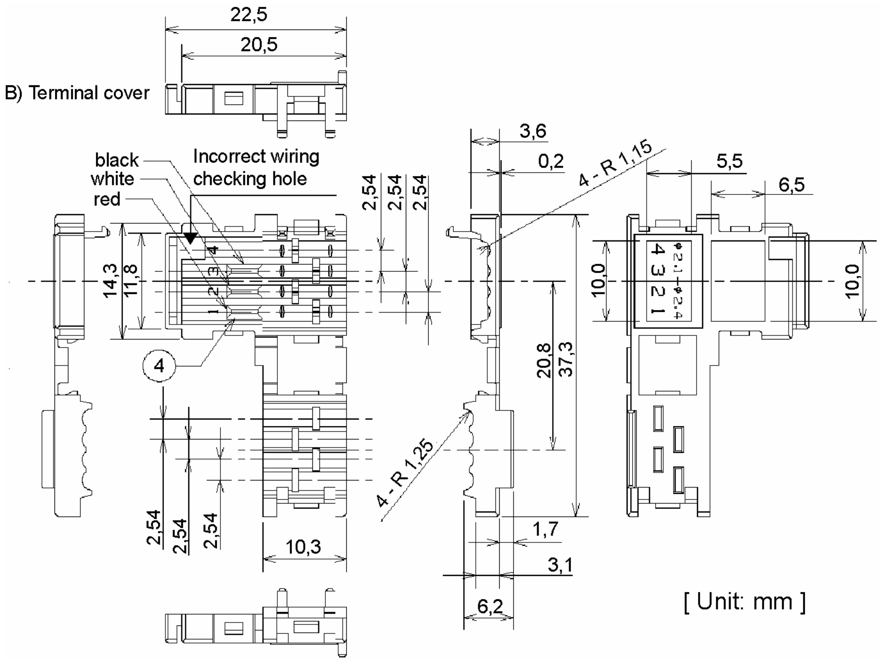


Figure Q.8 — Type 18-PhL-P round cable alternate connector terminal cover

Annex R
(normative)

Type 18: Media cable specifications

R.1 Type 18-PhL-B cable

The 3-core twisted-pair cable Type 18-PhL-B medium is specified in Table R.1.

Table R.1 — PhL-B cable specifications

Item		Specifications
Cable type		Shielded twisted cable
Outer diameter		8,0 mm or less
Number of cores		3
Conductor size		20 AWG
Insulation size		0,55 mm to 0,80 mm
Drain line		20 lines/0,18 mm or 24 lines/0,18 mm Insert separately or in a bundle between the ground cable bundle and aluminum tape.
Conductor resistance (20 ℃)		37,8 Ω/km or less
Insulation resistance		10 000 MΩ/km or more
Dielectric withstand voltage		500 VDC 1 min
Electrostatic capacity (1kHz)		60 nF/km or less
Impedance characteristic	1 MHz	110 ± 15 Ω
	5 MHz	110 ± 6 Ω
Attenuation (20 °C)	1 MHz	1,6 dB/100 m or less
	5 MHz	3,5 dB/100 m or less
Cross section	Twisted drain	See Figure R.1
	Non-twisted drain	See Figure R.2

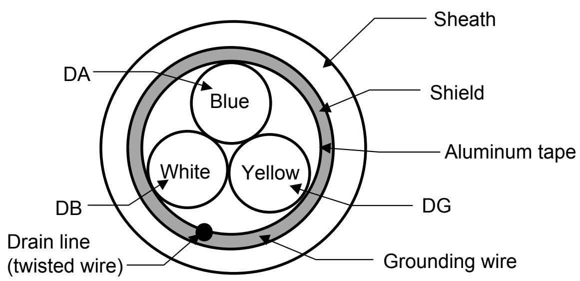


Figure R.1 — PhL-B cable cross section twisted drain

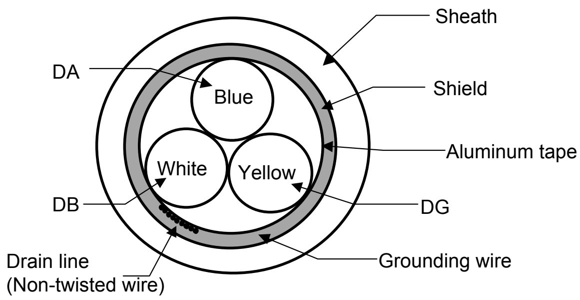


Figure R.2 — PhL-B cable cross section non-twisted drain

R.2 Type 18-PhL-P cable

R.2.1 Flat cable

The 4-core unshielded flat cable Type-18-PhL-P medium is specified in Table R.2.

Table R.2 — PhL-P flat cable specifications

Item		Unit	Specification	
Cable type		-	Flat cable	
Number of wire cores		-	4	
Conductor	Material	-	Tinned, annealed copper wire (collective twisting)	
	AWG	-	18	
	Construction	Lines/mm	43/0,16, 34/0,18, 30/0,18	
	Standard outline	mm	1,20 to 1,21	
	Pitch between twisted lines	mm	24,9 or less	
Insulating material	Material	-	Flexible resin	
	Standard thickness	mm	0,66 to 0,67	
	Outline (major axis × major axis)	mm	2,54 ± 0,15 × 10,16 ± 0,40	
	Line-to-line pitch	mm	2,54 ± 0,10	
Conductor resistance (at 20 ℃)		Ω/km	23,4 or less	
Insulation resistance (at 20 ℃)		MΩ/km	10 or more	
Withstand voltage		-	500 VAC, 1 min	
Characteristic impedance (reference value)		Ω	1 MHz	130 ± 25
			2 MHz	
Attenuation amount(reference value)		dB/100m	1 MHz	3,04 or less
			2 MHz	4,83 or less
Electrostatic capacity (reference value)		nF/km	1 kHz	55 or less
Cross section - with key (recommended)		–	See Figure R.3	
Cross section – without key		-	See Figure R.4	
Polarity marking		-	See Figure R.5	

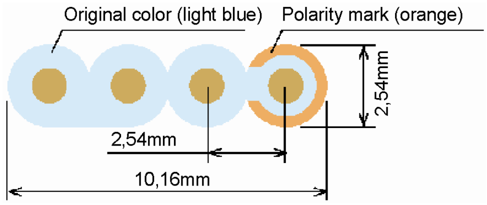


Figure R.3 — PhL-P flat cable cross section - with key

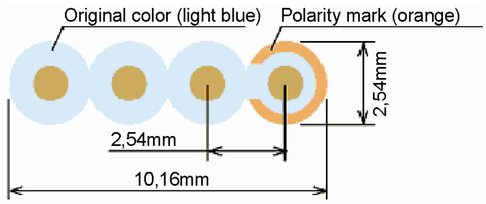


Figure R.4 — PhL-P flat cable cross section - without key

Figure R.5 — PhL-P flat cable polarity marking

R.2.2 Round cable - preferred

The preferred 4-core unshielded round cable for the Type-18-PhL-P medium is specified in Table R.3. This cable type is also known as VCTF cord and is compliant with IEC 60227-5.

Table R.3 — PhL-P round cable specifications - preferred

Item		Unit	Specification
Cable type		–	Polyvinyl chloride sheathed round cable
Number of wire cores		–	4
Conductor	Nominal cross-sectional area	mm^2	0,75
	Number of wires/diameter of a wire	wire/mm	30/0,18
	Outer diameter	mm	1,1
Insulator	Thickness	mm	0,6
	Outer diameter (approx.)	mm	2,3
Sheath	Thickness	mm	1,0
	Finish outer diameter (approx.)	mm	7,6
Conductor resistance (at 20 °C)		Ω/km	25,1
Cross-section		-	See Figure R.6

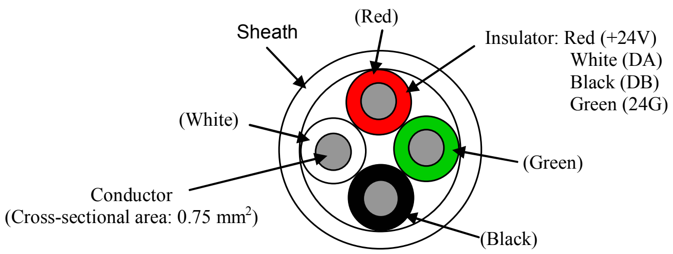


Figure R.6 — Round cable – preferred; cross section

R.2.3 Round cable - alternate

The alternate 4-core unshielded round cable for the Type-18-PhL-P medium is specified in Table R.4.

Table R.4 — PhL-P round cable specifications – alternate

Item		Unit	Specification	
Number of wire cores		-	4	
Conductor	Cross-sectional area	mm^2	0,75	
Insulator	Outer diameter	mm	1,8 to 2,4	
Conductor resistance (at 20 °C)		Ω/km	35 or less	
Conductor resistance (at 20 °C) (reference value)		MΩ/km	5 or more	
Withstand voltage (reference value)		-	500 VAC, 1min	
Characteristic impedance (reference value)		Ω	1 MHz	90 ± 30
			2 MHz	
Drop in decibel level (reference value)		db/100 m	1 MHz	4 or less
			2 MHz	5 or less
Electric capacity (reference value)		nF/km	1 MHz	100 or less
Cross section		-	See Figure R.7	

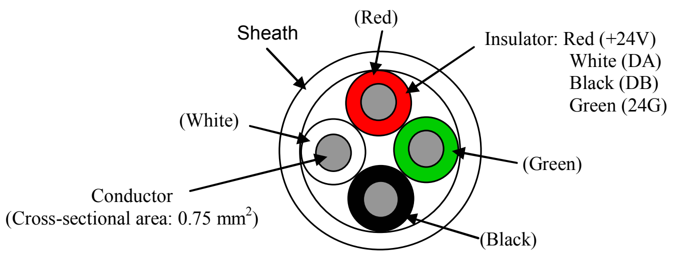


Figure R.7 — Round cable – alternate; cross-section

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NOTE A listing of relevant documents from consortia associated with some of the IEC 61158 series of fieldbus standards can be found in the bibliography of IEC/TR 61158-1.

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