INTERNATIONAL STANDARD

IEC 61158-2

Third edition
2003-05

Digital data communications for measurement and control – Fieldbus for use in industrial control systems –

Part 2: Physical layer specification and service definition

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CONTENTS

IECNORM.COM : Click to view the full PDF of IEC 61158-2:2003
Withdrawn

IECNORM.COM : Click to view the full PDF of IEC 61158-2:2003
Withdrawn

IECNORM.COM : Click to view the full PDF of IEC 61158-2:2003
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DIGITAL DATA COMMUNICATIONS FOR MEASUREMENT AND CONTROL – FIELDBUS FOR USE IN INDUSTRIAL CONTROL SYSTEMS –

Part 2: Physical Layer specification and service definition

FOREWORD

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5,396,197 [AB] Network Node TAP

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

The third edition cancels and replaces the second edition published in 2000 and its amendment. This third edition constitutes a technical revision.

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

FDIS	Report on voting
65C/289/FDIS	65C/297/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 edition includes the following significant changes from the prior edition:

a) specifications for Types 2, 4, 6 and 8 fieldbusses;
b) specifications for asynchronous operation of Type 3 fieldbusses;
c) specifications for increased data rates for Types 1 and 7 fieldbusses;
d) reorganisation and consolidation of Clauses 11 and following of the prior editions
   – to coalesce those common clauses or subclauses whose primary difference was due to data rate, and
   – to eliminate redundant figures and tables from within the clauses.

The following table attempts to correlate the content of the clauses of Edition 1 and its amendments, and of Edition 2 and its amendment, with the clauses and subclauses of this edition:

Edition 1 and amendments	Edition 2	Edition 3
1	1	1
2	2	2
3	3	3.1, 3.2
4	4	4.1.1, 4.2.1, 4.2.2
5	5	5.1, 5.2
6	6	6.1, 6.2
7	7	7.1, 7.2
8	8	8.1, 8.2
9	9	9.1, 9.2
10	10	10.1, 10.2
11	11	21
12	12	11
13	13	13
14	14	11
Amendment 3: 15	15	16
Amendment 3: 16	16	15
Amendment 3: 17	17	15
Amendment 3: 18	18	15
Amendment 1: 18	19	9.3
Amendment 1: 19	20	10.3
Amendment 1: 20	21	17
Amendment 2: 21	23	14
Amendment 4: 22	22	12
Annex A: Bibliography	Bibliography	Bibliography
Annex B	Annex A	Annex A
Annex C	Annex B	Annex B
–	Annex C	Annex B
Amendment 3: Annex D	Annex D	Annex C
Amendment 3: Annex E	Annex E	Annex D
Amendment 3: Annex F	Annex F	Annex E

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

The committee has decided that the contents of this publication will remain unchanged until 2007. At this date, the publication will be

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

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IEC 61158 consists of the following parts, under the general title *Digital data communications for measurement and control – Fieldbus for use in industrial control systems*:

Part 1: *Overview and guidance for the IEC 61158 series*

Part 2: *Physical Layer specification and service definition*

Part 3: *Data Link Service definition*

Part 4: *Data Link Protocol specification*

Part 5: *Application Layer Service definition*

Part 6: *Application Layer protocol specification*

The contents of the corrigendum of July 2004 have been included in this copy.

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0 Introduction

0.1 General

This part of IEC 61158 is one of a series produced to facilitate the interconnection of automation system components by fieldbus networks. It is related to other parts in the set as defined by the fieldbus Reference Model, which is based in principle on the Reference Model for Open Systems Interconnection. Both Reference Models subdivide the area of standardization for interconnection into a series of layers of specification, each of manageable size.

0.2 Fieldbus overview

A fieldbus is a digital, serial, multidrop, data bus for communication with industrial control and instrumentation devices such as -– but not limited to - transducers, actuators and local controllers. The Physical Layer specified in this International Standard provides for transparent transmission of data units between Data Link Layer entities across physical connections. The PhL provides services used by Data Link Protocol and Systems Management. The relationship between the fieldbus Data Link Layer standard, fieldbus Physical Service standard and Systems Management application is illustrated in Figure 1.

NOTE Systems Management, as used in this standard, is a local mechanism for managing the layer protocols.

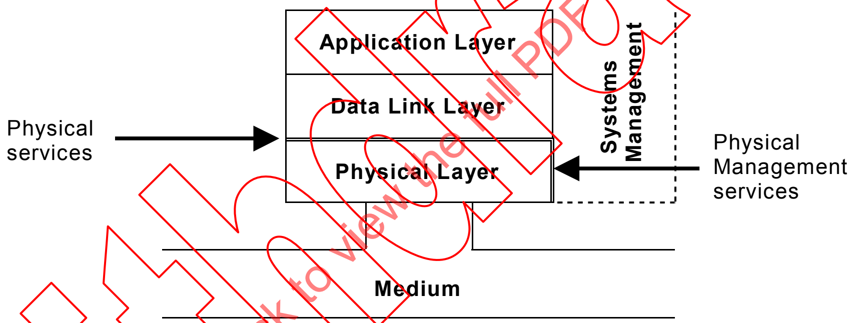

Figure 1 – Relationship of IEC 61158-2 to other fieldbus layers and to users of the fieldbus Physical layer service

0.3 Physical Layer overview

The primary aim of this International 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.

0.4 Document overview

This International Standard comprises Physical Layer specifications corresponding to the different DL-Layer protocol types specified in IEC 61158-4.

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NOTE 1 The protocol type numbers used are consistent throughout the IEC 61158 parts.

NOTE 2 Specifications for Types 1, 2, 3, 4, 6 and 8 are included. Type 5 does not use any of the specifications given in this standard. Type 7 uses Type 1 specifications.

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 International Standard to select for interworking sets of provisions. Refer to IEC 61784 for standardized communication profiles based on IEC 61158.

A general model of the Physical Layer is shown in Figure 2.

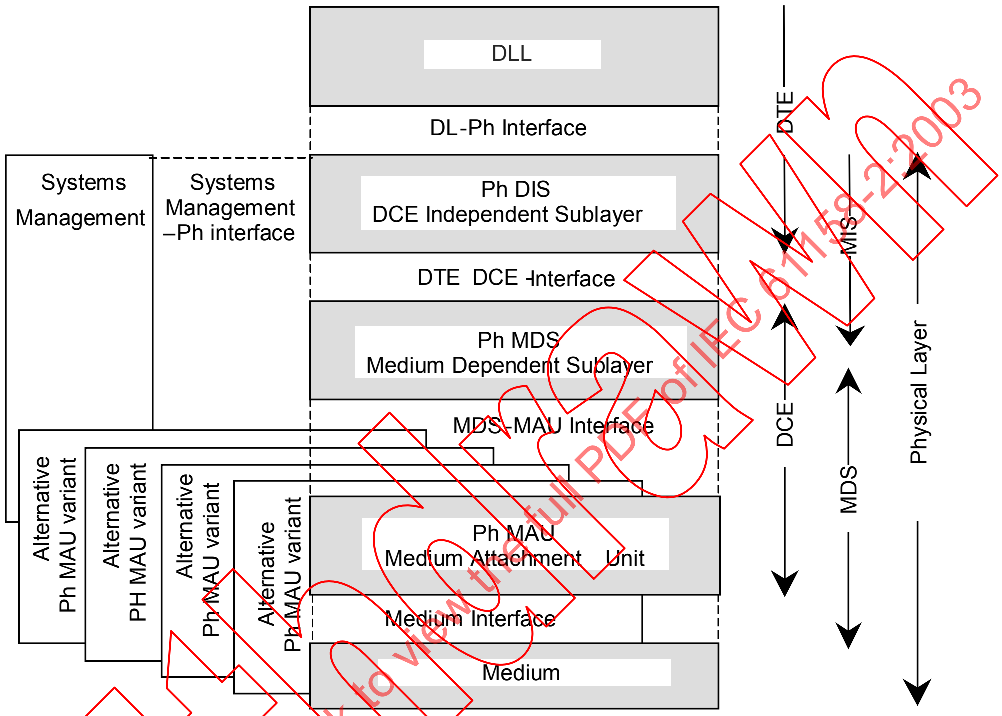

Figure 2 – General model of Physical Layer

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

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0.5 Major Physical Layer variations specified in this part of IEC 61158

0.5.1 Type 1 media

0.5.1.1 Type 1: twisted-pair wire, optical and radio media

For twisted-pair wire media, Type 1 specifies two modes of coupling and different signalling 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 part of IEC 61158 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.

0.5.1.2 Type 1: optical media

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

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

0.5.1.3 Type 1: radio media

The Type 1 radio medium specification provides a 4,8 kbit/s bit rate.

0.5.2 Type 2: coaxial wire and optical media

Type 2 specifies the following variants:

– coaxial copper wire medium, 5 Mbit/s
– optical fibre 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.

0.5.3 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 fibre medium, up to 12 Mbit/s

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0.5.4 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

0.5.5 Type 6: wire medium

Type 6 specifies wire media with the following characteristics:

– RS 485 wire medium up to 5 Mbit/s

The characteristics for wire media are as follows:

– half-duplex communication (bi-directional but in only one direction at a time)
– Manchester coding

0.5.6 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 fibre 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

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DIGITAL DATA COMMUNICATIONS FOR MEASUREMENT AND CONTROL – FIELDBUS FOR USE IN INDUSTRIAL CONTROL SYSTEMS –

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 .

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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(131):1978, *International Electrotechnical Vocabulary (IEV) – Chapter 131: Electric and magnetic circuits*

IEC 60050-731:1991, *International Electrotechnical Vocabulary, Chapter 731: optical fibre communication*

IEC 60079, *Electrical apparatus for explosive gas atmospheres*

IEC 60079-11, *Electrical apparatus for explosive gas atmospheres – Part 11: Intrinsic safety "i"*

IEC 60079-27, *Electrical apparatus for explosive gas atmospheres – Part 27: Fieldbus intrinsically safe concept (FISCO)*

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

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

IEC 60364-4-41, *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 and protective conductors*

IEC 60529:1989, *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 60793-2:2001, *Optical fibres – Part 2: Product specifications*

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, *Connectors for optical fibres and cables*

IEC 60874-2, *Connectors for optical fibres and cables — Part 2: Sectional specification for fibre optic connector – Type F-SMA*

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Withdrawn

IEC 60874-7, *Connectors for optical fibres and cables — Part 7: Sectional specification for fibre optic connector - Type FC*

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

IEC 60947-5-2, *Low-voltage switchgear and controlgear – Part 5-2: Control circuit devices and switching elements – Proximity switches*

IEC 61000-4, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques*

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

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

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

IEC 61131-2:1992, *Programmable controllers – Part 2: Equipment requirements and tests*

IEC 61156-1:1994, *Multicore and symmetrical pair/quad cables for digital communications – Part 1: Generic specification*

IEC 61158, *Digital data communications for measurement and control – Fieldbus for use in industrial control systems*

IEC 61158-3:2003, Digital data communications for measurement and control – Fieldbus for use in industrial control systems — Part 3: Data Link Service definition

IEC 61158-4:2003, Digital data communications for measurement and control – Fieldbus for use in industrial control systems — Part 4: Data Link protocol specification

IEC 61300-34:2001, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-4: Examinations and measurements – Attenuation*

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

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

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*

IEEE Std 100:1996, *The IEEE Standard Dictionary of Electrical and Electronics Terms*

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Withdrawn

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 bus

trunk and all devices connected to it

3.1.4 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

3.1.5 communication element

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

3.1.6 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]

3.1.7 coupler

physical interface between trunk and spur or trunk and device

3.1.8 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

3.1.9 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

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3.1.10 decibel(milliwatt) [dB(mW)]

a 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.

3.1.11 delimiter

flag that separates and organizes items of data

3.1.12 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.

3.1.13 effective launch power

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

3.1.14 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.

3.1.15 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.

3.1.16 fibre optic cable

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

3.1.17 fibre optic receiver

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

3.1.18 fibre 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

3.1.19 fibre optic transmitter

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

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3.1.20 fibre optic waveguide

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

3.1.21 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]

3.1.22 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]

3.1.23 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]

3.1.24 jabber

continuous transmission on the medium due to a faulty device

3.1.25 jitter

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

3.1.26 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

3.1.27 medium

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

NOTE In this part of IEC 61158 "media" is used only as the plural of medium.

3.1.28 network

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

3.1.29 node

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

3.1.30 optical active star

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

3.1.31 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

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3.1.32 optical passive star

passive device in which signals from input fibres are combined and then distributed among output optical fibres

3.1.33 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

3.1.34 peak emission wavelength (λp)

wavelength at which radiant intensity is maximized

3.1.35 receiver

receive circuitry of a communication element

3.1.36 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

3.1.37 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

3.1.38 separately powered device

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

3.1.39 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.

3.1.40 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 part of IEC 61158.

3.1.41 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 plug.

3.1.42 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.

3.1.43 transmitter

transmit circuitry of a communication element

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3.1.44 trunk

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

3.1.45 typical half-intensity wavelength (Δλ)

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 3.1.3]

3.2.4 cable plant interface connector (CPIC) [see 3.1.4]

3.2.5 communication element [see 3.1.5]

3.2.6 connector [see 3.1.6]

3.2.7 coupler [see 3.1.7]

3.2.8 Data Communications Equipment (DCE) [see 3.1.8]

3.2.9 Data Terminal Equipment (DTE) [see 3.1.9]

3.2.10 dBm [see 3.1.10]

3.2.11 delimiter [see 3.1.11]

3.2.12 device [see 3.1.12]

3.2.13 effective launch power [see 3.1.13]

3.2.14 effective power [see 3.1.14]

3.2.15 fibre optic cable [see 3.1.15]

3.2.16 fibre optic receiver [see 3.1.17]

3.2.17 fibre optic receiver operating range [see 3.1.18]

3.2.18 fibre optic transmitter [see 3.1.19]

3.2.19 fibre optic waveguide [see 3.1.20]

3.2.20 frame [see 3.1.21]

3.2.21 Gaussian Minimum Shift Keying

form of frequency modulation where a 1 is represented by a frequency of $Fc+f$ and a 0 is represented by $Fc-f$ 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

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3.2.22 Intrinsic Safety [see 3.1.22]

3.2.23 isolation [see 3.1.23]

3.2.24 jabber [see 3.1.24]

3.2.25 low speed radio medium fieldbus

fieldbus physical layer covered by this standard operating at the lower of the standard bit rates as defined in 21.2

3.2.26 Manchester encoding [see 3.1.25]

3.2.27 medium [see 3.1.27]

3.2.28 network [see 3.1.28]

3.2.29 node [see 3.1.29]

3.2.30 optical fall time [see 3.1.30]

3.2.31 optical rise time [see 3.1.32]

3.2.32 peak emission wavelength (λp) [see 3.1.34]

3.2.33 repeater [see 3.1.36]

3.2.34 segment [see 3.1.37]

3.2.35 separately powered device [see 3.1.38]

3.2.36 shield [see 3.1.39]

3.2.37 spur [see 3.1.40]

3.2.38 terminator [see 3.1.41]

3.2.39 transceiver [see 3.1.41]

3.2.40 transmitter [see 3.1.43]

3.2.41 trunk [see 3.1.44]

3.3 Type 2: Terms and definitions

3.3.1 activity [see 3.1.1]

3.3.2 bit

unit of data consisting of a 1 or a 0

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

3.3.3 blanking or blanking time

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

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3.3.4 bus [see 3.1.3]

3.3.5 communication element [see 3.1.5]

3.3.6 connector [see 3.1.6]

3.3.7 Data Communications Equipment (DCE) [see 3.1.8]

3.3.8 dBm [see 3.1.10]

3.3.9 delimiter [see 3.1.11]

3.3.10 device [see 3.1.12]

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

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

3.3.14 frame [see 3.1.21]

3.3.15 isolation [see 3.1.23]

3.3.16 jabber [see 3.1.24]

3.3.17 Manchester encoding [see 3.1.25]

3.3.18 medium [see 3.1.27]

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 3.1.28]

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 3.1.29]

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

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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 3.1.36]

3.3.29 segment [see 3.1.37]

3.3.30 shield [see 3.1.39]

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 3.1.40]

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 3.1.41]

3.3.36 tool

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

3.3.37 transceiver [see 3.1.41]

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 3.1.43]

3.3.40 trunk [see 3.1.44]

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

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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 3.1.3]

3.4.5 communication element [see 3.1.5]

3.4.6 confirmation (primitive) [ISO/IEC 10731]

3.4.7 connector [see 3.1.6]

3.4.8 coupler [see 3.1.7]

3.4.9 Data Communications Equipment (DCE) [see 3.1.8]

3.4.10 Data Terminal Equipment (DTE) [see 3.1.9]

3.4.11 dBm [see 3.1.10]

3.4.12 device [see 3.1.12]

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

3.4.14 fibre optic cable (FOC) [see 3.1.15]

3.4.15 frame [see 3.1.21]

3.4.16 indication (primitive) [ISO/IEC 10731]

3.4.17 Intrinsic Safety [see 3.1.22]

3.4.18 isolation [see 3.1.23]

3.4.19 jabber [see 3.1.24]

3.4.20 medium [see 3.1.27]

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

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

3.4.23 network [see 3.1.28]

3.4.24 node [see 3.1.29]

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

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

3.4.27 repeater [see 3.1.36]

3.4.28 request (primitive) [ISO/IEC 10731]

3.4.29 reset [ISO/IEC 7498-1]

3.4.30 segment [see 3.1.37]

3.4.31 separately powered device [see 3.1.38]

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3.4.32 shield [see 3.1.39]

3.4.33 spur [see 3.1.40]

3.4.34 station

node

3.4.35 terminator [see 3.1.41]

3.4.36 transceiver [see 3.1.41]

3.4.37 transmitter [see 3.1.43]

3.4.38 trunk [see 3.1.44]

3.5 Type 4: Terms and definitions

3.5.1 activity [see 3.1.1]

3.5.2 bus [see 3.1.3]

3.5.3 connector [see 3.1.6]

3.5.4 Data Communications Equipment (DCE) [see 3.1.8]

3.5.5 Data Terminal Equipment (DTE) [see 3.1.9]

3.5.6 device [see 3.1.12]

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 3.1.23]

3.5.9 medium [see 3.1.27]

3.5.10 network [see 3.1.28]

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 3.1.39]

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 3.1.43]

3.6 Type 6: Terms and definitions

3.6.1 activity [see 3.1.1]

3.6.2 bus

one or more connected (by repeaters) Ph-segments

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3.6.3 communication element [see 3.1.5]

3.6.4 connector [see 3.1.6]

3.6.5 delimiter [see 3.1.11]

3.6.6 device

physical entity connected to the fieldbus composed of communication element and possibly other functional elements

3.6.7 frame [see 3.1.21]

3.6.8 isolation [see 3.1.23]

3.6.9 Manchester encoding [see 3.1.25]

3.6.10 medium [see 3.1.27]

3.6.11 Ph-segment

trunk–cable section of a fieldbus that is terminated in its characteristic impedance, together with all stubs and connected devices

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

3.6.12 receiver [see 3.1.35]

3.6.13 repeater [see 3.1.36]

3.6.14 shield [see 3.1.39]

3.6.15 slot

a PhPDU and its associated Interframe Gap

3.6.16 stub

a short length of cable connecting a node to a segment

3.6.17 terminator [see 3.1.41]

3.6.18 transceiver [see 3.1.41]

3.6.19 transmitter [see 3.1.43]

3.6.20 trunk cable

cable used to connect devices on a Ph-segment of the fieldbus

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 3.1.4]

3.7.4 communication element [see 3.1.5]

3.7.5 connector [see 3.1.6]

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3.7.6 dBm [see 3.1.10]

3.7.7 effective launch power [see 3.1.13]

3.7.8 effective power [see 3.1.14]

3.7.9 fibre optic cable [see 3.1.15]

3.7.10 fibre optic receiver [see 3.1.17]

3.7.11 fibre optic receiver operating range [see 3.1.18]

3.7.12 fibre optic transmitter [see 3.1.19]

3.7.13 fibre optic waveguide [see 3.1.20]

3.7.14 frame [see 3.1.21]

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 3.1.23]

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 3.1.27]

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 3.1.28]

3.7.23 optical fall time [see 3.1.30]

3.7.24 optical rise time [see 3.1.32]

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 3.1.34]

3.7.27 polymer optical fibre (POF)

plastic fibre optic waveguide whose nominal characteristics are compatible with IEC 60793-2 [fibre type: A4a (980/1000)]

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3.7.28 plastic clad silica fibre (PCS)

fibre optic waveguide consisting of a glass core and a plastic cladding and whose nominal characteristics are compatible with IEC 60793-2 [fibre type: A3c (200/230)]

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 3.1.39]

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 3.1.41]

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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	Centre 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

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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 centre 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
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	pulldown resistor	Ω
R_t	Bus terminator	Ω
R_u	pullup 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

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Symbol	Definition	Unit
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: Symbols

Symbol	Definition	Unit
0	Manchester coded signal with a LO-HI transition at the middle of the bit cell	–
1	Manchester coded signal with a HI-LO transition at the middle of the bit cell	–
HI	differential bus signal level with Rx/ TxData-P positive with respect to Rx/ TxData-N	V
LO	differential bus signal level with Rx/ TxData-P negative with respect to Rx/ TxData-N	V
N+	Non-data symbol – positive; Manchester coded signal with a high level for one bit time, used for delimiters	–
N–	Non-data symbol – negative; Manchester coded signal with a low level for one bit time, used for delimiters	–
SILENCE	differential bus signal level with Rx/ TxData-P positive with respect to Rx/ TxData-N	V

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
V_{DD}	The most positive (or least negative) supply level	V
GND	Ground supply 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) – approximately Layer 2 of the OSI model [ISO/IEC 7498-1]
DLE	Data Link Entity

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DLL	Data Link Layer [ISO/IEC 7498-1]
DTE	Data Terminal Equipment
EMI	Electro-Magnetic Interference
ERP	Effective Radiated Power
FEC	Forward Error Correction
GMSK	Gaussian Minimum Shift Keying
IDU	Interface Data Unit [ISO/IEC 7498-1]
IS	Intrinsic Safety
kbit/s	Thousand bits per second
LbE	Loopback Enable signal (to MAU)
MAU	Medium Attachment Unit – For wire media, MAU = transceiver
Mbit/s	Million bits per second
MDS	Medium Dependent Sublayer
MIS	Media Independent Sublayer
NRZ	Non-return-to-zero code – High level = logic 1, Low level = logic 0
Ph	Physical (as a prefix) – Approximately Layer 1 of the OSI model [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
RMCF	Radio Medium dependent sublayer Code Frame
RPhPDU	Radio Physical Layer Protocol Data Units
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 N-series Coaxial connector – 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

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DCE	Data Communication Equipment
DL	Data Link (as a prefix) – approximately Layer 2 of the OSI model [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
Mbit/s	Million bits per second
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 61158-3]
Ph	Physical (as a prefix) – Approximately Layer 1 of the OSI model [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 61158-3]
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

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EMC	Electro-Magnetic-Compatibility
EMI	Electro-Magnetic Interference
FEC	Forward Error Correction
FISCO	Fieldbus Intrinsically Safe COncept [7]
FO	Fibre optic
FOC	Fibre optic cable
IS	Intrinsic Safety
kbit/s	Thousand bits per second
LbE	Loopback Enable signal (to MAU)
LSS	Line Selector Switch
M/S	Master / Slave station
MAU	Medium Attachment Unit – For wire media, MAU = transceiver
Mbit/s	Million bits per second
MDS	Medium Dependent Sublayer
MIS	Media Independent Sublayer
n	Number of a station
NRZ	Non-return-to-zero code – High level = logic 1, Low level = logic 0
OST	Overshot of transition
PC	Physical Contact
Ph	Physical (as a prefix)
Ph-ASYN-DATA	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 like M/S
TPC	Twisted-pair Cable
TxC	Transmit Clock signal (from DCE)
TxD	Transmit Data signal (to DCE)

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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) – approximately Layer 2 of the OSI model	[ISO/IEC 7498-1]
DLE	Data Link Entity	
DLL	Data Link Layer	[ISO/IEC 7498-1]
DTE	Data Terminal Equipment	
kbit/s	Thousand bits per second	
MAU	Medium Attachment Unit – For wire media, MAU = transceiver	
MDS	Medium Dependent Sublayer	
MIS	Media Independent Sublayer	
NRZ	Non-return-to-zero code – High level = logic 1, Low level = logic 0	
Ph	Physical (as a prefix) – Approximately Layer 1 of the OSI model	[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: Abbreviations

BSD	Bus-sync delimiter
Control-	Control negative - connector pin provided for repeater control
Control+	Control positive - connector pin provided for repeater control
DGND	Data ground - connector pin connected to ANSI TIA/EIA-485-A C/C'
DIS	Device independent sublayer
DLE	Data Link entity
DLL	Data Link layer
ED	End of data delimiter
ETF	End transfer frame delimiter
ExV	Excitation voltage - connector pin supplying terminator excitation voltage
MAC	Medium access control
MAU	Medium access unit
MDS	Medium dependent sublayer
MIS	Media Independent Sublayer
PAD	PAD idle sequence
PhE	Ph entity
PhICI	Ph interface control information
PhID	Ph interface data

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PhIDU	Ph interface data unit
PhL	Physical layer
PhPDU	Ph protocol data unit
PhS	Ph service
PhSDU	Ph service data unit
PRE	Preamble
Pwr-	Power Negative - connector pin supplying 24 V power negative
Pwr+	Power Positive - connector pin supplying 24 V power positive
Rx/ TxData-N	Receive/ Transmit Data Negative - connector pin connected to ANSI TIA/EIA-485-A A/A'
Rx/ TxData-P	Receive/ Transmit Data Positive - connector pin connected to ANSI TIA/EIA-485-A B/B''
ST	Start delimiter
SYN	the Strobe signal for bus synchronization by each node's DLE
TR	the Strobe signal for Data-Strobe by each node's DLE

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) – approximately Layer 2 of the OSI model	[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	
kbit/s	Thousand bits per second	
LbE	Loopback Enable	
LSB	Least Significant Byte	
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 Fibre	
Ph	Physical (as a prefix) – Approximately Layer 1 of the OSI model	[ISO/IEC 7498-1]
PhE	Physical Layer Entity	[ISO/IEC 7498-1]
PhICI	Physical Interface Control Information	

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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 Fibre
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

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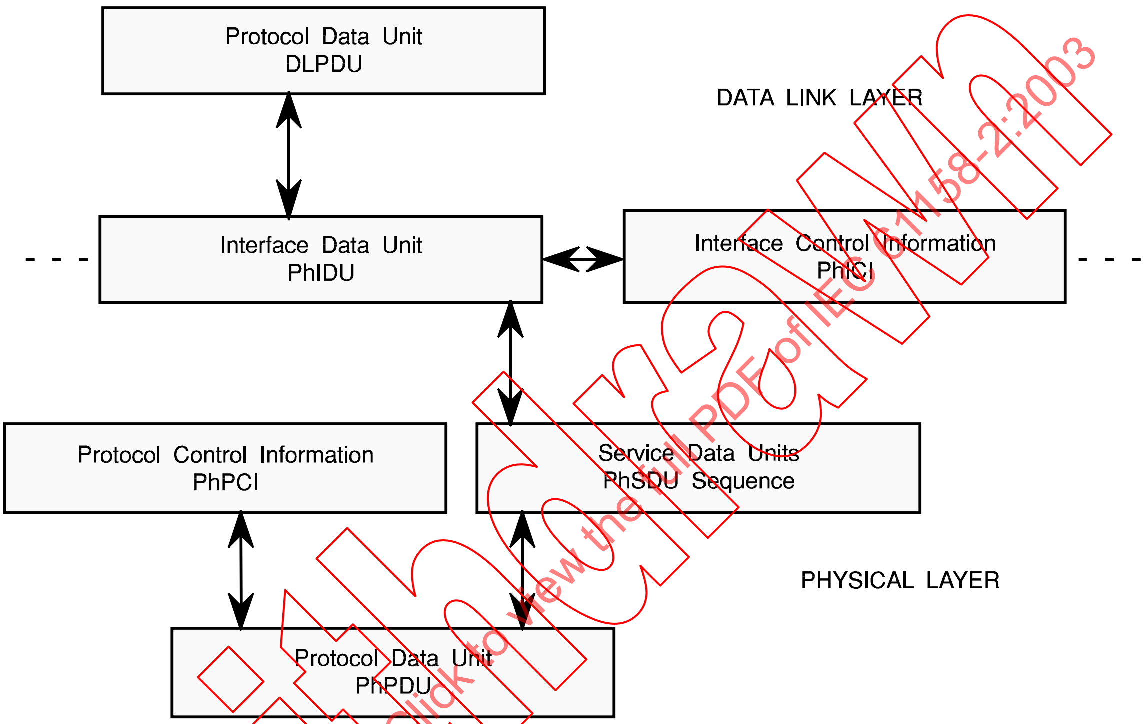
5 DLL – PhL interface

5.1 General

Clause 5 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 3.



NOTE PhPCI and PhICI support are type specific.

Figure 3 – Mapping between data units across the DLL – PhL interface

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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/second, 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 0,9999 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.

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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.

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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.

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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 1024 bytes (8192 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 2048 bytes (16384 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).

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”	≥ 1024 bytes
true	false = “REPEATER”	≥ 2048 bytes
false	true = “NODE”	< 1024 bytes
false	false = “REPEATER”	< 2048 bytes

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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 4.

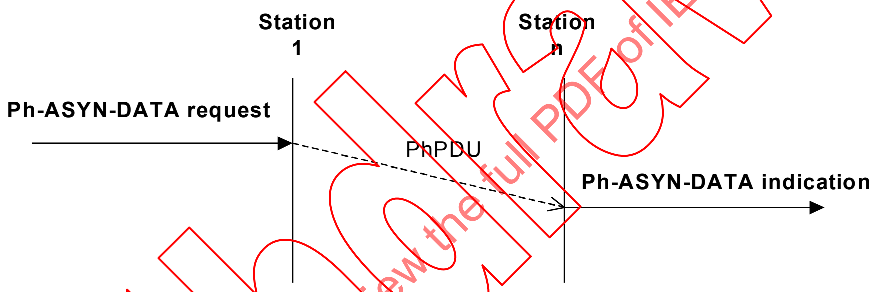

Figure 4 – Data service for asynchronous transmission

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.

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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.

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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.

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5.6 Type 6: Required services

5.6.1 Primitives of the PhS

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

5.6.1.1 Ph-CHARACTERISTICS indication

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

Ph-CHARACTERISTICS indication (minimum-data-rate)

where

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

NOTE A PhE with a nominal data rate of 1 Mbit/s ± 0,01% would specify a minimum data rate of 0,9999 Mbit/s.

5.6.1.2 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 SILENCE, as specified in bit periods by InterFrameGap, followed by the Ph symbols of the PhPDU 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;

END-OF-DATA-AND-TRANSFER – the Ph symbols which terminate Ph-user data, with the last delimiter being ETF, shall be transmitted after the last preceding octet of Ph-user data, culminating in the cessation of active transmission; and

END-OF-DATA-AND-SYNC – the Ph symbols that terminate Ph-user data, including the specified octets of PAD, with the last delimiter being BSD, shall be transmitted after the last preceding octet of Ph-user data, culminating in the cessation of active transmission.

NOTE 1 PAD defines the length in octets of the PAD sequence transmitted following the ED delimiter of the PhPDU.

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

START-OF-ACTIVITY – reception of the ST delimiter of an apparent transmission from one or more PhEs has occurred;

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 the ED delimiter;

NOTE 2 Correctly formed data is received in 8 bit multiples and with no sync slip errors or invalid Manchester codes.

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

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END-OF-TRANSFER – occurrence of END-OF-DATA followed by reception of the ETF delimiter - this indication shall be concurrent with the end of the ETF delimiter shown as TR in Figure 45;

END-OF-SYNC – occurrence of END-OF-DATA followed by reception of the BSD delimiter - this indication shall be concurrent with the end of the BSD delimiter shown as SYN in Figure 45.

END-OF-TRANSFER-AND-ACTIVITY – simultaneous occurrence of END-OF-TRANSFER and END-OF-ACTIVITY - this indication shall be concurrent with the end of the ETF delimiter shown as TR in Figure 45;

END-OF-SYNC-AND-ACTIVITY – simultaneous occurrence of END-OF-SYNC and END-OF-ACTIVITY - this indication shall be concurrent with the end of the BSD delimiter shown as SYN in Figure 45.

data – shall specify the PhID component of the PhIDU. It consists of either:

a) one octet of Ph-user-data to be transmitted (PH-DATA request) or

b) one octet of Ph-user-data which was received successfully (PH-DATA indication) or

c) null if no Ph-user-data was transmitted or received.

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

5.6.2 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 startup.

5.6.3 Transmission of Ph-user-data

The DLL (MAC) shall determine the timing of all transmissions.

When a DLE (MAC) transmits a sequence of PhSDUs, the DLE shall send the sequence of PhSDUs by making a single request specifying START-OF-ACTIVITY, followed by well-formed sequence of 2 to 50 consecutive PH-DATA requests, inclusive, specifying DATA, each conveying a PhSDU, and concluded by a single request specifying END-OF-DATA-AND-TRANSFER or END-OF-DATA-AND-SYNC.

The PhE shall signal its completion of each 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.

During the period from the end of transmission of a PhPDU until another PH-DATA request is received from the DLL, the PhL shall transmit SILENCE.

5.6.4 Reception of Ph-user-data

After passage of the number of bit periods specified by InterFrameGap from the end of the previous PhPDU, the PhE shall enable its receiver and report a received transmission that consists of either:

a) a single indication specifying START-OF-ACTIVITY; followed by a correctly-formed sequence of PH-DATA indications specifying DATA, each conveying a PhSDU; followed by a single indication specifying END-OF-DATA; followed by a single indication specifying END-OF-TRANSFER or END-OF-SYNC and concluded by a single indication specifying END-OF-ACTIVITY; or

b) a single indication specifying START-OF-ACTIVITY; followed by a correctly-formed sequence of PH-DATA 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-TRANSFER-AND-ACTIVITY or END-OF-SYNC-AND-ACTIVITY; or

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c) a single indication specifying START-OF-ACTIVITY; optionally followed by a correctly formed sequence of PH-DATA indications specifying DATA and possibly END-OF-DATA 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, END-OF-TRANSFER, END-OF-TRANSFER-AND-ACTIVITY, END-OF-SYNC, OR END-OF-SYNC-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.

5.7 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.

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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.

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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 5 through Figure 8.

– 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 5 and Figure 6 show the interactions for a data sequence (identification cycle and data cycle) at the DL-Ph interface of a master (controller board).

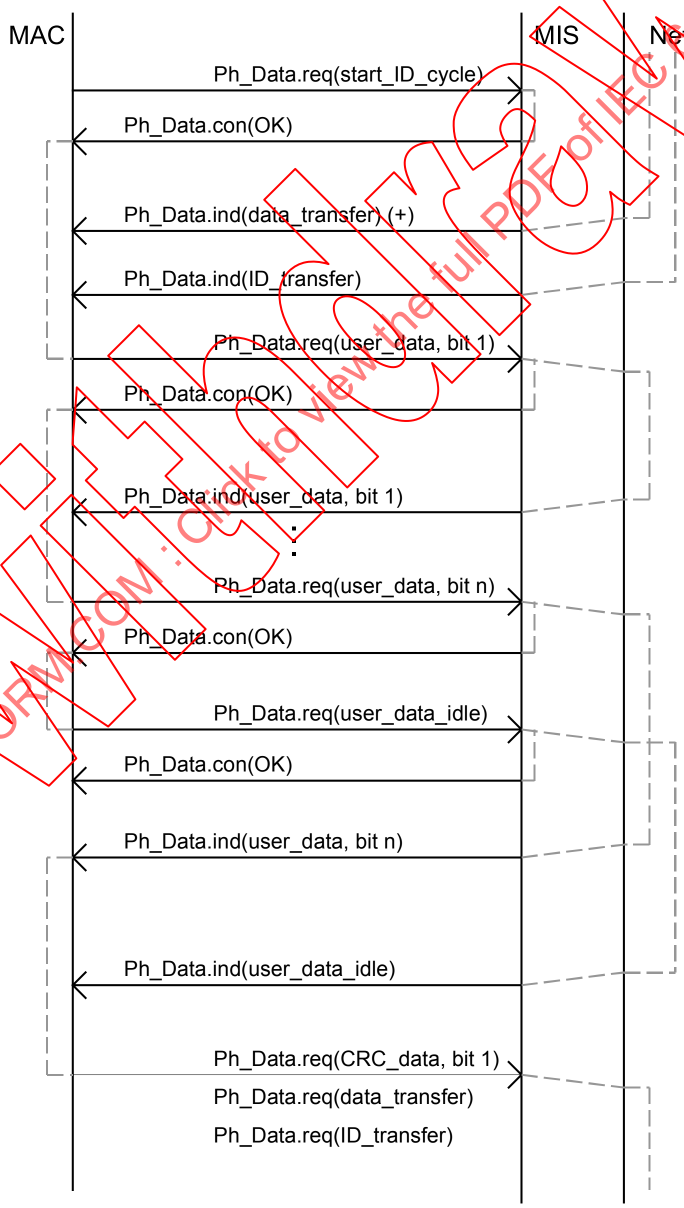

Figure 5 – Interactions for a data sequence of a master: identification cycle

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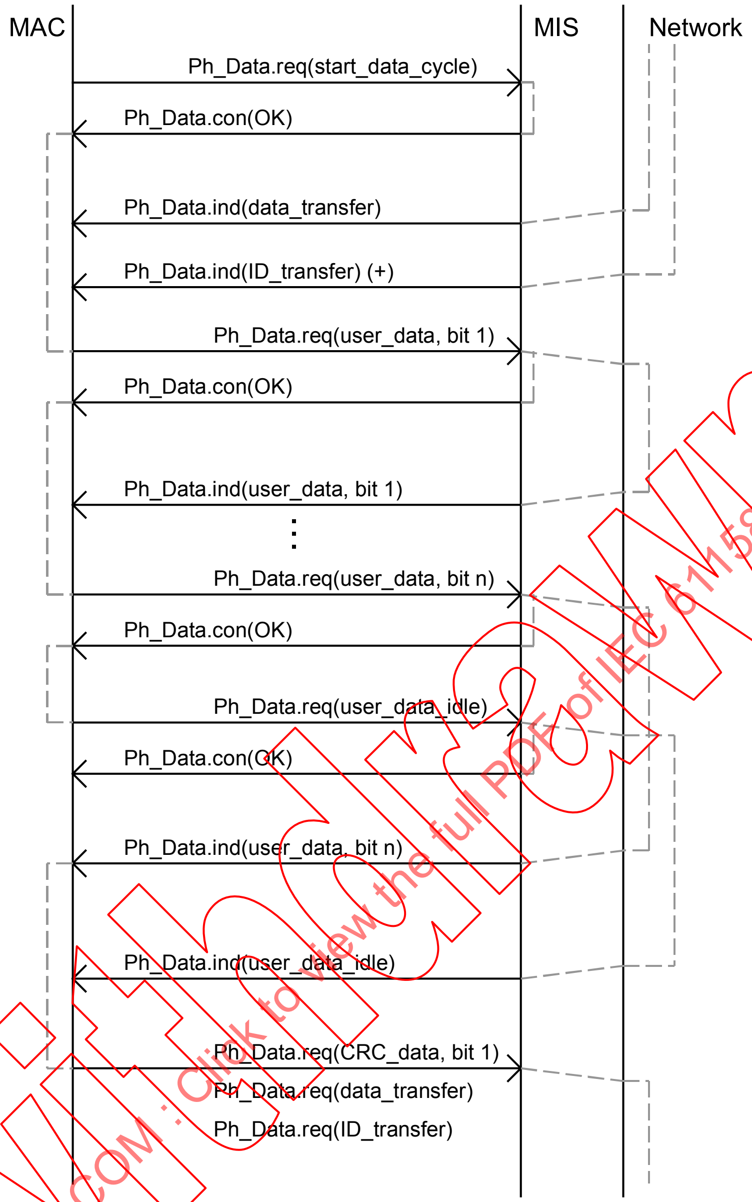

Figure 6 – Interactions for a data sequence of a master: data cycle

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5.7.3.1.2 Slave

Figure 7 and Figure 8 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).

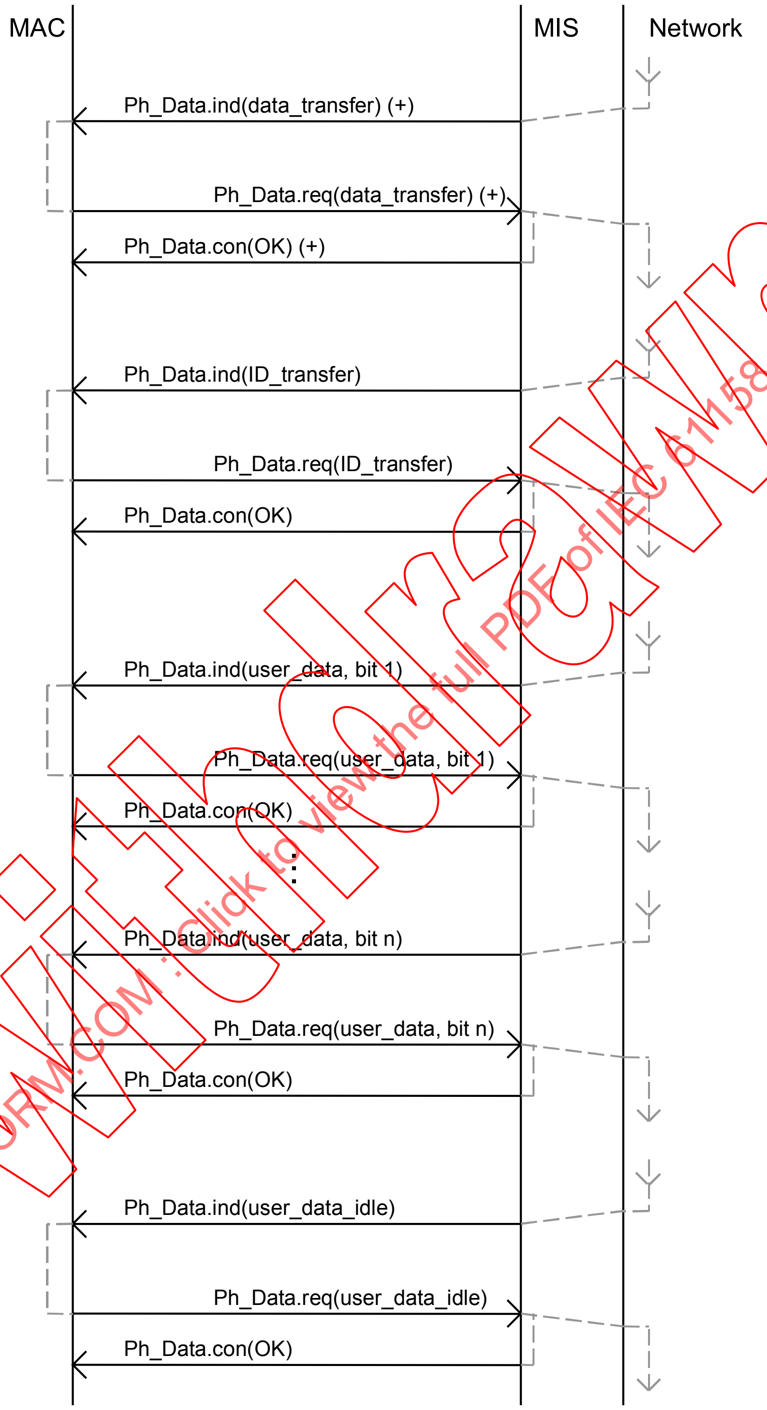

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Figure 7 – Interactions for a data sequence of a slave: identification cycle

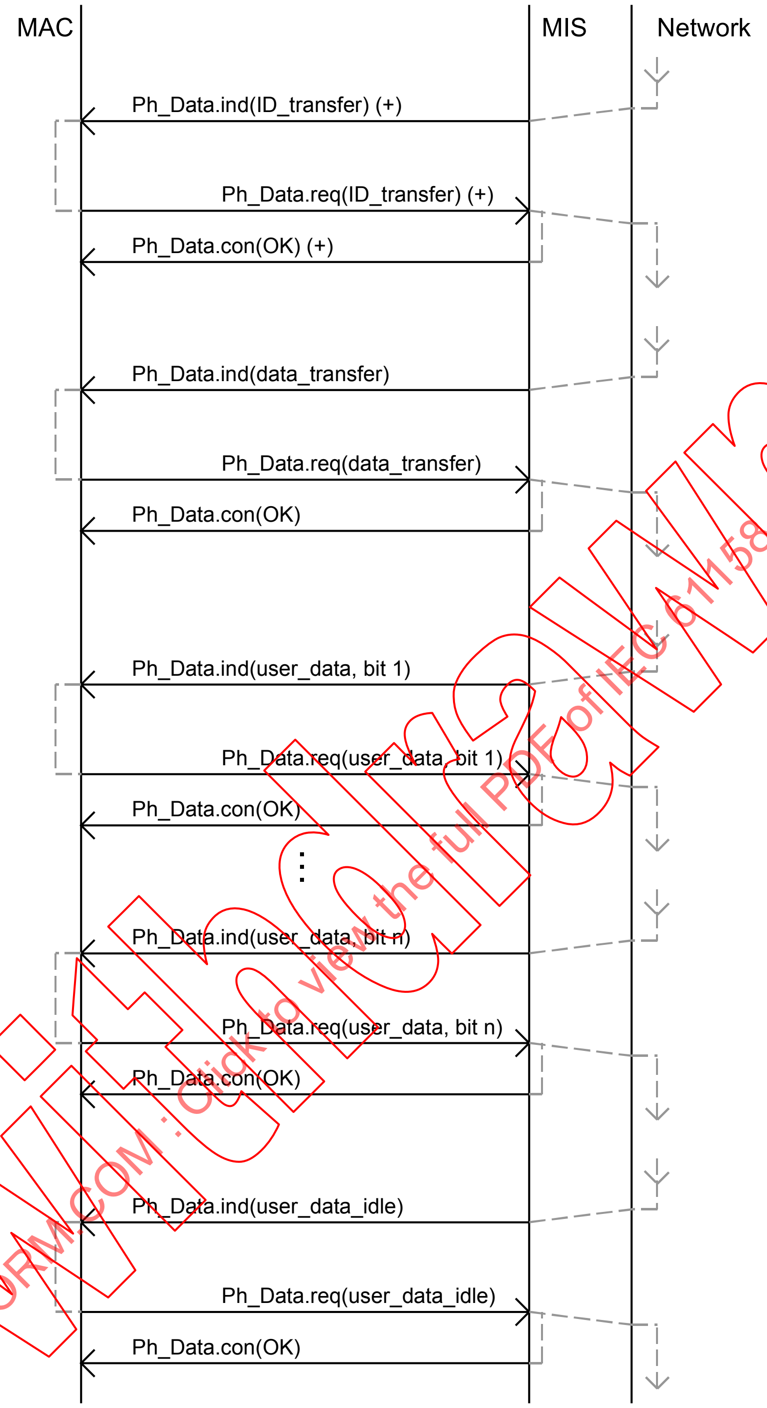

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Figure 8 – Interactions for a data sequence of a slave: data cycle

5.7.3.2 Check Sequence

5.7.3.2.1 Master

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

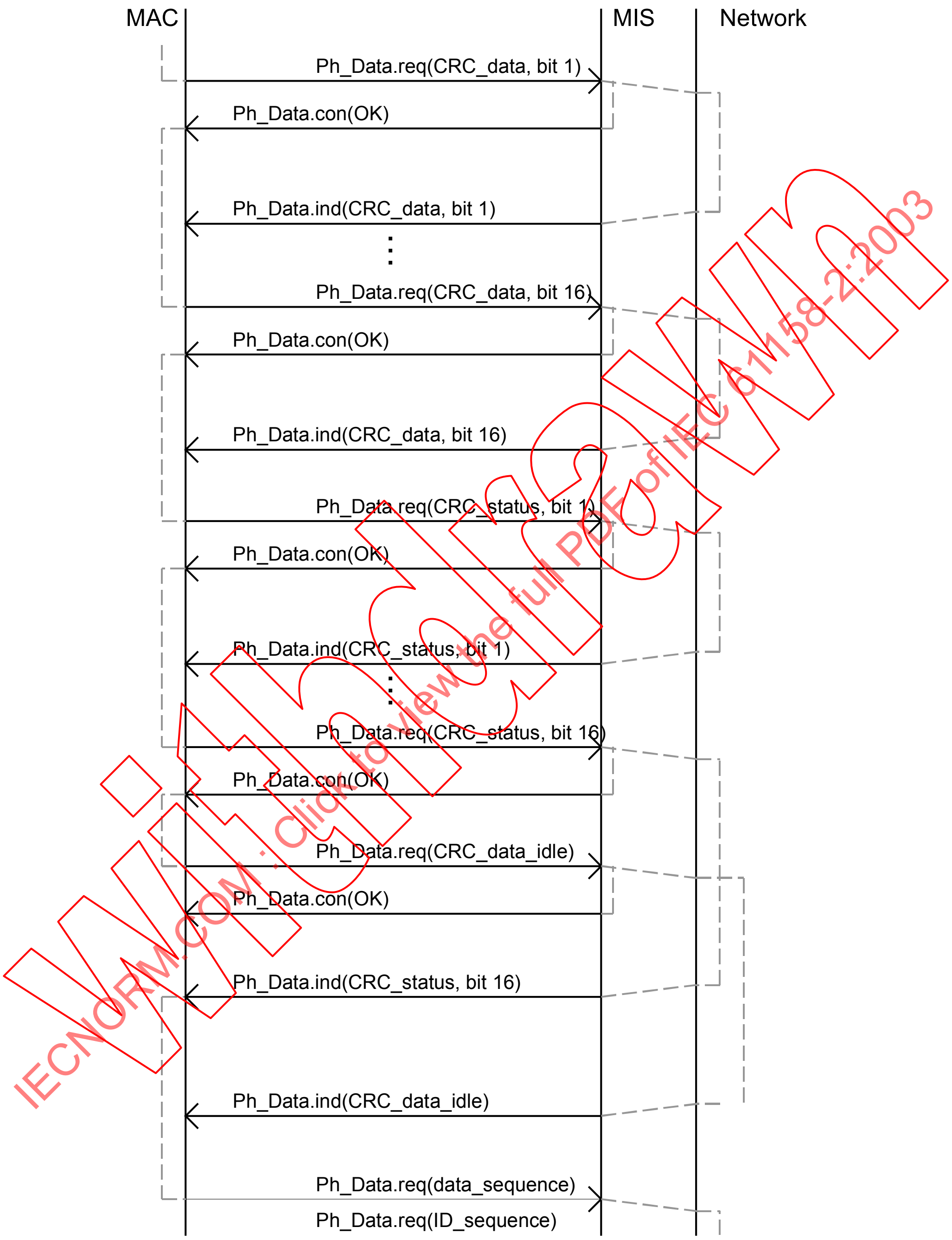

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Figure 9 – Interactions for a check sequence of a master

5.7.3.3 Slave

Figure 10 shows the interactions for a check sequence at the DL-Ph interface of a slave.

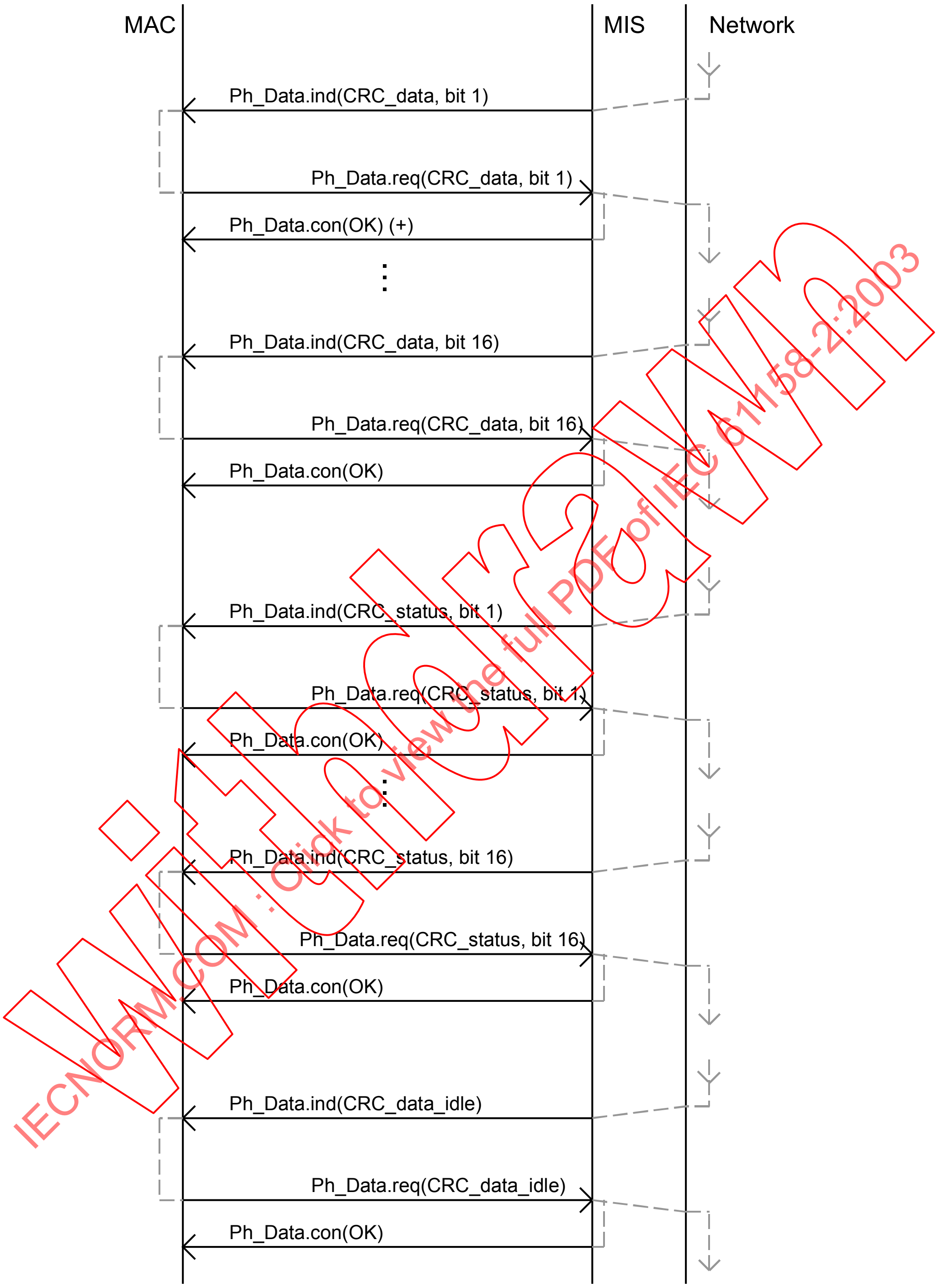

Figure 10 – Interactions for a check sequence of a slave

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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, fibre 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 6.6. 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.

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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* ($1 \leq N \leq 8$)	• ENABLED • DISABLED
Receiver input channel *N* ($1 \leq N \leq 8$)	• 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.

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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 IEC 61158-2 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:

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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 11 and Figure 12.

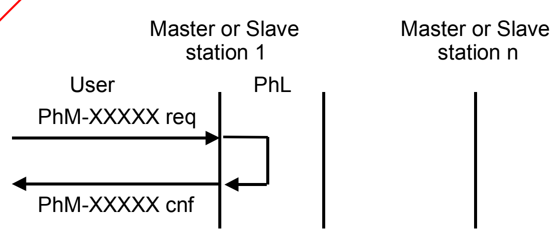

Figure 11 – Reset, Set Value, Get Value

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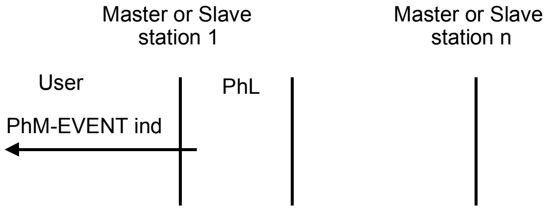

Figure 12 – Event service

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.

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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.

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

Short name	Status	Definition	temporary or permanent
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.

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

Short name	Status	Definition	temporary or permanent
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.

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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
Baud rate	230400 76800 38400 19200 9600

6.5 Type 6: Systems management – PhL interface

6.5.1 Required services

The service primitives for PhL management shall be:

a) PH-RESET request

b) Ph-SET-VALUE request / Ph-SET-VALUE confirm

c) Ph-GET-VALUE request / Ph-GET-VALUE confirm

6.5.2 Service primitive requirements

6.5.3 PH-RESET request

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

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

This primitive is used to allow Systems management to modify the parameters of the PhL. Standard parameter names and value ranges are given in Table 19.

Table 19 – Parameter names and values for Ph-SET-VALUE request

Parameter name	Range of values
Loop-back mode	DISABLED in MDS in MAU near line connection
Transmitter output channel N (1 ≤ N ≤ 8)	ENABLED DISABLED
Receiver input channel N (1 ≤ N ≤ 8)	ENABLED DISABLED
Preferred receive channel	NONE 1..8
PAD	0 to 31 (octets)
InterFrameGap	4 to 35 (bit periods)

The presence and default setting of the first four parameters of the Ph-SET-VALUE request is a conformance-class issue.

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6.5.5 Ph-SET-VALUE confirm

This primitive has a single parameter indicating the status of the request:

— Success or

— Failure.

This primitive is used to acknowledge completion of the Ph-SET-VALUE request in the PhL.

6.5.6 Ph-GET-VALUE request (parameter name)

This primitive is used to allow Systems management to read the parameters of the PhL. The parameter shall have one of the names given in Table 19.

Usage of the Ph-GET-VALUE request is a conformance-class issue

6.5.7 Ph-GET-VALUE confirm (current value)

This primitive is the response of the PhL to the Ph-GET-VALUE request.

This primitive is used to report the value of a single parameter reporting either:

— Failure or

— the present value of the requested parameter, which shall be one of those permitted by 6.5.4.

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 13 shows the interface between PhL and PNM1 in the layer model.

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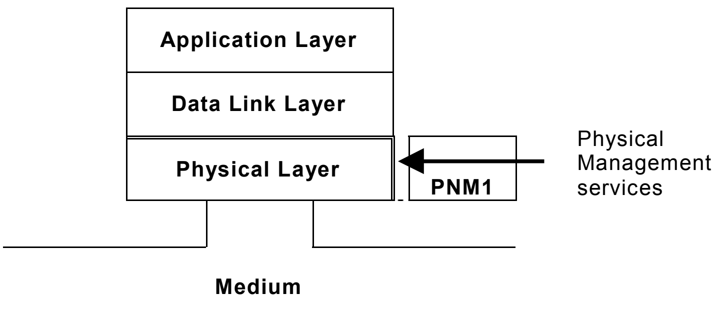

Figure 13 – Interface between PhL and PNM1 in the layer model

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 14 and Figure 15 show the time relations of the service primitives.

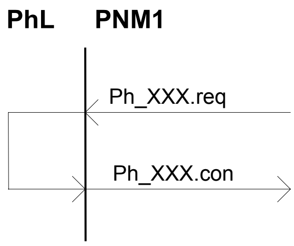

Figure 14 – Reset, Set Value, Get Value PhL services

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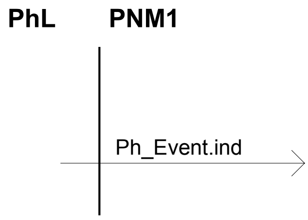

Figure 15 – Event PhL service

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 20).

Table 20 – 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 21).

Table 21 – 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 22 provides information on which PhL variable may be set to which new value.

Table 22 – PhL variables

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

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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 16).

— 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".

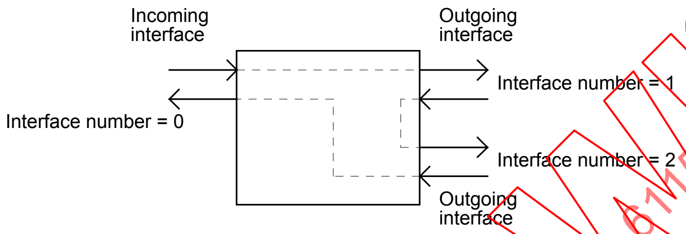

Figure 16 – Allocation of the interface number

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 16).

— 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 16).

— 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 16). Value range (1 to 2)

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— 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 23).

Table 23 – 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 24).

Table 24 – 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 25 have the following values:

Table 25 – 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

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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.

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7.4 Type 6: DIS

NOTE 1 This subclause does not specify a DTE – DCE interface.

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.

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 2 This is a guarantee of transparency.

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 17, Figure 18 and Figure 19 show possible configurations for the bus master and slaves using the 2-wire medium and an alternative type of transmission.

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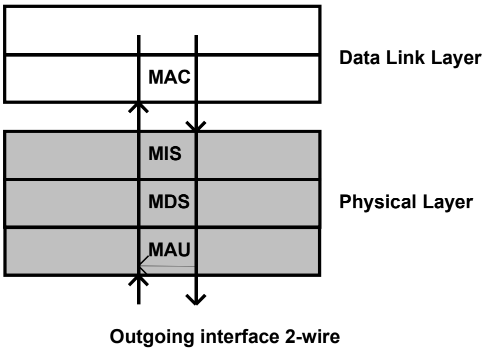

Figure 17 – Configuration of a master

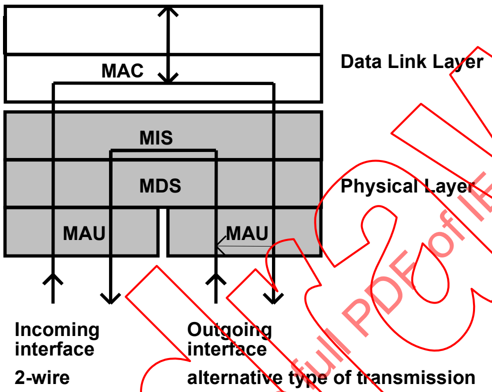

Figure 18 – Configuration of a slave with an alternative type of transmission

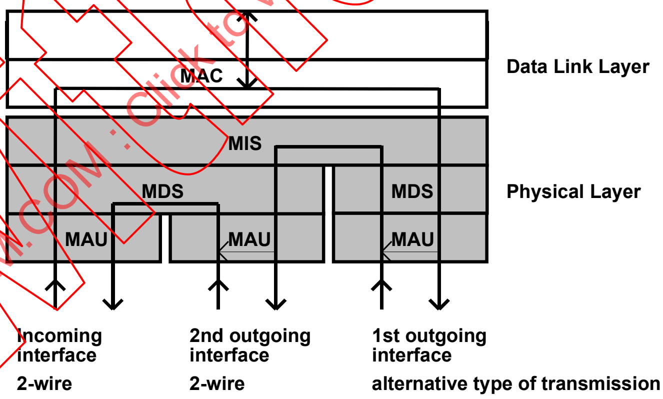

Figure 19 – Configuration of a bus coupler with an alternative type of transmission

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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 2.)

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 signalling interactions at the interface.

8.2 Type 1: DTE – DCE interface

8.2.1 Services

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.

8.2.1.1 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.

8.2.1.2 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.

8.2.1.3 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.

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8.2.1.4 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.

8.2.1.5 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 signalling from itself or other Ph-Layer entities. While loopback is enabled, this service reports only the signalling 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.

8.2.1.6 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 Interface signals

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.

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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 I_{out} = +1,6 mA	0,1 0,4	V V	see Note 1
V_{OH}	Minimum high-level output voltage	I_{out} = ±100 µA I_{out} = –0,8 mA	V_{DD} – 0,1 V_{DD} – 0,8	V V	see Note 1 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}.

The timing characteristics of these signals shall be at least equal to those specified for the relevant DCE in the requirements of this part of IEC 61158. 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).

8.2.2.1 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 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.

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8.2.2.3 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.

8.2.2.4 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.

8.2.2.5 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 8.2.3.6), 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 8.2.3.6).

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

8.2.2.6 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.

8.2.2.7 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.

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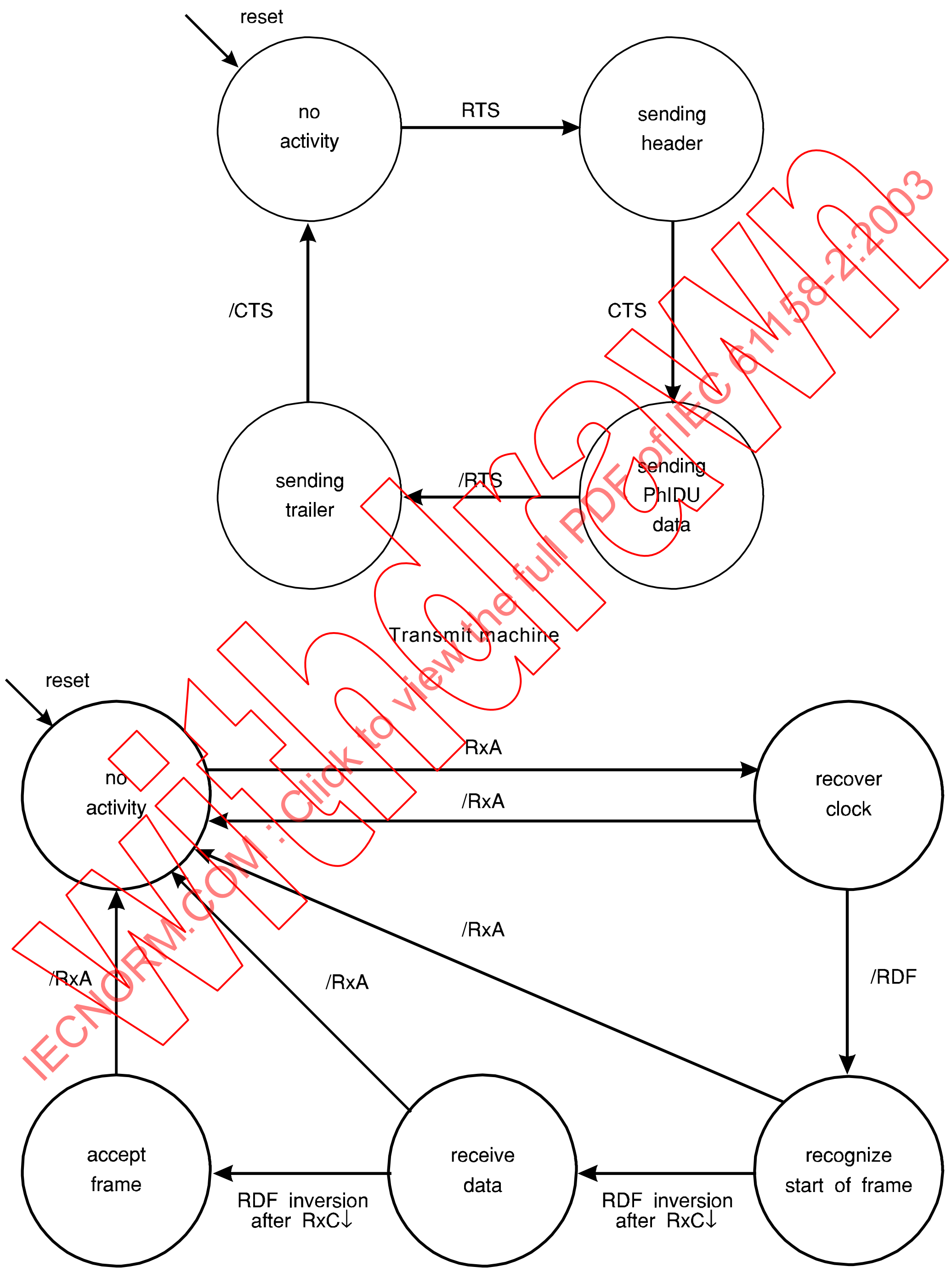
8.2.3 Encoding of services in signals

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 20, which is included in this part of IEC 61158 for explanatory purposes and does not imply a specific implementation.



Receive machine

Figure 20 – DTE/DCE sequencing machines

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8.2.3.1 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.

8.2.3.2 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 8.2.4) 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 8.2.4. 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 8.2.4).

8.2.3.3 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.

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

1) 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.
2) 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.

3) 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.

8.2.3.4 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.

8.2.3.5 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.

8.2.3.6 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.

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8.2.3.6.1 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 signalling on RxC and RDF, they do meet these conditions.

1) After detecting received signalling, training on that signalling, and recovering a data clock from that signalling 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 \1,\2.

NOTE 1 RxA is already asserted at this time.

2) The DCE shall continue training and attempting to match the received signalling 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 signalling 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 \1,\2, each before the immediately subsequent falling edge of \1,\2.

   Upon detecting an exact match between the received signalling and the expected start delimiter, the DCE shall invert RDF after the falling edge, and before the next rising edge, of \1,\2.

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.

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

   The DCE shall report each data bit decoded from the received signalling 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

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

   b) upon detecting an exact match between the received signalling 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.

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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.

4) 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.

8.2.3.6.2 Erroneous reception

An error may be detected during any phase of the reception process described in 8.2.3.6.1. 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 signalling; 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.

8.2.4 DCE configuration messages

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;

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Withdrawn

11 – extendible status-report invocation message.

8.2.4.1 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 fibre-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 signalling, received from one of the attached media as specified in 8.2.4.2 b) and c). The interface mode is as specified in 8.2.4.1 a);

   01 internal-status reporting, see 8.2.4.4 and 8.2.5;

   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).

8.2.4.2 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:

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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 signalling 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 signalling which is suitable for receiver-training is detected;

 1000 to 1111 (= 7 + N, 1 ≤ N ≤ 8) – The Nth medium should be selected, except when signalling 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 8.2.4.1 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 8.2.4.1 d), 8.2.4.2 b), and note 3 of 6.2.2.2).

8.2.4.3 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 8.2.4.1.

8.2.4.4 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 8.2.4.1. The information specified shall select some DCE-internal source of received signalling, and if the DCE-internal-data-source mode is status-reporting (see 8.2.4.1 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.

8.2.5 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 8.2.4.1 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.

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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.

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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

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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 21 to Figure 29:
The symbol "*" corresponds to "logically and", the symbol "/" corresponds to "negated".

8.4.4.2 Identification Cycle Request Service

Figure 21 describes this service with the four services marked in grey and their transitions.

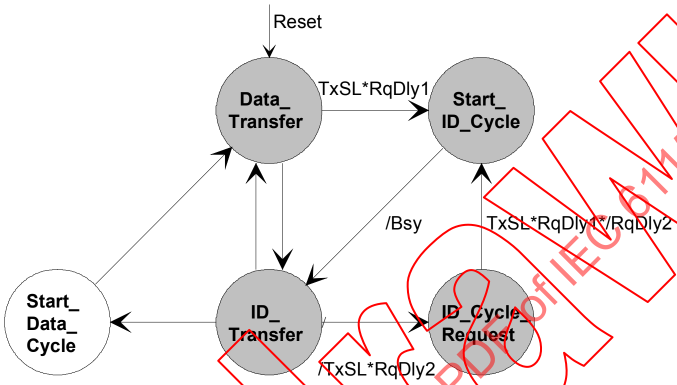

Figure 21 – State transitions with the ID cycle request service

NOTE 1 Transitions not shown in Figure 21 are used for other services see Figure 24 and Figure 26 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 22 shows the corresponding signal forms at the MIS-MDS interface for an identification cycle request service after a preceding data cycle.

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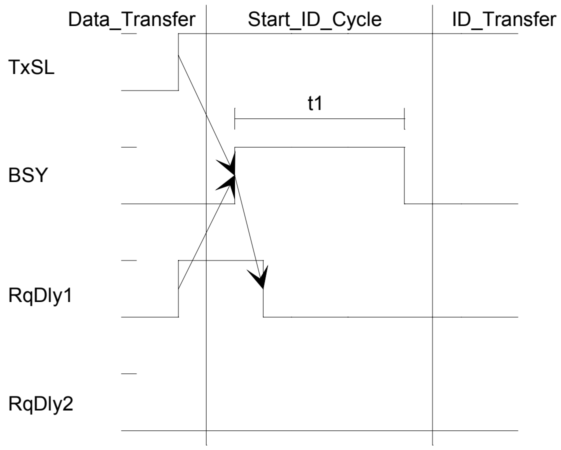

Figure 22 – MIS-MDS interface: identification cycle request service

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

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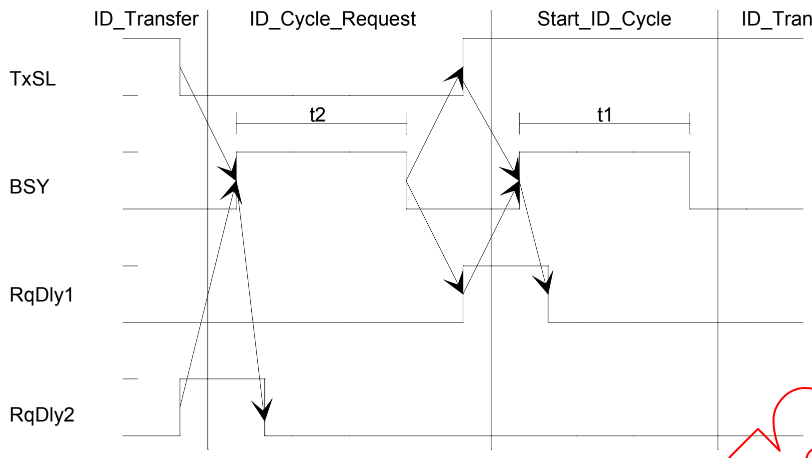

Figure 23 – MIS-MDS interface: identification cycle request service

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

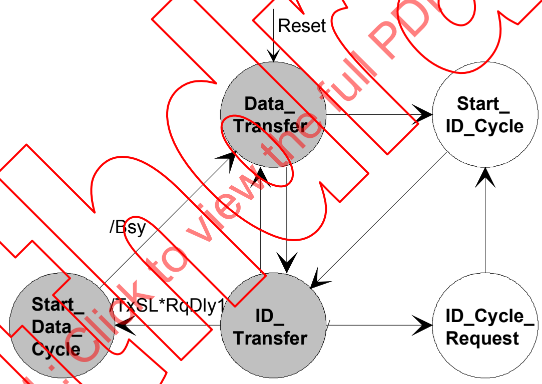

Figure 24 – State transitions with the data cycle request service

NOTE 1 Transitions not shown in Figure 24 are used for other services see Figure 21 and Figure 26 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 25 shows the corresponding signal forms at the MIS-MDS interface for a data cycle request service after a preceding identification cycle.

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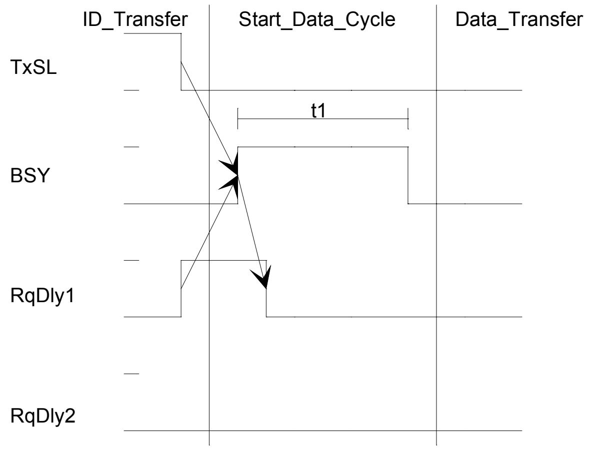

Figure 25 – MIS-MDS interface: data cycle request service

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

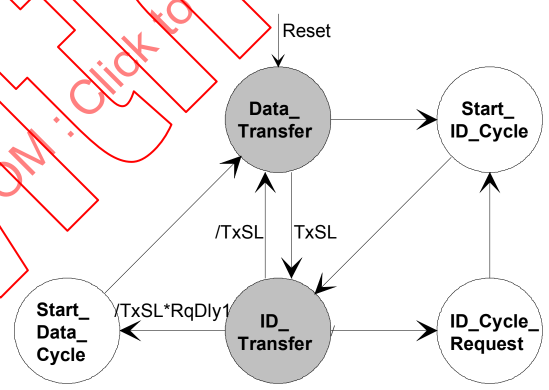

Figure 26 – State transitions with the data sequence classification service

NOTE 1 Transitions not shown in Figure 26 are used for other services see Figure 21 and Figure 24 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.

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Withdrawn

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 27 describes this service with the six states and their transitions.

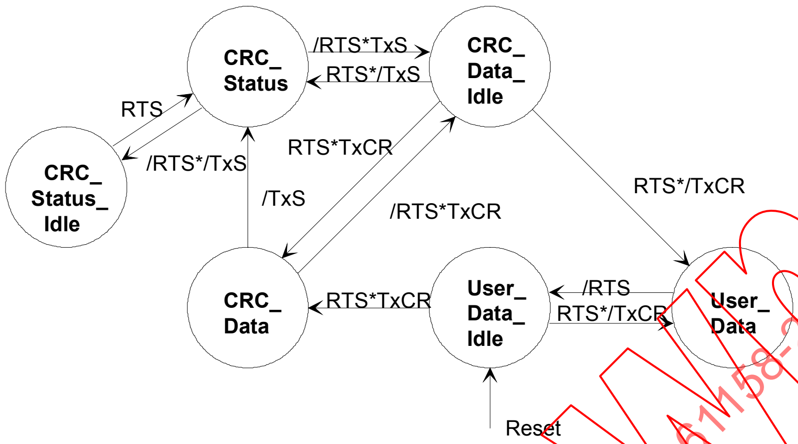

Figure 27 – Protocol machine for the message transmission service

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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 28 describes this service with the two states and their transitions.

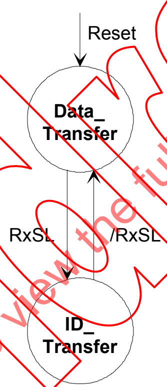

Figure 28 – Protocol machine for the data sequence identification service

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 29 describes this service with the six states and their transitions.

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NOTE 1 Data is received in multiples of octets.

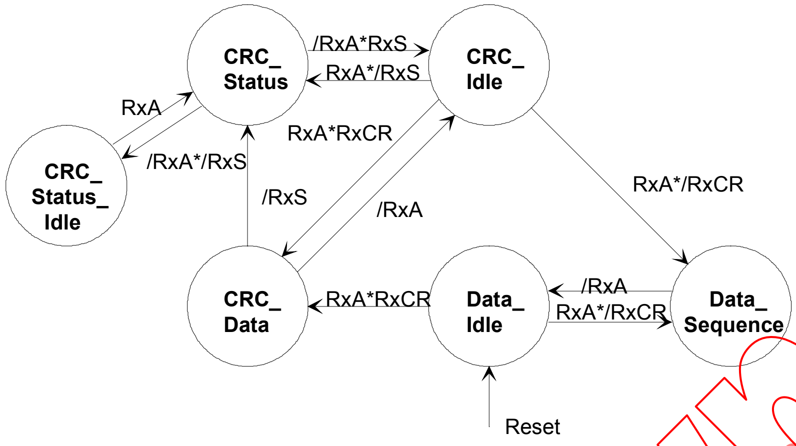

Figure 29 – Protocol machine for the message receipt service

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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

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9 Medium Dependent Sublayer (MDS)

9.1 General

The Medium Dependent Sublayer (MDS) is part of the Data Communication Equipment (DCE). (See Figure 2.) It exchanges serial PhSDU sequences across the DTE – DCE interface specified in clause 8 and it communicates encoded bits 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 30 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 30, i.e. preamble first, followed by start delimiter, PhSDU sequence and finally end delimiter.

PREAMBLE	START DELIMITER	PhSDU SEQUENCE	END DELIMITER

Figure 30 – 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 31 (Manchester Biphase L). The encoding rules are formally given in Figure 32 and Table 30.

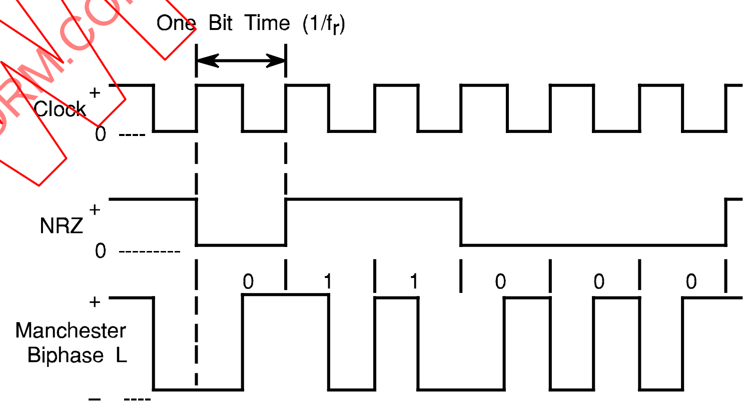

Figure 31 – PhSDU encoding and decoding

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NOTE 1 Figure 31 is included for explanatory purposes and does not imply a specific implementation.

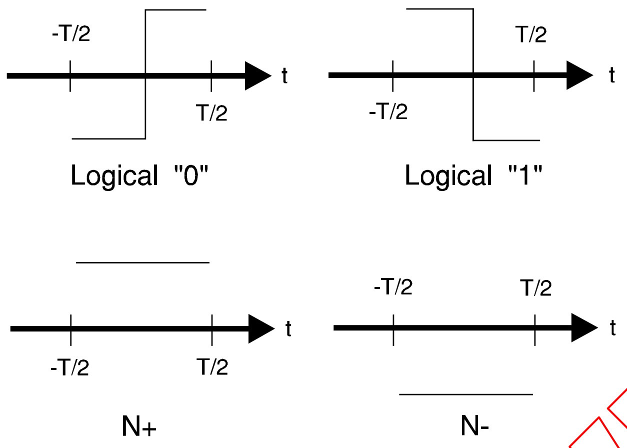

Figure 32 – Manchester encoding rules

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 32 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 33)

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.

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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 33)

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 33)

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.

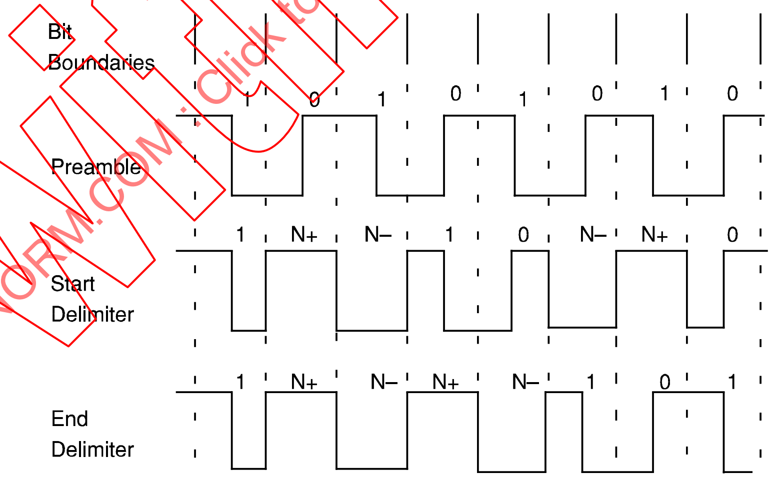

Figure 33 – Preamble and delimiters

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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 32 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 signalling. 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.

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9.3 Type 1: MDS: Low speed radio medium

9.3.1 General

NOTE The Medium Dependent Sublayer (MDS) is part of the Data communications equipment (DCE), see Figure 34. It exchanges serial PhSDU sequence across the DL-Ph interface defined in clause 5 and communicates the resulting bits across the MDS-Medium Attachment Unit interface. The main MDS functions are the separation of PhSDU sequence into radio frames, computation and processing of forward error check data and addition and detection/removal of preamble and synchronization words/delimiters. The MDS also carries out timing and synchronization functions.

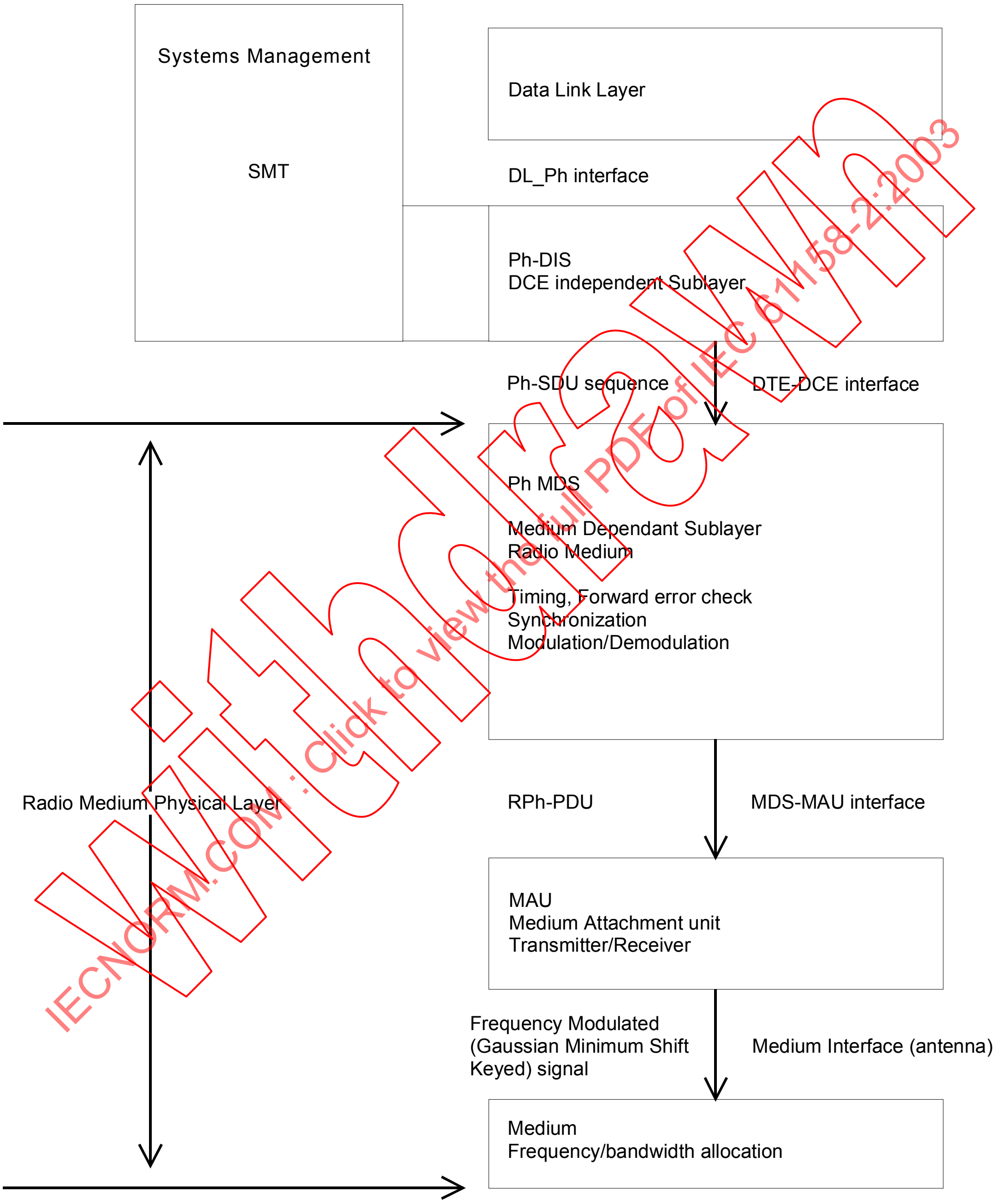

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Figure 34 – General model of the PhL with the low speed radio medium

9.3.2 Radio Physical Protocol Data Units (RPhPDU)

The radio medium fieldbus MDS shall divide the serial PhSDU sequence data transferred from the DIS across the DTE-DCE interface to produce one or more radio medium fieldbus code frames as shown in Figure 35, Figure 37 and Figure 38. Each of these frames shall have up to 5 octets of PhSDU sequence information. Where the PhSDU sequence does not contain an exact multiple of 5 octets, the last frame will be padded with octets containing the idle octet as defined in 9.3.7. To each of these 5 octet blocks a single octet shall be added containing length information and end of PhSDU sequence code as shown in Table 31 to form a radio medium fieldbus code frame (RMCF). This octet shall be placed after the synchronization word, see Figure 37 and Figure 38. The length information shall specify the number of octets in the RMCF (1 to 5) containing PhSDU sequence information. The radio medium fieldbus MDS shall report to the corresponding DLL entity, via the DIS, any PhSDU sequence that does not have a legal length code as the sixth octet in every RMCF or does not have an end of sequence code before more than the maximum number of PhSDU sequence octets as PH-DATA indication (PhIDU, error).

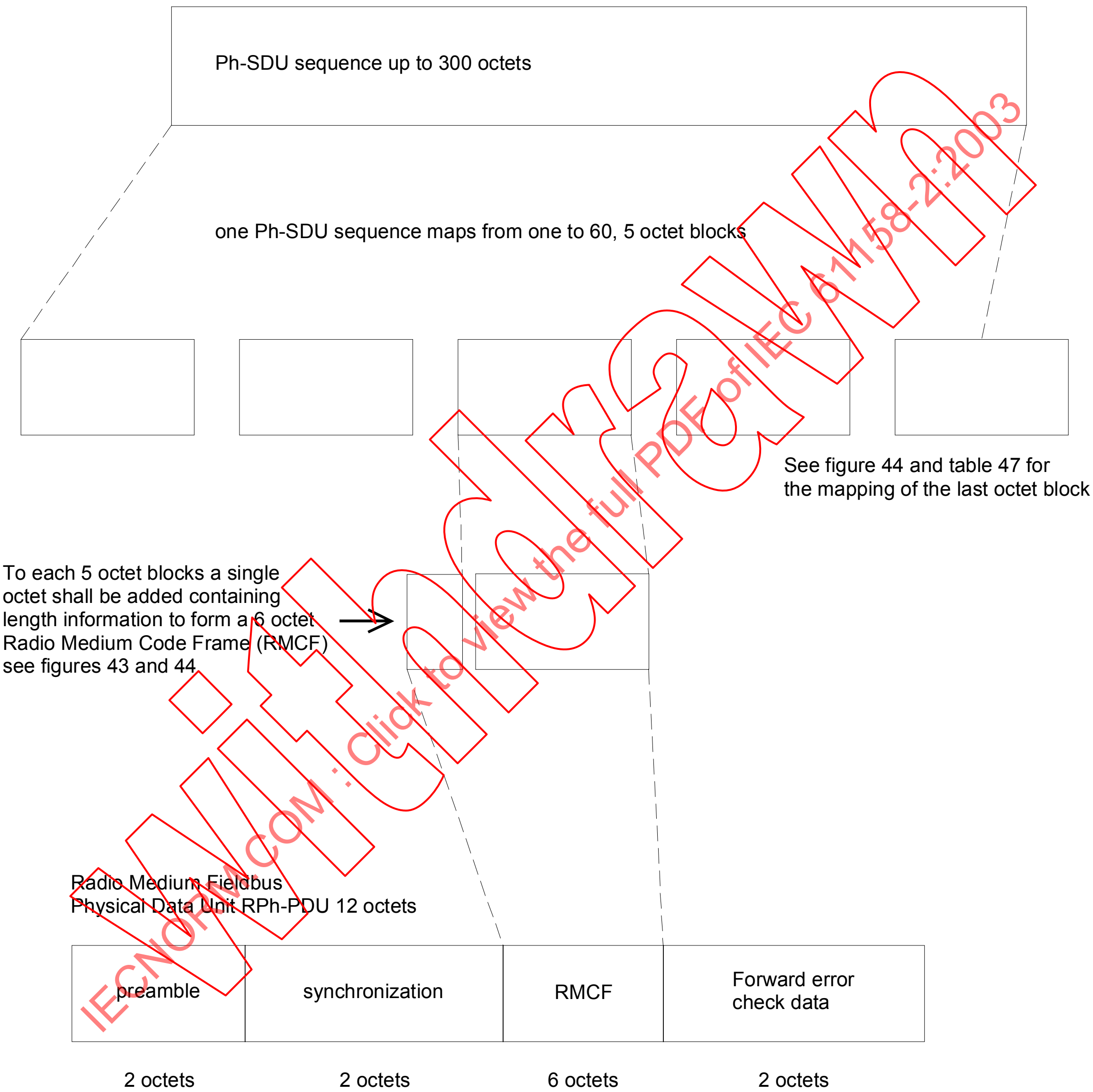

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Figure 35 – Radio medium fieldbus code frames and radio Physical Data Units for all but the last code frame of a corresponding PhSDU sequence

octet 1	length and end of PhSDU sequence code
octet 2	part of PhSDU sequence
octet 3	part of PhSDU sequence
octet 4	part of PhSDU sequence
octet 5	part of PhSDU sequence
octet 6	part of PhSDU sequence

Figure 36 – Radio medium fieldbus code frame

Bit	8	7	6	5	4	3	2	1
							CRC MSB	octet 1
	check parity	CRC LSB						octet 2

Figure 37 – Radio medium fieldbus forward error correction octets 1 and 2

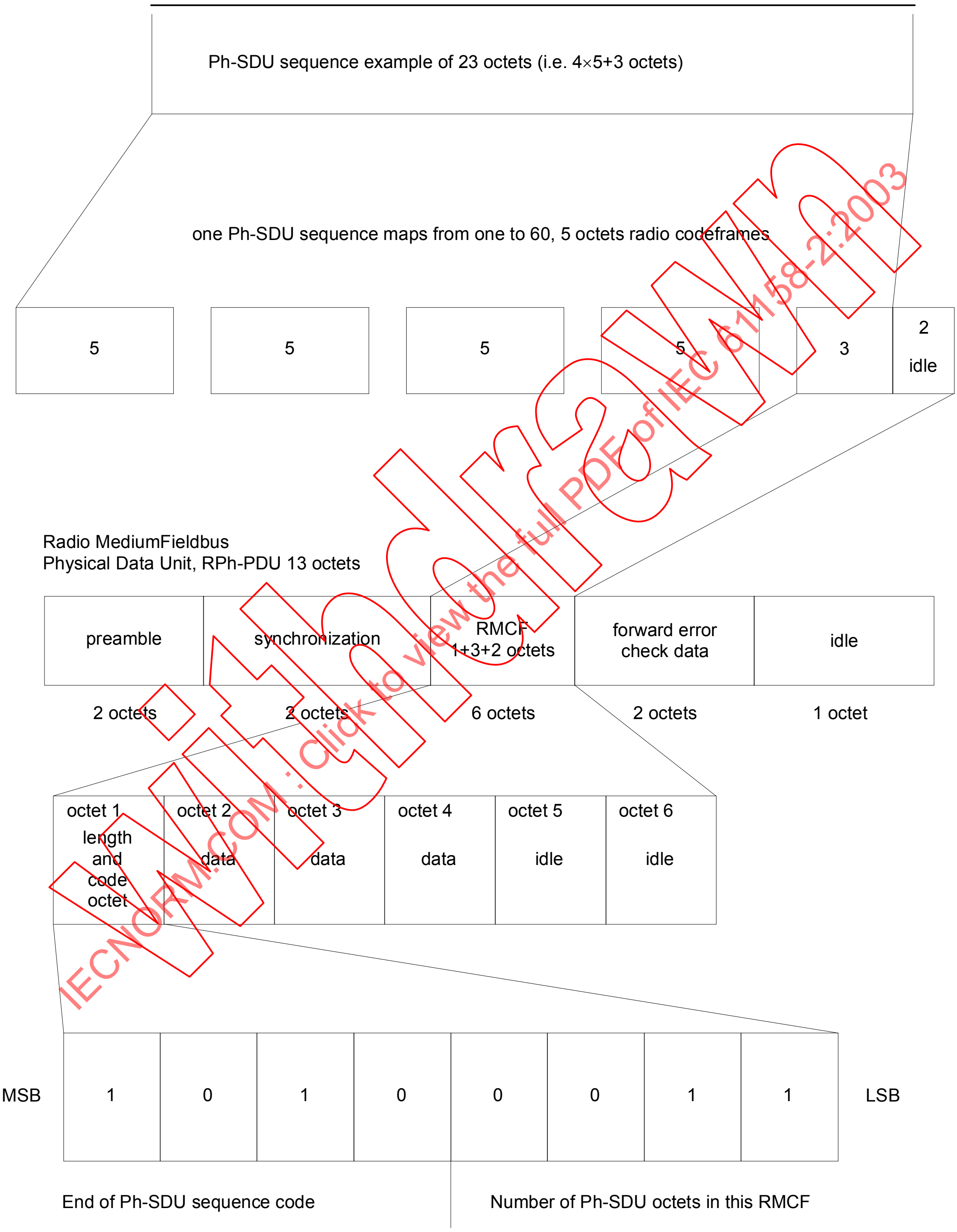

Figure 38 – Radio medium fieldbus code frames and radio Physical Data Units example of last code frame of a PhSDU sequence encoding

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Table 31 – Length and end of PhSDU sequence code

End of sequence code	Meaning of end of sequence code	Length code	Meaning of length code
0101	Not end of sequence	0001	1 octet in PH-SDU sequence in RMCF
1010	End of sequence	0010	2 octets in PH-SDU sequence in RMCF
All other codes illegal		0011	3 octets in PH-SDU sequence in RMCF
		0100	4 octets in PH-SDU sequence in RMCF
		0101	5 octets in PH-SDU sequence in RMCF
		All other codes illegal	

To these 6 octet RMCFs the radio medium fieldbus MDS shall add computed PhFEC (forward error correction data), preamble and synchronization words to produce the RPhPDU shown in Figure 35. Conversely, the radio medium fieldbus MDS shall remove the preamble and synchronization words, perform the forward error correction on a received RPhPDU to produce corresponding PhSDU sequence. Transmission sequence shall be from left to right as shown in Figure 35, i.e. preamble first followed by synchronization word, Ph interface data, PhFEC and finally an idle word if it is the last radio medium fieldbus code frame of a single PhSDU sequence.

A PhSDU sequence shall have a maximum length of 300 octets.

9.3.3 PhSDU throughput

The PhSDU sequence throughput shall be matched to the speed of the connected radio medium fieldbus Medium Attachment Unit.

9.3.4 PhFEC calculation

The PhFEC forward error correction data shall be calculated on each 6 octet RMCF using the following algorithm. 15 check bits are appended to the 48 information bits (octets 1 to 6) see Figure 37, by encoding them in a (63,48) cyclic code. For encoding, the 48 information bits shall be considered the coefficients of a polynomial having terms from x^{62} down to x^{15}. This polynomial shall be divided by the generating polynomial:

$$x^{15}+x^{14}+x^{13}+x^{11}+x^{4}+x^{2}+1$$

The 15 check bits (octet 1 and bit 1 to 7 of octet 2 of the forward error check data) shall correspond to the coefficients of the terms from x^{14} to x^{0} in the remainder polynomial found at the completion of the division. Bit 7 of octet 2 of the forward error check data shall be inverted and bit 8 shall be added such that the whole of the 64 bit combination of RMCF plus forward error check data has even parity.

NOTE A forward error check is required to bring the residual error rate of the radio medium up to that typically seen on a wired medium to ensure that error performance on the two media is in the same order of magnitude. The forward error correction code has the property that any single error burst of length 5 or less can be corrected. It is recommended that such correction be implemented.

9.3.5 Preamble

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

1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0

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The sequence shall contain a minimum of 16 bits starting always with a 1 and ending with a zero. The sequence may be extended to allow for link establishment and for use with repeaters.

9.3.6 Synchronization word

The following sequence of 16 bits, shown from left to right in the order of transmission shall immediately precede the RMCF to allow establishment of radio medium fieldbus framing in the receiving radio medium fieldbus MDS:

1,1,0,0,0,1,0,0,1,1,0,1,0,1,1,1

9.3.7 Idle octet

The following idle octet shall be transmitted at the end of the formation of the radio medium fieldbus code frames corresponding to one PhSDU sequence, and to pack any unused data octets in the last RPhPDU corresponding to 1 PhSDU:

1,1,1,1,1,1,1,1

9.3.8 PhSDU reception

At reception, the radio medium fieldbus MDS shall detect the following errors:

a) bit cell jitter during preamble and synchronization;
b) bit period outside limits during preamble and synchronization;
c) no synchronization word in time-out period, equal to the maximum number of bits in an RPhPDU multiplied by 1,5 times the bit period, while waiting for an end of PhSDU sequence code;
d) no end of PhSDU sequence within 300 octets of the start of the sequence.

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

The radio medium fieldbus MDS shall remove the preamble, synchronization and idle octets from the RPhPDU, perform the forward error correction and assemble the PH-SDU sequence before transferring the PhSDU sequence to the DIS. If a receiving radio medium fieldbus MDS does not detect an end of PhSDU sequence code after forward error correction in an incoming RMCF within 300 octets from the beginning of the PhPDU frame as defined by the first radio medium fieldbus code frame after detecting preamble, the radio medium fieldbus MDS shall report to the corresponding DLL entity via the DIS, as PH-DATA indication (PhIDU, frame_too_long).

9.3.9 Timing and synchronization

a) During reception of a PhSDU sequence the clock recovery circuits will check the period of the bits from subsequent RPhSDUs to be within 90 % to 110 % of the nominal bit period within the resolution of the radio medium fieldbus MDS clock.
b) During reception of a PhSDU sequence the clock recovery circuits will check the synchronization word timing to be within 1 bit time of previous synchronization words of the same PhSDU.

Deviation outside these limits shall be reported to the corresponding DLL entity, via the corresponding DIS, as PH-DATA indication (PhIDU, error).

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NOTE These requirements for reporting bit jitter and period variation are specified to avoid full bit slip errors that could reduce data integrity.

9.3.10 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 receipt of a PhPDU, the receiving PhL Entity shall ignore all received signals. A radio medium fieldbus MDS entity shall set a minimum post transmission gap of 0 nominal bit times. The period may be extended, but not reduced, by systems management or by an associated radio medium fieldbus MAU entity.

NOTE The post transmission gap is set at 0 as there are already 8 bits of gap provided by the idle octet.

9.3.11 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 two active channels, using the same media type, as measured from the first bit of a receiving PhSDU sequence, shall not exceed five nominal bit times. This period may be extended, but not reduced, by systems management as given in Table 4. The gap extension sequence as given in Table 4 shall be defined as four nominal bit times.

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 10.4.

9.4.1 Clock accuracy

The timing specifications for PhL Signalling shall be as defined in Table 32.

Table 32 – 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 32. 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 32. 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 32 shall be achieved prior to the beginning of the start delimiter (see IEC 61158-4, Type 2 for definition of start delimiter).

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 33 and Figure 39. 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 33. 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 39 to provide an example of the data encoding rules shown in Table 33.

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Table 33 – 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

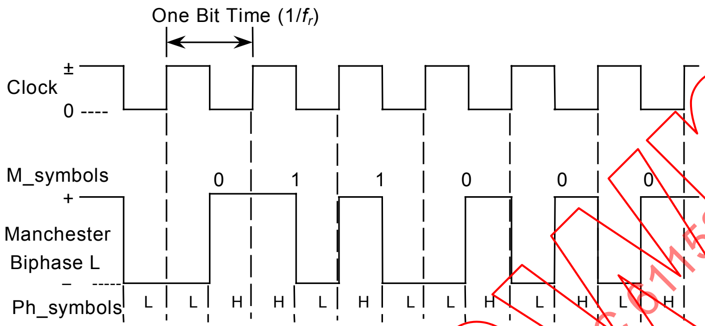

Figure 39 – Manchester coded symbols

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 40.

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Start	Data8 ... Data1	Address/data	Stop
0	X....X	1 for first octet, 0 for remaining	1

Figure 40 – 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).

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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).

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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 41.

Start	Data8 ... Data1	Stop
0	X....X	1

Figure 41 – PhPDU format, full duplex

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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.

9.7 Type 6: MDS: Wire and optical media

9.7.1 General

NOTE The Medium Dependent Sublayer (MDS) exchanges serial PhSDU sequences with the DIS and communicates encoded bits to the MAU. 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.

No MDS – MAU interface is specified.

Any medium that supports Manchester encoding and has predictable transmission delays over one path can be used for the PhL.

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9.7.2 PhPDUs

On transmission, the MDS shall produce the PhPDU shown in Figure 42 by adding preamble, PAD and delimiters to the serial sequence of PhSDUs (bits) transferred from the DIS. The transmission sequence shall be from left to right as shown in Figure 42, i.e. preamble first, followed by start delimiter, PhSDU sequence, end data delimiter, pad (if specified) and finally end transfer frame delimiter or bus sync delimiter.

PDU field	**Preamble**	**Start delimiter**	**sequence of PhSDUs**	**End data delimiter**	**pad (if present)**	**End transmission delimiter**
Acronym for field	PRE	ST		ED	PAD	End transfer frame delimiter ETF or Bus sync delimiter BSD

Figure 42 – 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 this happens.

9.7.3 Slots

On transmission, the MDS shall produce the slot shown in Figure 43 by adding a period of SILENCE, specified in bit periods by InterFrameGap as described in 6.5.4, prior to transmission of preamble.

Figure 43 – Ph-slot

Conversely, the MDS shall wait for the number of bit periods specified by InterFrameGap, before attempting to receive a PhPDU.

9.7.4 Encoding and decoding

See 9.2.2.

9.7.5 Polarity detection

See 9.2.3.

9.7.6 Preamble - PRE

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

0, 0, 0, 0, 0, 0, 0, 0.

(shown as a waveform in Figure 44)

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

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9.7.7 Start of frame delimiter - ST

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

1, 1

(shown as a waveform in Figure 44)

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

9.7.8 End of Data delimiter - ED

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

1, N+, N-, N+, N-, 1,

(shown as a waveform in Figure 45)

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 PhPDUs received via the medium which do not include this sequence within 50 octets of the start of PhPDU as PH-DATA indication (PhIDU, frame-too-long). The MDS shall report to the corresponding DLL entity, via the corresponding DIS, any PhPDUs 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).

9.7.9 PAD

In order to maintain constant length Bus-sync PhPDUs a PAD sequence of the length in octets specified in 6.5.4 shall be transmitted following the End of Data delimiter of each PhPDU that is terminated by a PH-DATA request specifying END-OF-DATA-AND-SYNC. Each octet of PAD shall consist of the following sequence of eight bits, shown from left to right in order of transmission:

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

(shown as a waveform in Figure 44)

The MDS shall remove this sequence from the PhPDU before transferring the PhSDU sequence to the DIS.

9.7.10 End Transfer Frame delimiter - ETF

If the last PH-DATA request of a PhPDU specifies END-OF-DATA-AND-TRANSFER, as described in 5.6.1.2, the following sequence of four symbols, shown from left to right in order of transmission, shall immediately follow the End of Data delimiter, to delimit the end of the PhPDU.

0, N-, N+, 0

(shown as a waveform in Figure 45)

The MDS shall remove this sequence from the PhPDU before transferring the PhSDU sequence to the DIS.

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NOTE The end of the last symbol of the ETF delimiter, shown as TR in Figure 45 is the DLL timing reference for emission of Data Strobes.

9.7.11 end Bus-Sync Delimiter - BSD

If the last PH-DATA request of a PhPDU specifies END-OF-DATA-AND-SYNC, as described in 5.6.1.2, the following sequence of four symbols, shown from left to right in order of transmission, shall immediately follow the PAD sequence, or the End of Data delimiter if PAD-length = 0, to delimit the end of the PhPDU.

1, N+, N-, 1

(shown as a waveform in Figure 45)

The MDS shall remove this sequence from the PhPDU before transferring the PhSDU sequence to the DIS.

NOTE 1 The end of the last symbol of the BSD delimiter, shown as SYN in Figure 45, is the DLL timing reference for Bus-synchronization.

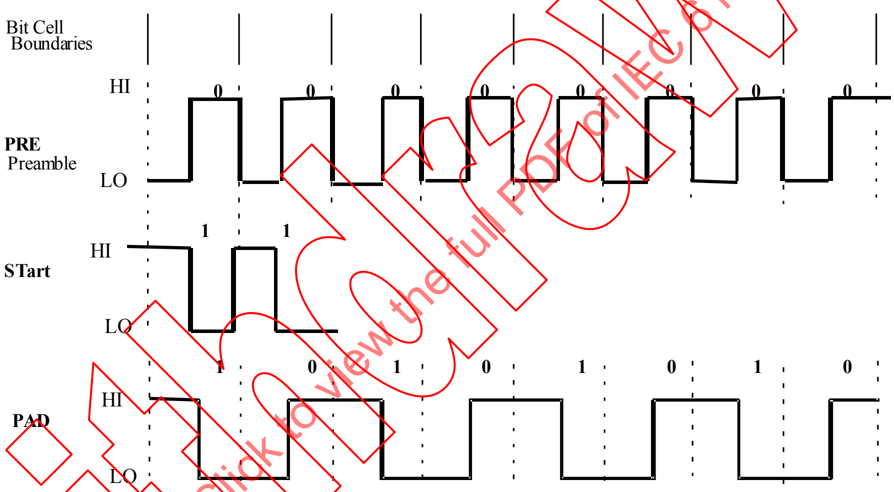

Figure 44 – Preamble, Start delimiter and PAD

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NOTE 2 These waveforms do not extend the frequency range outside the band required for transmission of binary PhSDUs (conveying data symbols).

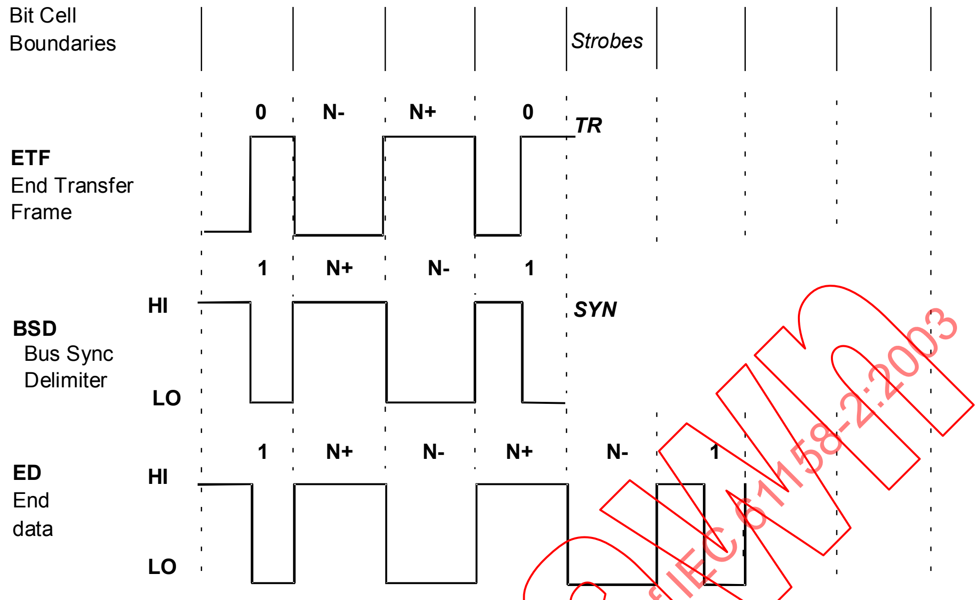

Figure 45 – End Transfer Frame, Bus Sync and End of Data delimiters, with Strobes

NOTE 3 These waveforms do not extend the frequency range outside the band required for transmission of binary PhSDUs (conveying data symbols).

9.7.12 Bit synchronization

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

NOTE 1 This synchronization specification allows the loss of four 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.

9.7.13 InterFrame Gap

Prior to transmission of a PhPDU there shall be a period SILENCE, specified by InterFrameGap as described in 6.5.4. For the same period the receiving PhL entity shall ignore all received signalling.

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

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 6.6, 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

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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 46 shows the structure of the data sequence PhPDU.

Figure 46 – 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 46, 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 47.

SL	1	0

Figure 47 – 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

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at which the data sequence PhPDU is to be transmitted via the MDS-MAU interface to the MAU (see Table 34):

Table 34 – 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 35).

Table 35 – 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 48 shows the structure of the check sequence PhPDU.

Figure 48 – 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 48, 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 49.

SL	0	0

Figure 49 – 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.

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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 36).

Table 36 – 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 37).

Table 37 – 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 50.

Figure 50 – 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 51.

SL	0/1	1

Figure 51 – Structure of the header in a status PhPDU

According to Figure 51 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 38).

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Withdrawn

Table 38 – 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 39).

Table 39 – 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 52.

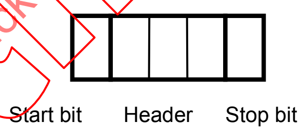

Figure 52 – Structure of the medium activity status PhPDU

The header in a medium activity status PhPDU is structured according to Figure 53.

1	1	1

Figure 53 – Structure of the header in a medium activity status PhPDU

According to Figure 53 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.

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9.8.2.5 Coding and decoding

Coding and decoding is done in accordance with the rules in Table 40.

Table 40 – 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 41.

Table 41 – 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 54 shows the structure of the reset PhPDU.

0	0	0	0	0	0		…….	0	0	0	0	0	0

Short reset or long reset

Figure 54 – 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.

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9.8.4.2 Coding and decoding

The coding rules for the reset PhPDU are given in Table 42 and Table 43.

Table 42 – 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 43 – 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 42 and Table 43 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 55, Figure 56 and Figure 57 show possible configurations for the bus devices when the 2-wire medium is used.

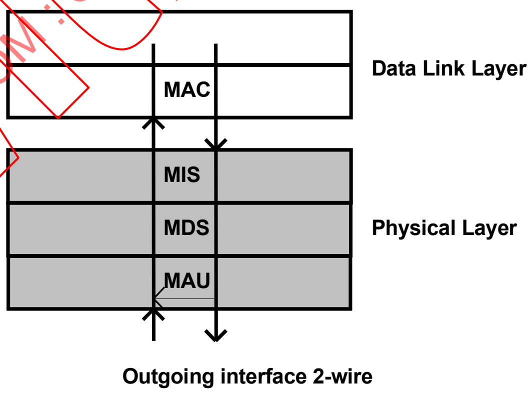

Figure 55 – Configuration of a master

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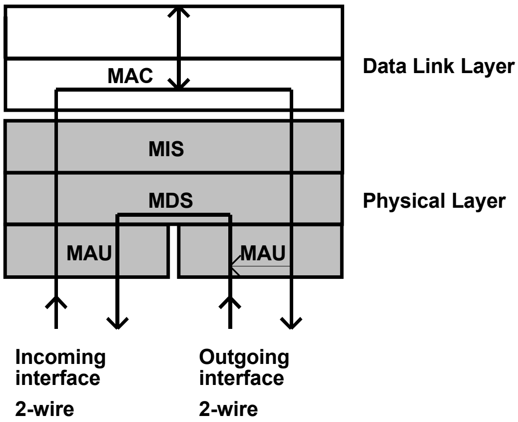

Figure 56 – Configuration of a slave

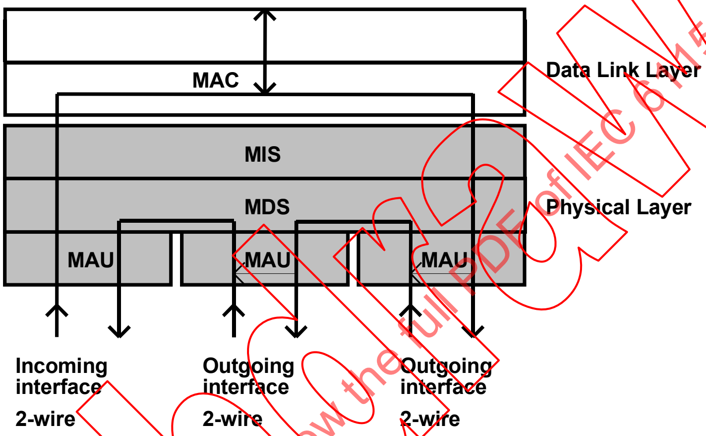

Figure 57 – Configuration of a bus coupler

NOTE When two MAUs are directly coupled, code-transparent repeaters may be used for the time regeneration.

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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 2.) For electrical signalling 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 being optionally exposed. The following subclauses list for each Type 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).

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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 part of IEC 61158 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}	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}.

10.2.4 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).

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10.3 Type 1: MDS – MAU interface: Low speed radio medium

10.3.1 Services

NOTE The Medium Attachment Unit (MAU) is an optionally separate part of a communication element that connects to the medium directly or via passive components. For electrical signalling variants the MAU is the transceiver, which provides level shifting and wave shaping for transmitted and received signals. The MAU interface links the MAU to the MDS. The services are defined as physical signals to facilitate this interface being optionally exposed. Table 46 lists the minimum set of required services at the MDS – MAU interface. See clause 6 for management services. fieldbus MAU accepts raw bit data for modulation onto the carrier frequency using Gaussian Minimum Shift Keying (GMSK) modulation techniques.

If the MDS – MAU interface is exposed it shall support at least the required set of services given in Table 46.

Table 46 – 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

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10.3.2 Service specifications

10.3.2.1 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 onto the medium if the Transmit Enable (TxE) is set to logic 1 (high level).

10.3.2.2 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 entity. The RxS shall echo the signal transmitted via TxS by simultaneously receiving the transmissions from the medium.

10.3.2.3 Transmit Enable (TxE)

The Transmit Enable service (TxE) shall provide an MDS entity with the facility to enable an MAU to transmit. The enable state 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).

10.3.2.4 Loopback Enable (LbE)

If the optional Loopback Enable 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.

10.3.3 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 signal levels as shown in Table 47. Both sides of the interface shall operate with the same value of V_{DD}.

Table 47 – Signal levels for an exposed MDS – MAU interface

Symbol	Parameter	Conditions	Limits	Units	Remarks
V_{ol}	Maximum low-level output voltage	|Iout| = ±100 µA	0,1	V	see Note 1
		Iout = +1,6 mA	0,4	V	
V_{oh}	Minimum high-level output voltage	|Iout| = ±100 µA	V_{DD} – 0,1	V	see Note 1
		Iout = –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}.

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10.3.4 Communication mode

The communication mode at this interface shall allow simultaneous transmission and reception.

10.3.5 Timing characteristics

The MDS – MAU interface shall function correctly with a PhSDU throughput 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).

10.4 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 48 below.

Table 48 – 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 48. 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 48. 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 48.

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 32), these Ph-symbols shall be decoded into the appropriate MDS M_symbols as shown in Table 33.

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.

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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 fibre medium MDS-MAU interface, as shown in Table 49 below.

Table 49 – MDS-MAU interface 5 Mbit/s, optical fibre 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 fibre medium as 'light on'. A false signal shall be represented on the fibre medium as 'light off'. The fibre 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 fibre medium. NETENABLE shall enable the MAU for transmission of TXDATAOUT light levels on the fibre medium. NETENABLE false shall prevent transmission of TXDATAOUT signals, as shown in Table 49.

10.4.3.4 RxData

RXDATA shall represent the raw, distorted, unsynchronised Ph-symbols (H or L) as recovered from the fibre 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 32), these Ph-symbols shall be decoded into the appropriate PLS_DATA_INDICATION M_symbols as shown in Table 33. RXDATA shall report false if the medium is broken, missing or power is removed from the transmitting end of the fibre.

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 fibre 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 fibre.

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.

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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 50).

Table 50 – 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.

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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 58. The variation for the sample clock shall be within the range of ± 0,1%.

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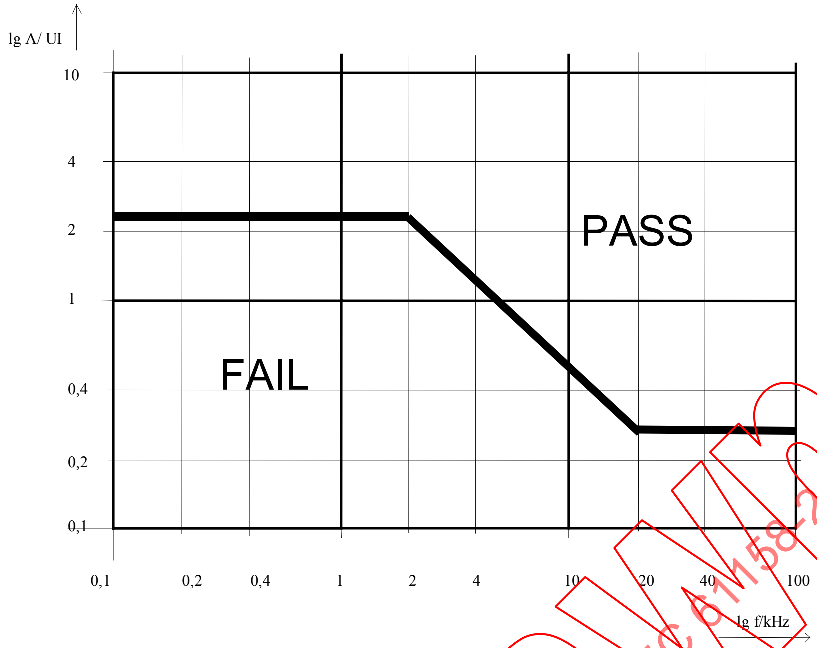

Figure 58 – Jitter tolerance

10.6.4 Transmission Mode

The MDS-MAU interface shall allow a simultaneous, independent sending and receiving.

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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 electro-magnetic 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%				
Signalling 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	8000	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* ± Δ*BR*, averaged over a frame having a minimum length of 16 octets. The instantaneous bit time shall be $T_{bit} \pm \Delta T_{bit}$.

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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 IEC 61158 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 IEC 61158, 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.

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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}:

$$\left| \frac{Z - Z_{fr}}{Z + Z_{fr}} \right| \leq MD_{max}$$

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 6.2.2.2and 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.

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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 59)	Limits
Output level (peak-to-peak, see Figure 60) 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 (signalling bias) as shown in Figure 61	± 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 60)	±10 %
Quiescent transmitter output; i.e. transmitter noise (measured over the frequency band 1 kHz to $f_{QTO_{max}}$)	≤ 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 59)	Limits
Transmitted bit rate	$BR \pm \Delta BR$
Instantaneous bit time	$T_{bit} \pm \Delta T_{bit}$
Rise and fall times (10 % to 90 % of peak-to-peak signal, see Figure 60)	≤ 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 61)	± 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 59)	Limits
Transmitted bit rate	$BR \pm \Delta BR$
Instantaneous bit time	$T_{bit} \pm \Delta T_{bit}$
Rise and fall times (10 % to 90 % of peak-to-peak signal, see Figure 60)	≤ 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 61)	± 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}

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11.4.2 MAU test configuration

Figure 59 shows the configuration that shall be used for testing MAUs.

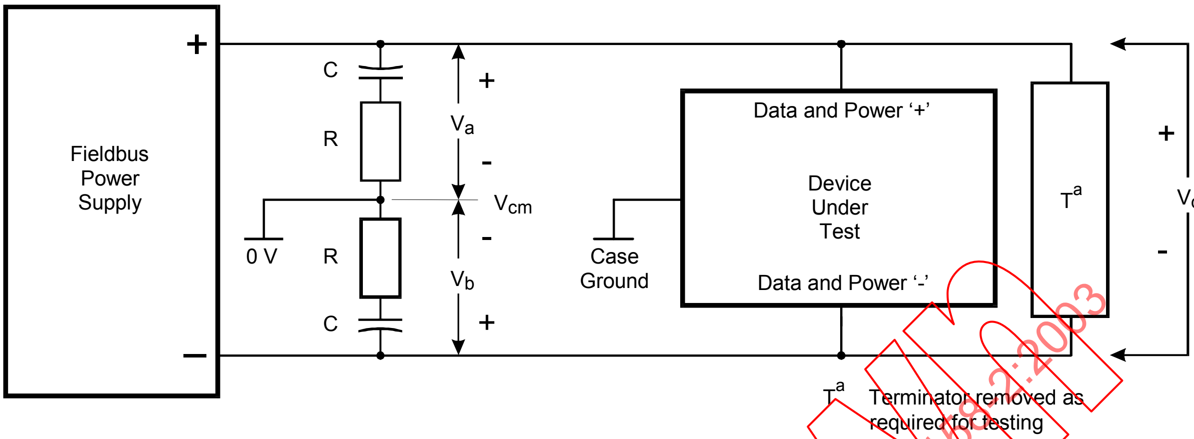

Figure 59 – Transmit circuit test configuration

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.

11.4.3 MAU output level requirements

Figure 60 describes the output form of the signal for the twisted-pair voltage output level requirements.

NOTE Figure 60 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.

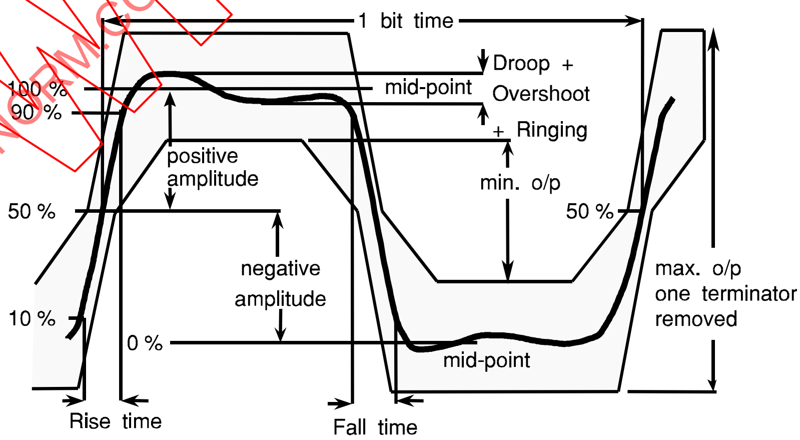

Figure 60 – Output waveform

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 60):

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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 60;

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 60);

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 60, 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 $f_{QTO_{max}}$, 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 61);

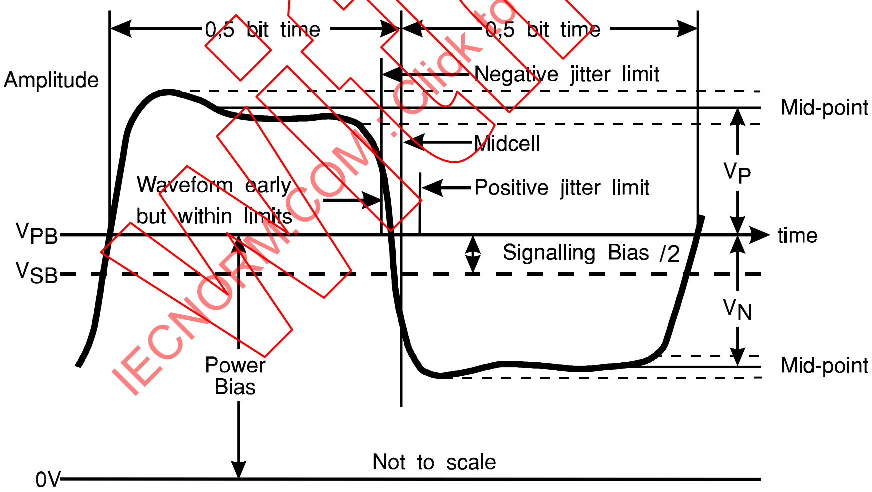

Figure 61 – Transmitted and received bit cell jitter (zero crossing point deviation)

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 60;

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

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configuration of Figure 59 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 60);

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 60);

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:

Max. slew rate = 2 × Min. slew rate = 2 × 0,8 V_o / 0,25 T_{bit} = 6,4 × 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 60);

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 60);

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:

Max. slew rate = 36 × Min. slew rate = 3 × 0,8 V_o / 0,2 T_{bit} = 12 × 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 59.

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 62.

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.

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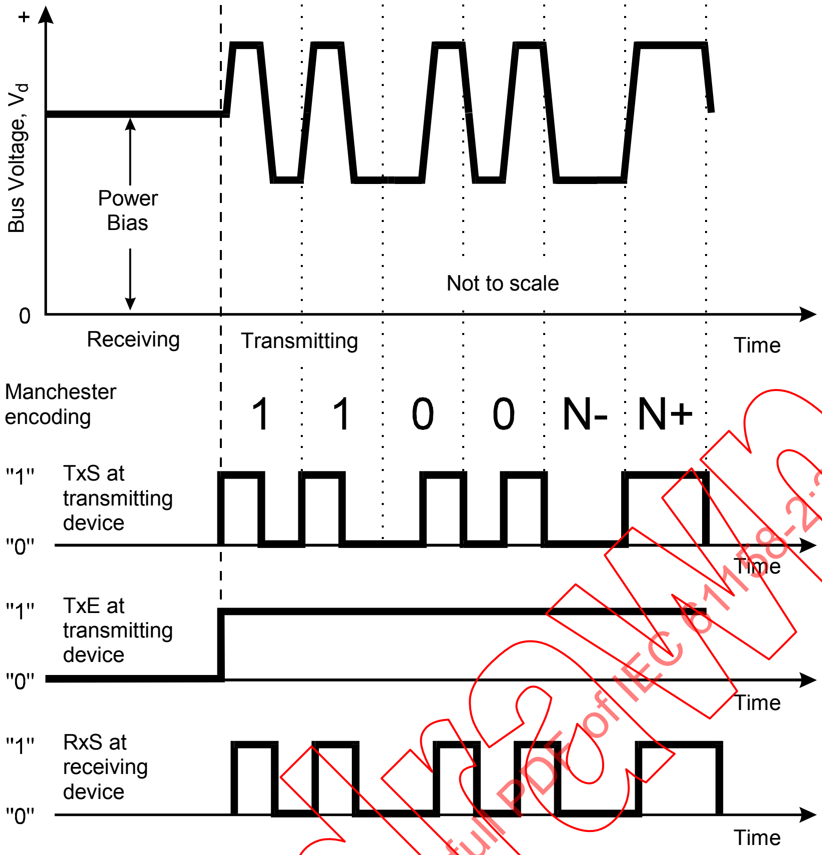

Figure 62 – Signal polarity

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NOTE 2 The waveform in Figure 62 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 62 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 62 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 63)	700 mV
Noise rejection; max. peak-to-peak noise required to be rejected (see Figure 63)	280 mV
Maximum received bit cell jitter (zero crossing-point deviation, see Figure 60)	±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 63).

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 63).

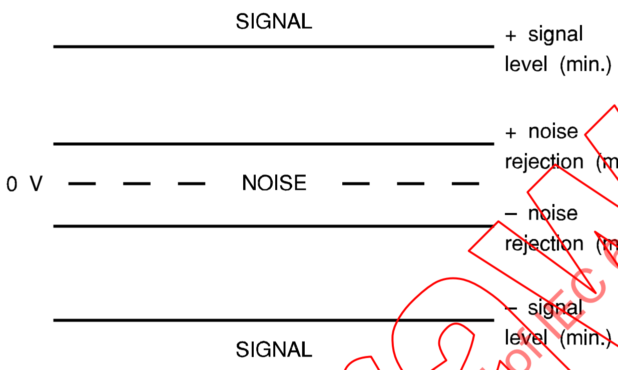

Figure 63 – Receiver sensitivity and noise rejection

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 61.

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 signalling.

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.

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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, 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 5000 T_{bit} and 15000 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.

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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 64
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 IEC 61158 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 64, which gives the level and the frequencies for power via signal conductors.

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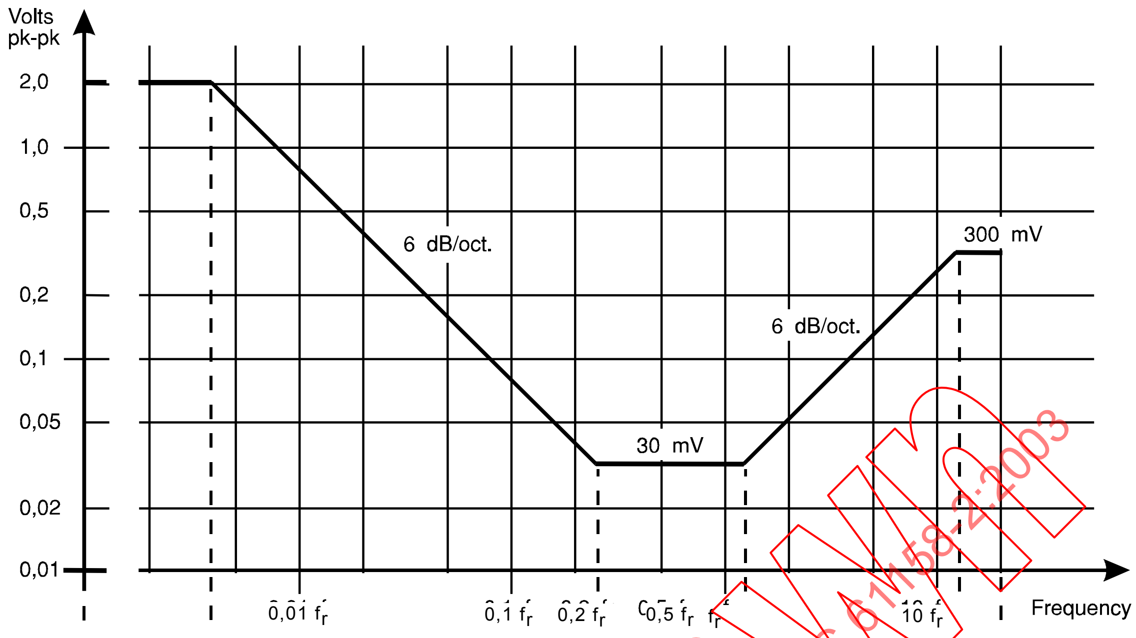

Figure 64 – Power supply ripple and noise

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.

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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 IEC 61158, 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.

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11.8.3 Coupler

The coupler, as shown in Figure 65, shall provide one or several point(s) of connection to the trunk. It is generally integrated with a fieldbus device.

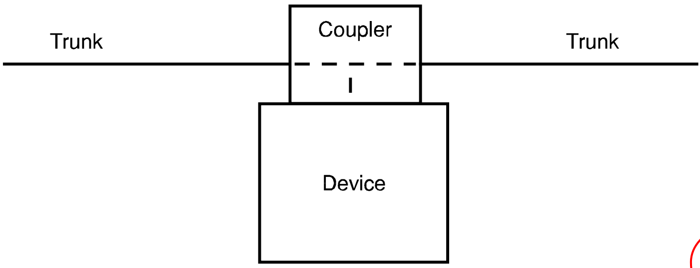

Figure 65 – Fieldbus coupler

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.

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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 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 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 centre 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 Colour coding of cables

NOTE Regional practice should be considered in the choice of cable colours.

Within North America, colours of inner cable conductors and outer cable sheath (jacket) should be assigned as specified in Table 59.

Table 59 – Recommended colour coding of cables in North America

Colour 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
Colour 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

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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 of IEC 61158-2 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.

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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 of IEC 61158-2. 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 of IEC 61158-2, 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 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.

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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:

$$0 \leq [\text{Attenuation } (1{,}25\ f_r) - \text{Attenuation } (0{,}25\ f_r)] \leq 6 \text{ dB}$$

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):

$$\left| \frac{Z - Z_{f_r}}{Z + Z_{f_r}} \right| \leq 0{,}2$$

where Z_{f_r} is the impedance of the trunk cable at frequency f_r (31,25 kHz) and Z is the parallel combination of Z_{f_r} 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 6.5.4 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 signalling, 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 signalling 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.

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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 59)	Limits
Output level (peak-to-peak, see Figure 60) 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 (signalling bias) as shown in Figure 61	±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 60)	±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 59)	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 60)	≤ 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 61)	± 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}

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12.4.2 MAU test configuration

Figure 59 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 60 describes the output form of the signal for the twisted-pair voltage output level requirements.

NOTE 1 Figure 60 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 60):

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 60);

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 60);

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 60, 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 61);

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 60;

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 60);

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 60);

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NOTE 2 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:

Max. slew rate = 2 × min. slew rate = 2 × 0,8 V_o / 0,25 T_{bit} = 6,4 × 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

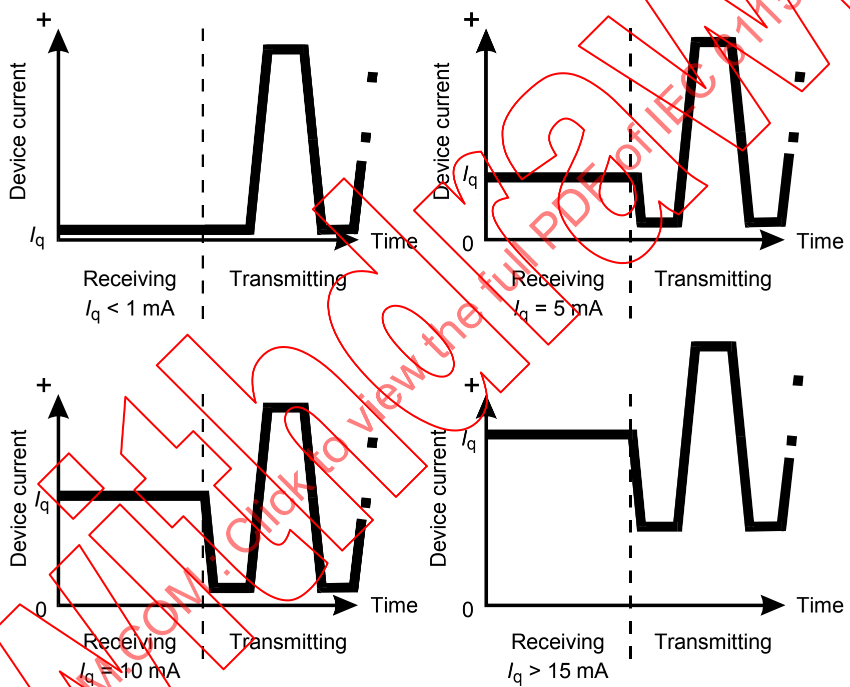
See 11.4.5.

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 66 shows four examples of different values of device quiescent current.



NOTE This figure is included in this part of IEC 61158 for explanatory purposes and does not imply a specific implementation.

Figure 66 – Transition from receiving to transmitting

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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 63)	150 mV
Noise rejection; max. peak-to-peak noise required to be rejected (see Figure 63)	75 mV
Maximum received bit cell jitter (zero crossing-point deviation, see Figure 60)	±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 63).

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 63).

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 61.

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 signalling.

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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, 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.

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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 This part of IEC 61158 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 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.	

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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 67
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 1,25 f_r, up to a maximum of 25 MHz;

h) levels at intermediate frequencies generally in accordance with Figure 67.

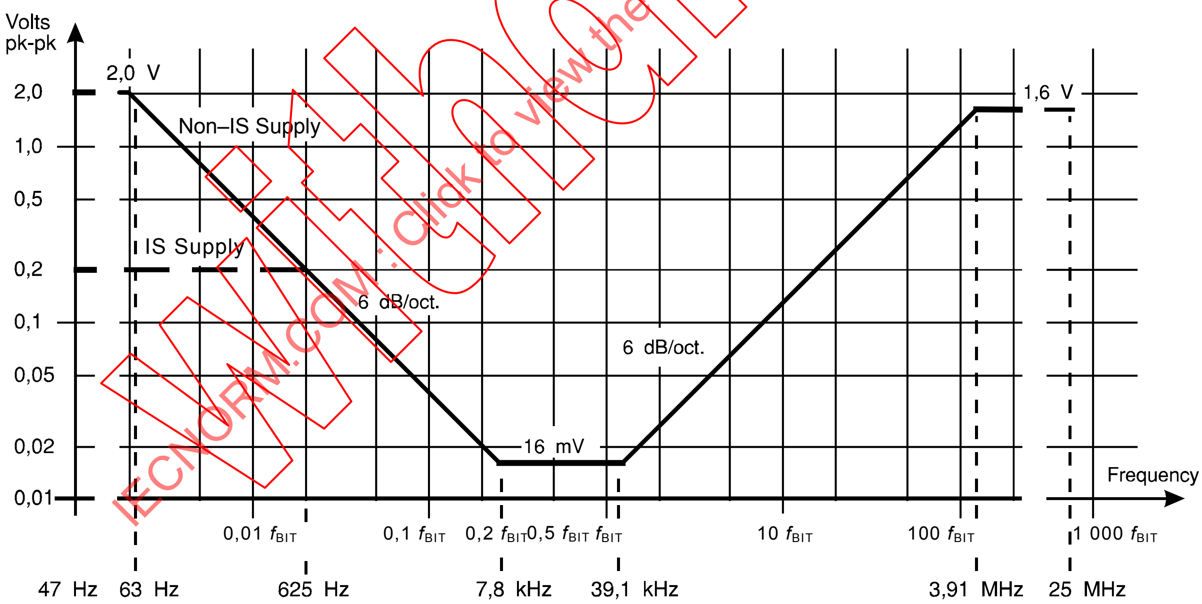

Figure 67 – Power supply ripple and noise

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.

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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 68.

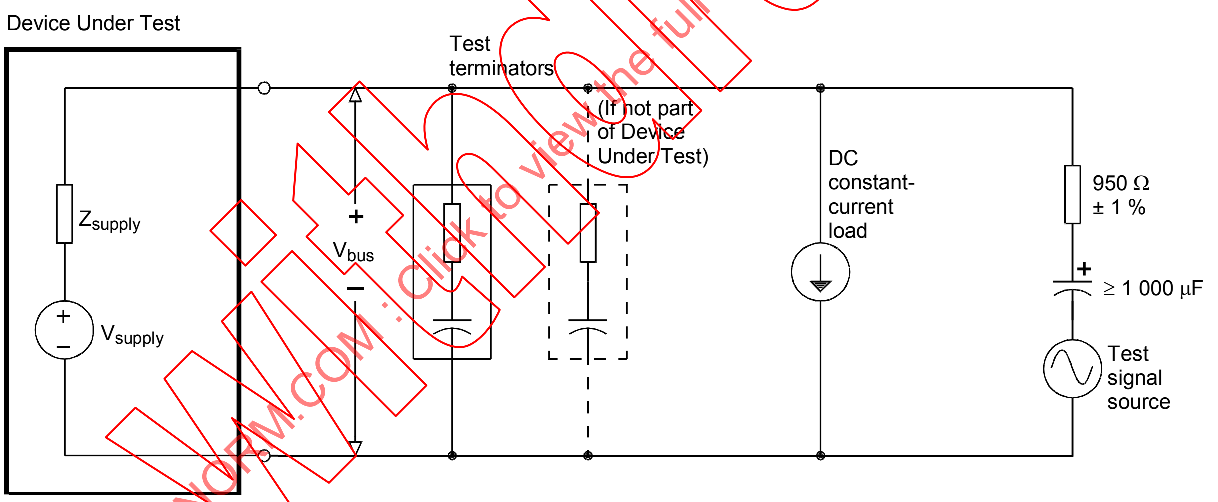

Figure 68 – Test circuit for single-output power supplies

The test terminators shown in Figure 68 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).

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The power supply shall be tested by monitoring the a.c. 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} 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-pk} and 0,60 V_{pk-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-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 and terminator to be combined as long as the combination is electrically equivalent to the independent devices meeting the requirements of this clause of IEC 61158-2, 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 69.

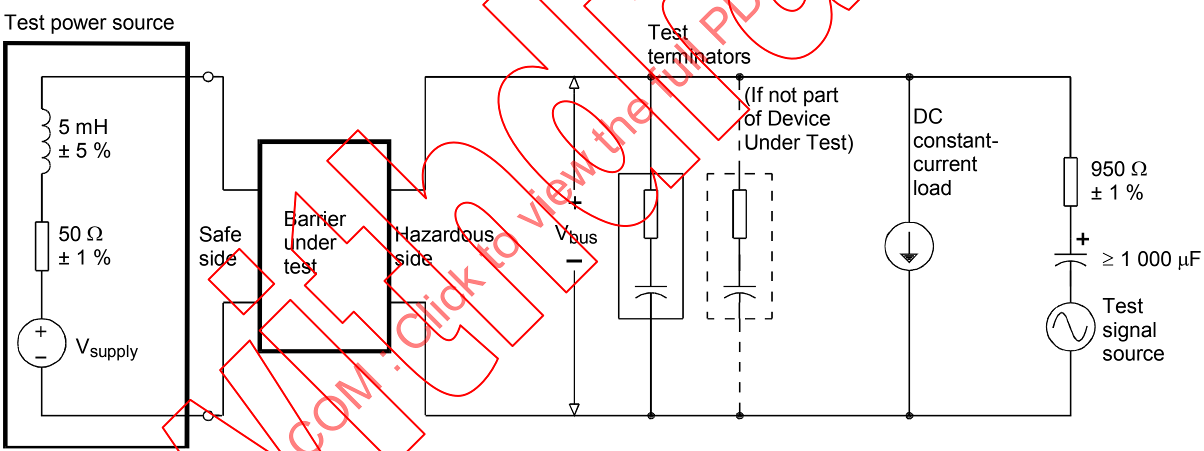

Figure 69 – Test circuit for power distribution through an IS barrier

The test power source shown in Figure 69 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.

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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 of IEC 61158-2, 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 section 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 70.

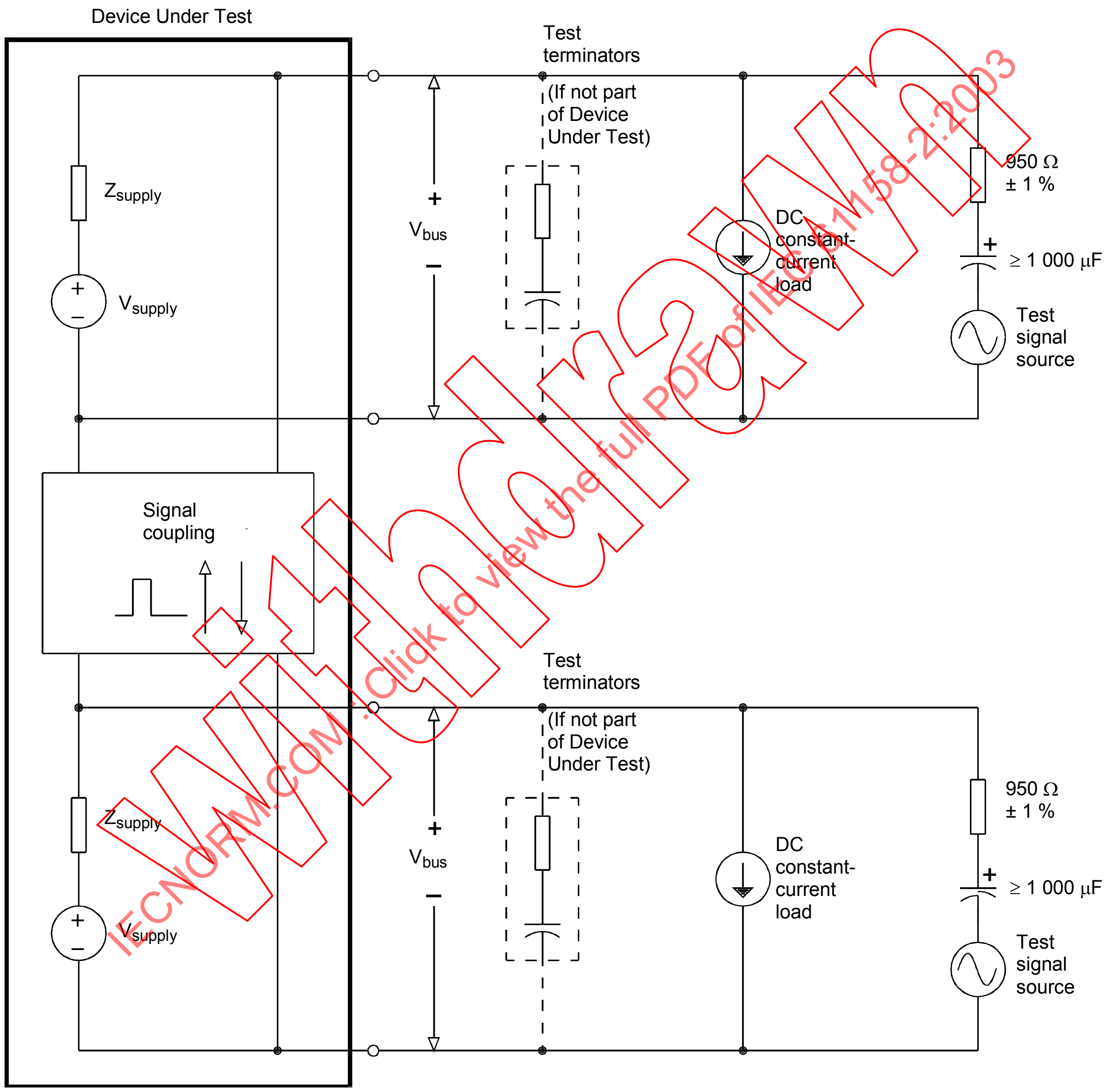

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Figure 70 – Test circuit for multiple output supplies with signal coupling

The test terminators shown in Figure 70 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 of IEC 61158-2 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.

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12.8.2 Standard test cable

The cable used for testing fieldbus devices which claim conformance to this clause of IEC 61158-2 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 71: one for the spur and one for each side of the trunk.

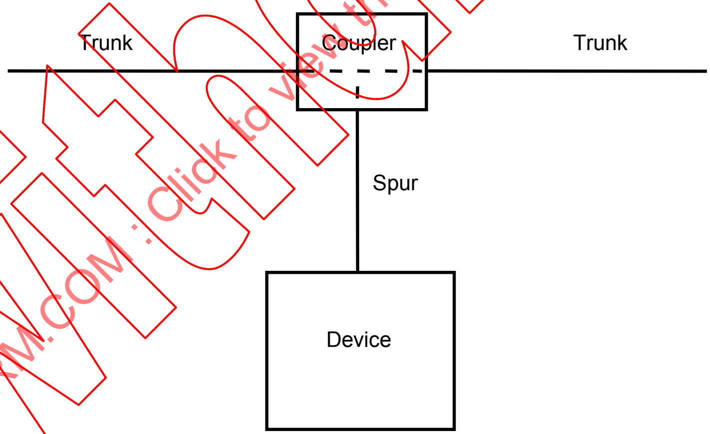

Figure 71 – Fieldbus coupler

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 72, to protect bus traffic between other devices from the effects of a short-circuit spur on an unpowered, non-intrinsically-safe trunk.

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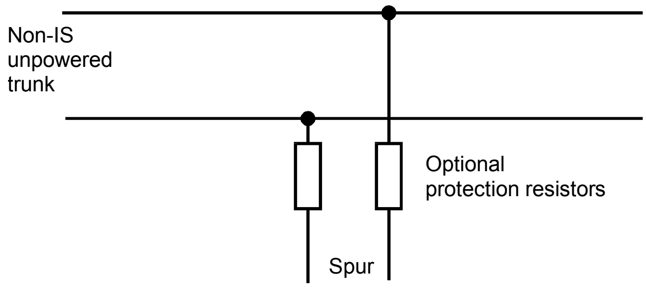

Figure 72 – Protection resistors

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.

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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 of IEC 61158-2 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 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 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 centre 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 Colour 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 colours are recommended for Type 3 systems, as shown in Table 65:

Table 65 – Type 3 cable colour specification

Cable Parameter	Colour
Colour of sheath non-IS	black
Colour of sheath IS	blue or blue/black stripe
Colour of inner cable conductor A (PA-)	green
Colour inner cable conductor B (PA+)	red

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12.9 Intrinsic Safety

12.9.1 General

This part of IEC 61158 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 of IEC 61158-2 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.

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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, $BR \pm \Delta BR$, 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 of IEC 61158-2.

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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 of IEC 61158-2 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.

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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):

$$\left|\frac{Z - Z_0}{Z + Z_0}\right| \leq 0{,}2$$

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 73)	Limits (bus-powered and/or IS)
Output level (peak-to-peak, see Figure 60) With test load (>2 × nominal Z_o of trunk cable)	≥2,5 V 320 Ω ± 1 %
Maximum positive and negative amplitude difference (signalling bias) as shown in Figure 61	±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 60)	±10 %
Quiescent transmitter output; i.e. transmitter noise (measured over the frequency band 1 kHz to 4 MHz)	≤1 mV (r.m.s.)

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Table 67 – MAU transmit timing specification summary

Transmit timing characteristics, values referred to trunk (but measured using test load as shown in Figure 73)	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 60)	≤ 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 61)	± 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 73 shows the configuration that shall be used for testing.

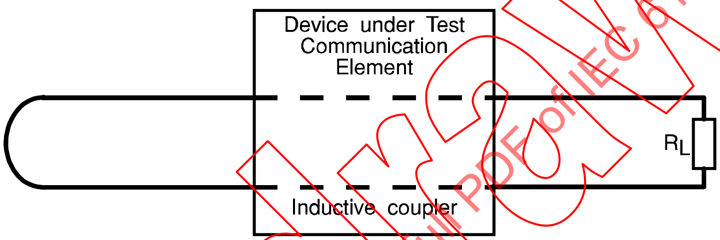

Figure 73 – Test configuration for current-mode MAU

The test configuration for this clause shall be as shown in Figure 73 except where otherwise stated in a specific requirement.

NOTE Test load resistance R = 320 Ω (twice maximum cable Z_0) as the output is loaded by a series loop of the trunk.

13.4.2 Output level requirements

NOTE Figure 60 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 60):

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 60);

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 60). 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 60, 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;

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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 60);

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 60);

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 formul1a:

Max. slew rate = 3 × Min. slew rate = 3 × 0,8 V_o / 0,2 T = 12 × 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 74);

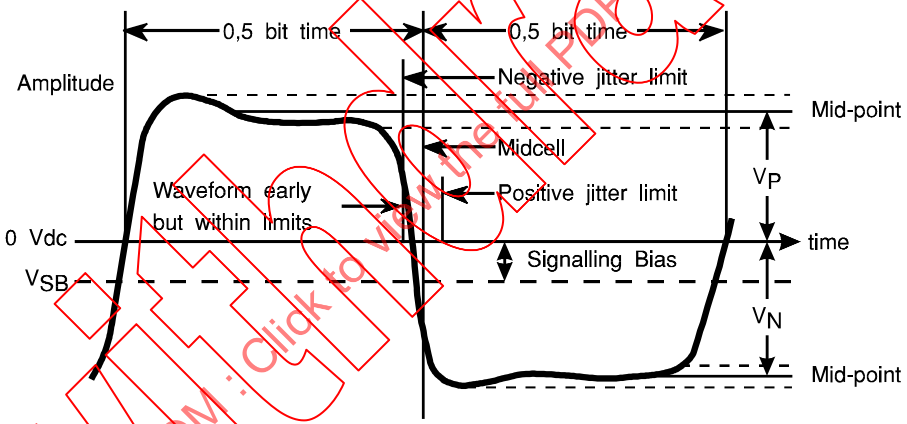

Figure 74 – Transmitted and received bit cell jitter (zero crossing point deviation)

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 13.4.2 e) 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 13.4.2 e), 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 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.

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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 63)	1,3 mA
Noise rejection; max. peak-to-peak noise required to be rejected (see Figure 63)	0,8 mA
Maximum received bit cell jitter (zero crossing-point deviation, see Figure 74)	±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 60).

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 63).

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 74.

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 signalling.

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.;

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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 75.

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 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, 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.

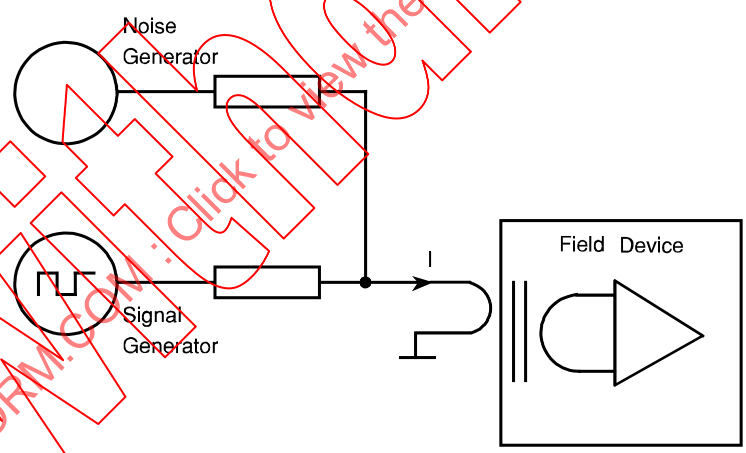

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Figure 75 – Noise test circuit for current-mode MAU

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 part of IEC 61158 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.

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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 of IEC 61158-2 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 %.

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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.

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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 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 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 Colour coding of cables

See 11.8.8.

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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.

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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 of IEC 61158-2, 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 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, 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.

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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:

$$[\text{Attenuation } (1{,}25\ f_r) - \text{Attenuation } (0{,}25\ f_r)] \leq 6 \text{ dB}$$

$$\text{Attenuation } (1{,}25\ f_r) \geq \text{Attenuation } (0{,}25\ f_r)$$

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):

$$\left| \frac{Z - Z_0}{Z + Z_0} \right| \leq 0{,}2$$

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.

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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 73)	Limits (bus powered and/or IS)
Output level (peak-to-peak, see Figure 60) 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 60)	±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 73)	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 60)	≤ 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 76)	± 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 73 shows the configuration which shall be used for testing.

The test configuration for this clause shall be as shown in Figure 73 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 60 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 60):

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 60);

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.

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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 60);

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 60);

transmitted bit cell jitter shall not exceed ±0,025 T_{bit} from the ideal zero crossing point, measured with respect to previous zero crossing (see Figure 76);

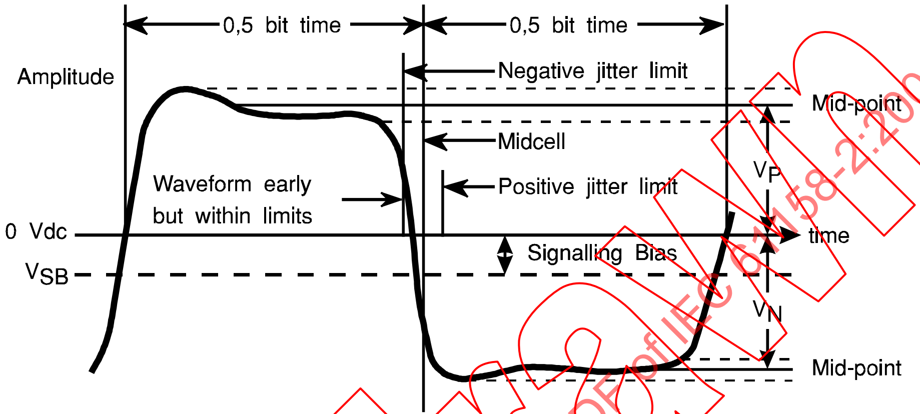

Figure 76 – Transmitted and received bit cell jitter (zero crossing point deviation)

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 T_{bit}. 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 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 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.

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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 63)	4,0 mA
Noise rejection; max. peak-to-peak noise required to be rejected (see Figure 63)	2,0 mA
Maximum received bit cell jitter (zero crossing-point deviation, see Figure 74)	±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 60).

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 63).

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 T_{bit} or less. See Figure 76.

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 signalling.

14.5.5 Interference susceptibility and error rates

See 13.5.5.

14.6 Jabber inhibit

See 13.6.

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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 part of IEC 61158 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 77
Output impedance, measured over the frequency range 0,25 f_r to 1,25 f_r (250 kHz to 1,25 MHz)	≤5 Ω

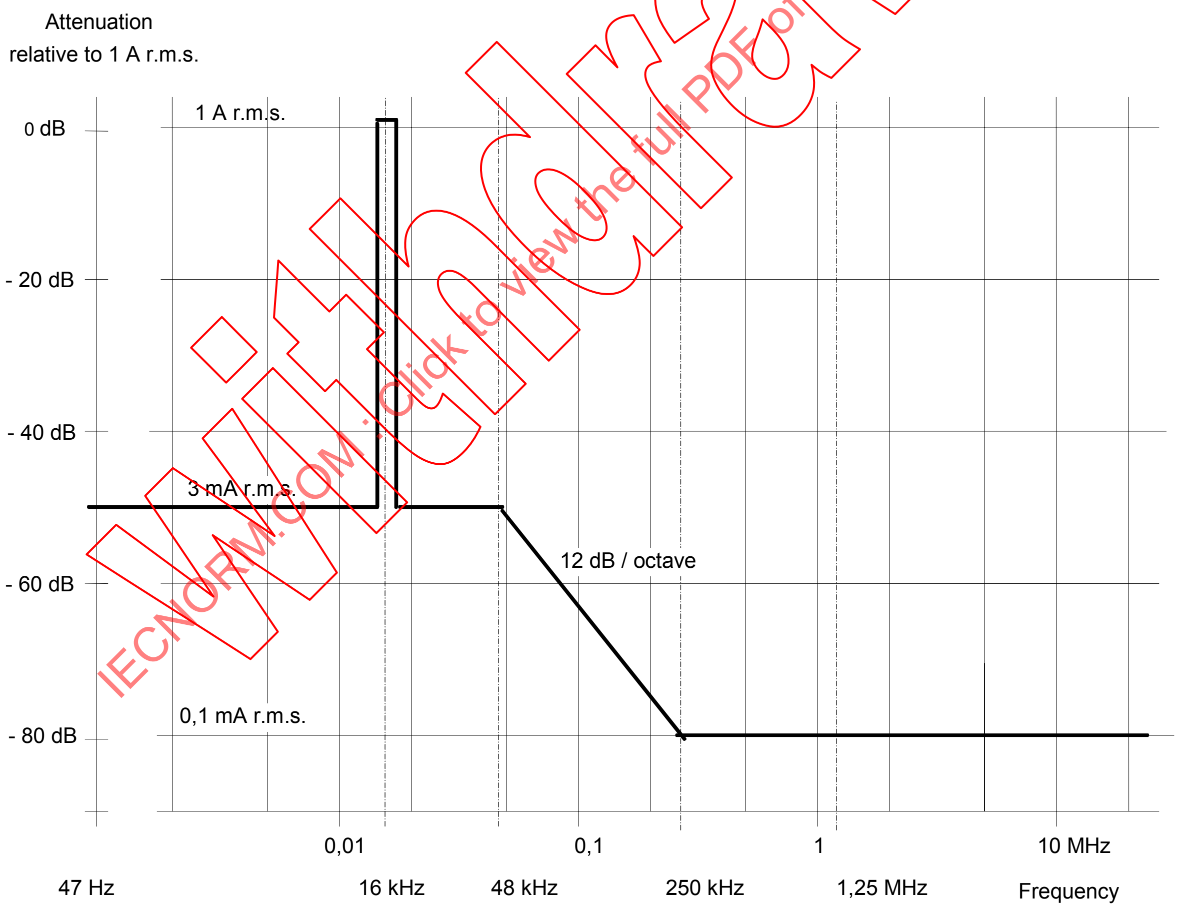

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Figure 77 – Power supply harmonic distortion and noise

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:

   i) 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);

   ii) 3,0 mA r.m.s. over the frequency range 47 Hz to 48 kHz, with the exception of 16 kHz ± 0,5 %;

   iii) levels at other frequencies in accordance with Figure 77.

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 of IEC 61158-2 shall be a single twisted-pair cable with overall shield meeting the following minimum requirements at 25 °C:

a) Z_0 at 0,25 f_r (250 kHz) = 80 Ω ± 10 %;

b) Z_0 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.

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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 Colour coding of cables

See 11.8.8.

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15 Types 1 and 7: Medium Attachment Unit: dual-fibre optical media

15.1 General

The network medium consists of a pair of fibre optic waveguides providing bidirectionality by use of a separate fibre for each direction of signal propagation. These are known collectively as an elementary optical path.

In all networks involving more than two devices, the fibre 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 fibres connect to the CPIC of a fieldbus device. The fibre 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-fibre 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 clause:

Table 74 – Bit-rate-dependent quantities of high-speed (≥1 Mbit/s) dual-fibre 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 $BR \pm \Delta BR$, averaged over a frame having a minimum length of 16 octets. The instantaneous bit time shall be $T_{bit} \pm \Delta T_{bit}$.

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.

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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 fibre 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.

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Table 75 – Transmit level and spectral specification summary

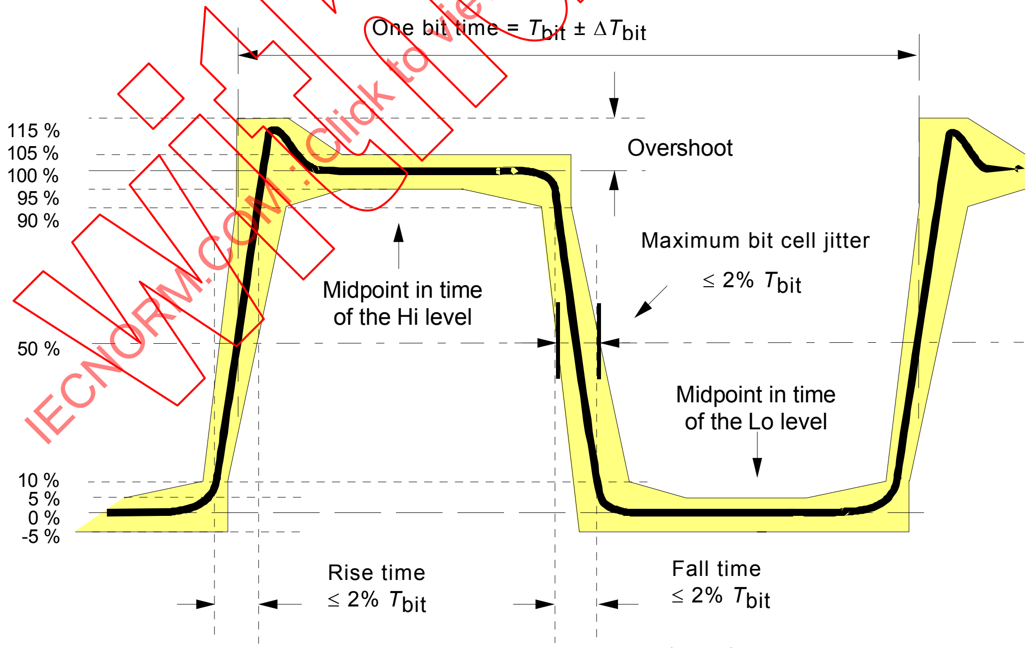
Transmit level and spectral characteristics (values referred to the CPIC with standard test fibre)	Limits, using 62,5/125 μm fibre
Peak emission wavelength (λp)	(850 ± 30) nm
Typical half-intensity wavelength (Δλ)	≤50 nm
Effective launch power Hi level	(–11,5 ± 1,5) dBm
Overshoot of transitions	≤15 % 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 78). 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 fibre)	Limits
Transmitted bit rate	*BR* ± Δ*BR*
Instantaneous bit time	$T_{bit} \pm \Delta T_{bit}$
Rise and fall times (10 % to 90 % of peak-peak signal)	≤ 2,0 % T_{bit}
Difference between rise and fall times	≤ 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 78 – Optical wave shape template

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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 fibre)	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 % T_{bit}	

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 % T_{bit} 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 T_{bit} or 0,5 T_{bit}.

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

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-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, 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 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.

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 fibre

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 fibre optic cable with two silica fibre optic waveguides. The characteristics of those waveguides shall be compatible with IEC 60793-2 [fibre 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

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– 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 fibres are allowed. Operation using a 50 µm or 100 µm alternate test fibre 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

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:

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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 fibre)	Limits, with 62,5/125 μm fibre	
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 % T_{bit}
Maximum temporal deformation between optical input ports and optical output ports (see NOTE 1)	±3 % T_{bit}
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 T_{bit}
Maximum transmitted bit cell jitter for an optical active star with timing regenerative function (see NOTE 2)	±2,0 % T_{bit}
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.	

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16 Type 1: Medium Attachment Unit: 31,25 kbit/s, single-fibre optical medium

16.1 General

The network medium consists of a set of bidirectional single-fibre optic waveguides, each known as an elementary optical path.

In all networks involving more than two devices, the fibre optic waveguides conveying signals from the devices are combined by a reflective passive star coupler, where the received signals are retransmitted on all the fibre 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 fibres connect to the CPIC of a fieldbus device. The fibre optic transmission system is itself intrinsically safe.

16.2 Transmitted bit rate

The transmitted bit rate, $BR \pm \Delta BR$, shall be 31,25 kbit/s ± 0,2 %, averaged over a frame having a minimum length of 16 octets. The instantaneous bit time, $T_{bit} \pm \Delta T_{bit}$, 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.

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Table 80 – Transmit level and spectral specification summary

Transmit level and spectral characteristics (values referred to the CPIC with standard test fibre)	Limits for 31,25 kbit/s (100/140 μm fibre)
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 78). 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 fibre 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 fibre

silica fibre optic waveguide whose nominal characteristics are compatible with IEC 60793-2 [fibre type: A1d (100/140 μm)].

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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 fibre optic cable with one fibre 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 fibres are allowed. Operation using a 50 µm or 62,5 µm alternate test fibres 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

a) 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 fibre)	Limits, with 100/140 µm fibre	
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

b) Timing characteristics

The timing characteristics of 15.7.4.3 apply.

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17 Type 1: Medium Attachment Unit: low speed radio medium

17.1 Transmitted bit rate

The radio medium fieldbus MAU transmitted Bit rate shall be 4 800 bit/s ± 0,2 % over a frame having a minimum length of 24 octets.

NOTE This will allow five PhPDU messages of 35 octets per second to be handled, or three messages of 75 octets that is considered sufficient for the application area of the low speed radio medium. Most radio fieldbus applications in the process industries where the low speed, low power medium is required, are for monitoring only, where 1 message per minute sending the average, minimum and maximum of a measured value is sufficient. Even for control applications, more than 80 % of loops in the process industries can be handled at 1 update per second or slower. Higher speed factory and short distance line of site process applications will be handled by the higher speed radio media.

17.2 Network specification

17.2.1 Components

The network shall be composed of combinations of the following types of hardware.

a) Cable
b) Radio transponder modules composed of devices with a radio medium PhL
c) Intrinsic safety barriers
d) Couplers
e) Devices (may or may not be powered from the network)
f) Connectors
g) Power supplies
h) Combined power supplies/devices
j) Antennas
k) Terminators

17.2.2 Topologies

The radio medium fieldbus MAU shall operate in a network using a single radio channel for each network. Each network shall be capable of operating as a separate fieldbus or as a radio segment between two physically separate segments of a wired fieldbus.

17.2.3 Network configuration rules

A low speed radio MAU shall be required to conform to the requirements of this clause of IEC 61158-2 when used in a network that complies with these rules.

Rule 1: The maximum propagation delay between any two devices shall not exceed 20 T_{bit}.

Rule 2: That part of the turnaround time of a device that is introduced by a PhL entity between the end of a received frame and the beginning of the transmitted frame, containing an associated immediate response, shall not exceed five bit times.

Rule 3: The following rules shall apply to systems implemented with redundant media:

a) each channel (frequency) 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;

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e) channel numbers shall be maintained throughout the fieldbus, i.e. channel 1,2,3… from Systems management shall always connect to physical channels 1,2,3…

Rule 4: All communicating elements on one fieldbus using radio medium shall operate at the same bit rate and use the same radio channel.

NOTE 1 This rule defines the basic communication as half duplex. Only one channel shall be used for a single radio fieldbus with all devices using the single radio channel and only one device transmitting at any one time, (however all devices can receive at the same time) as controlled by the link layer.

Rule 5: More than one independent radio medium fieldbus may operate in the same physical location, but then each separate network shall operate on a different radio channel.

Rule 6: 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 centres are less than 40 m apart shall use different radio channels. Non-adjacent cells using class 2 receivers whose geographic centres are less than 400 m apart shall use different radio channels. Non-adjacent cells using class 3 receivers whose geographic centres are less than 4 000 m apart shall use different radio channels.

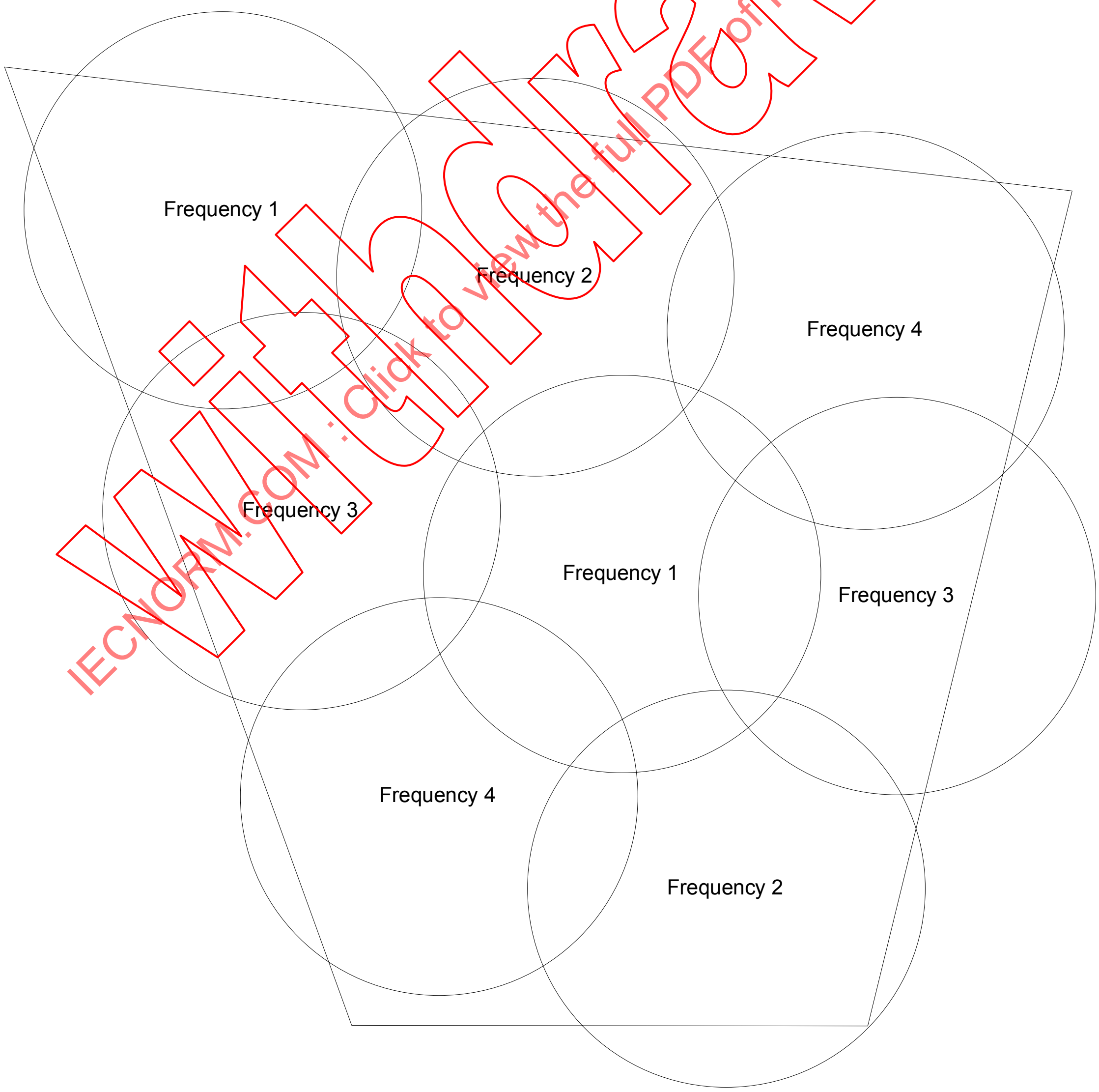

Figure 79 – Cellular radio topology and reuse of frequencies

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NOTE 2 See Figure 79 for the cellular structure using radio medium fieldbus networks covering a large industrial site. Examples of the topologies are given in Figure 80 and Figure 81. These three figures are included for explanatory purposes and do not imply a particular implementation.

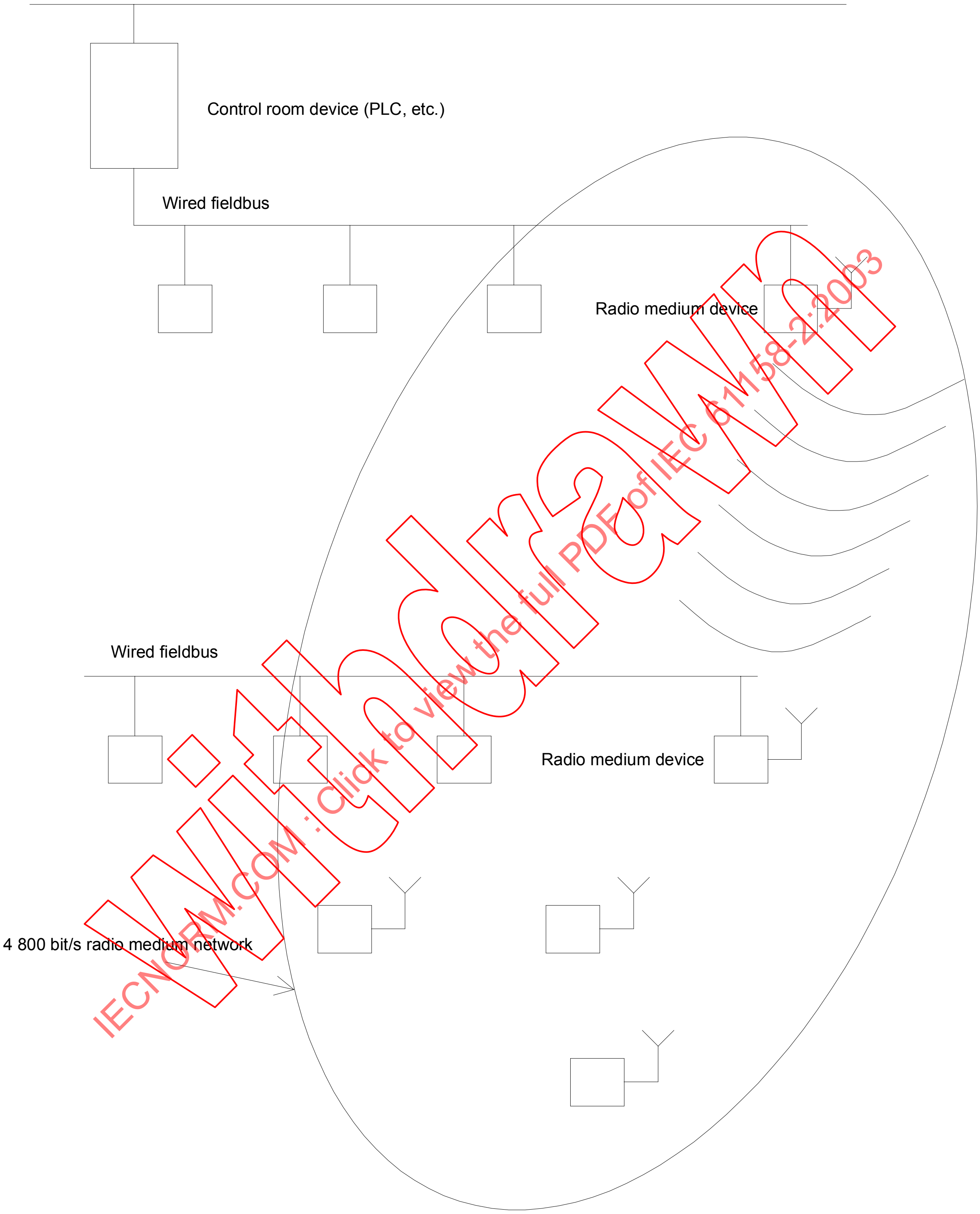

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Figure 80 – Radio segment between wired segments topology

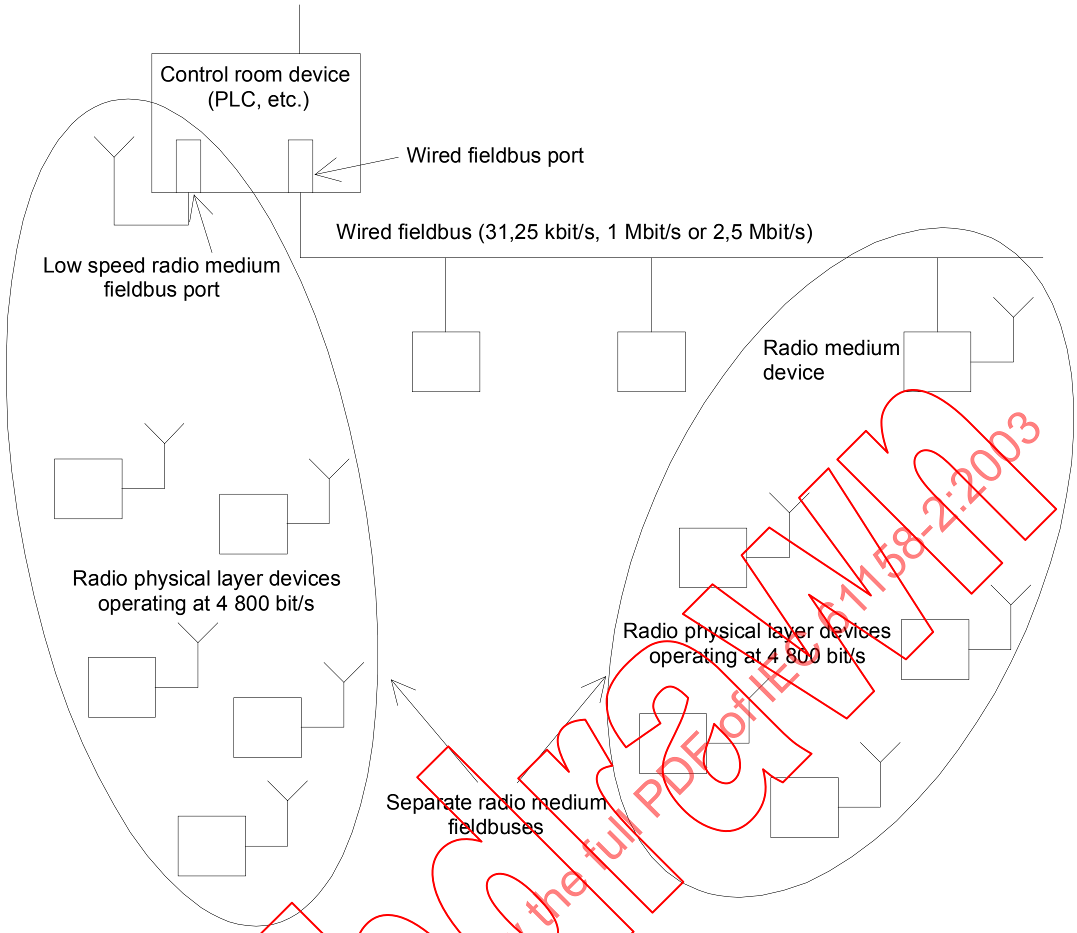

Figure 81 – Mixed wired and radio medium fieldbus topology

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NOTE 3 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 4 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. The network management layer may optionally include a service to read and or set the carrier frequency in megahertz to three places after the decimal point.

NOTE 5 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 7: It shall be possible to use radio repeaters to extend the range of a specific installation, providing that the overall propagation time between any two devices on either side of a chain of repeaters does not exceed 20 bit times. These repeaters will use different frequency channels.

17.3 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 both frequencies adequately.

17.4 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 2 s and 4 s 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 50 s ± 50 %.

NOTE This inhibits bus traffic for no more than 8 % (≤ 1/12,5) of the available time.

17.5 Common air interface

17.5.1 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.

Channel bandwidths shall be 12,5 kHz, even where local radio regulations allow a greater bandwidth. The number of channels shall be determined by the local regulations, and where these specify allowable bandwidths of an integral multiple of 12,5 kHz then extra radio medium fieldbus channels may be used by subdividing the allowable channels.

Channel frequency accuracy will be as specified by the local radio regulations or giving a delta of less than or equal to ±0,001 % of the nominal centre frequency between this frequency and the actual centre 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.

17.5.2 Modulation

The modulation employed shall be 2-level Minimum Frequency Shift Keying shaped by a Gaussian filter (GMSK) with a filter constant Bn of 0,41 ± 0,2 % where Bn = bandwidth of the filter multiplied by the symbol time. With a Bn of 0,41 the filtered waveform of one symbol is spread over 2,439 symbol times, see Figure 82.

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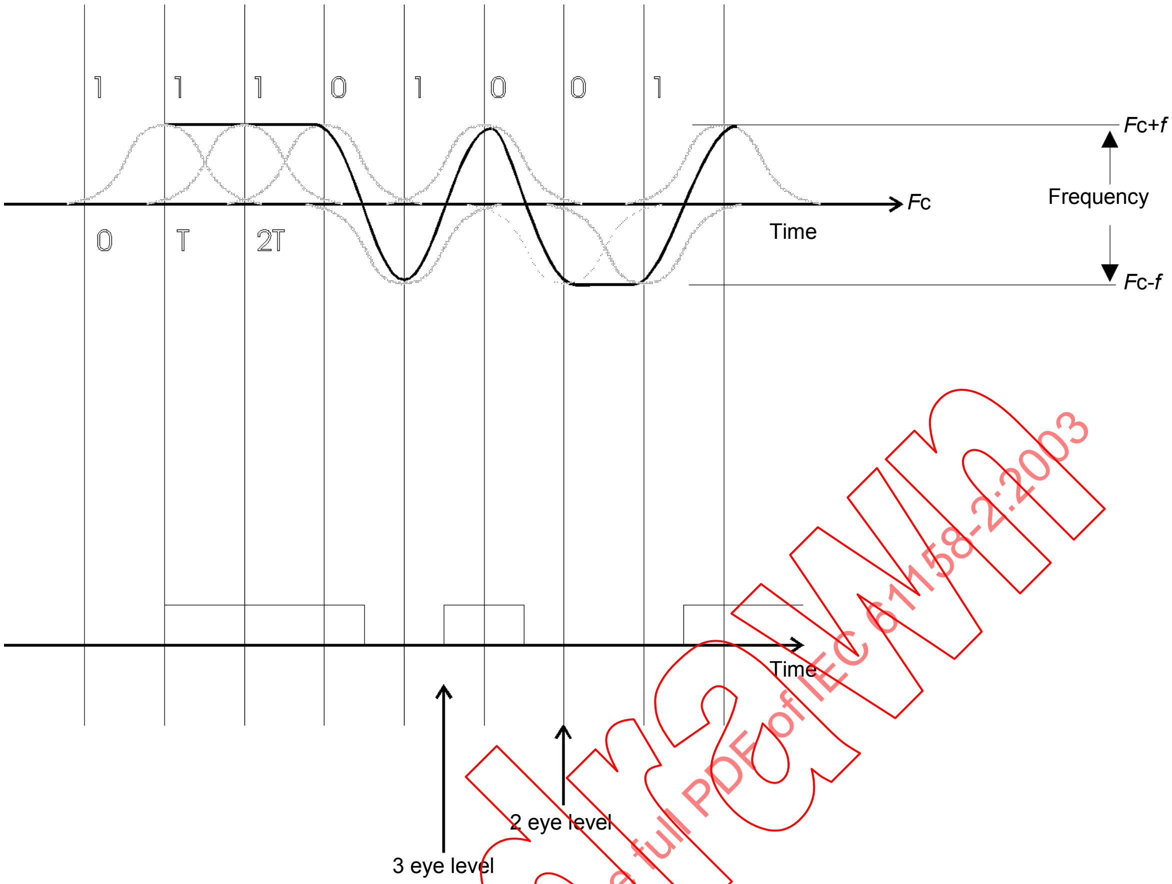

Figure 82 – Gaussian Minimum Shift Keying modulation with Bn = 0,41

A binary 1 shall be encoded as a frequency higher than the carrier frequency (*Fc*+*f*); a binary 0 shall be encoded as a frequency lower than the carrier frequency (*Fc*-*f*), where *f* is the bit rate divided by four.

NOTE 1 The RF envelope is shown in Figure 83.

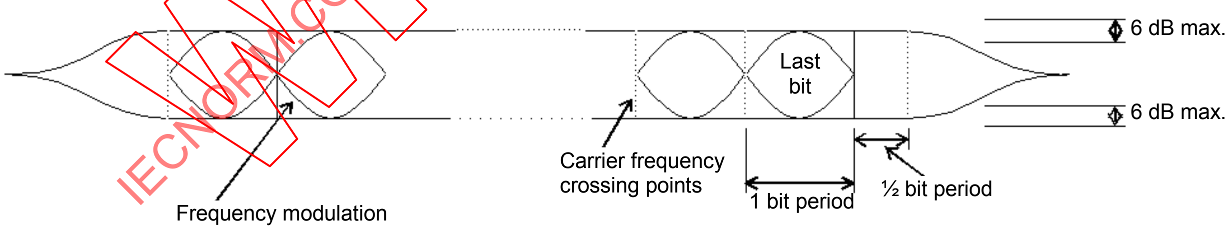

Figure 83 – Radio envelope using GMSK

NOTE 2 The frequency shift for minimum shift keying is defined as 1/4**T* where *T* is the bit time or symbol time for a binary signalling system.

The amplitude of the RF envelope shall be within 3 dB of the final envelope at the start of the first bit being transmitted.

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17.5.3 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 set 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.

17.5.4 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 32 random user data bits with maximum frame rate, shall produce no more than 10 detected errors in 1 000 frames after forward error correction by the radio medium MDS, 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 centre 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, 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: with forward error correction (if applied by the radio medium MDS), 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.

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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 forward error correction by the radio medium MDS, 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 centre 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, 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: with forward error correction (if applied by the radio medium MDS), 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 4000 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 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 forward error correction by the radio medium MDS, 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 centre 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, 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: with forward error correction (if applied by the radio medium MDS), 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.

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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 centre 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.	

17.5.5 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.

17.5.6 Transmit receive turnaround time

The transmit to receive and the receive to transmit turnaround times shall be no more than 10 bit times.

17.5.7 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.

17.6 Device specifications

17.6.1 Operation during commissioning and power up/down

The fieldbus shall be capable of continued operation while a device is being commissioned, powered up, powered down, connected or disconnected. Data errors induced during such operations shall be detected. Devices shall inhibit radio transmission during their own power up or down operation.

17.6.2 Device failures

Failure of any communication element (with the exception of jabber) shall not interfere with transactions between other communication elements for more than 1 000 ms.

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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 signalling 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 1000 m long with up to 48 nodes (see 18.5).

The MAU shall consist of a transceiver, transformer, and connector as shown in Figure 84. 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 connectors as specified in Annex F. Ground isolation shall be provided via the transformer as specified in 18.3.

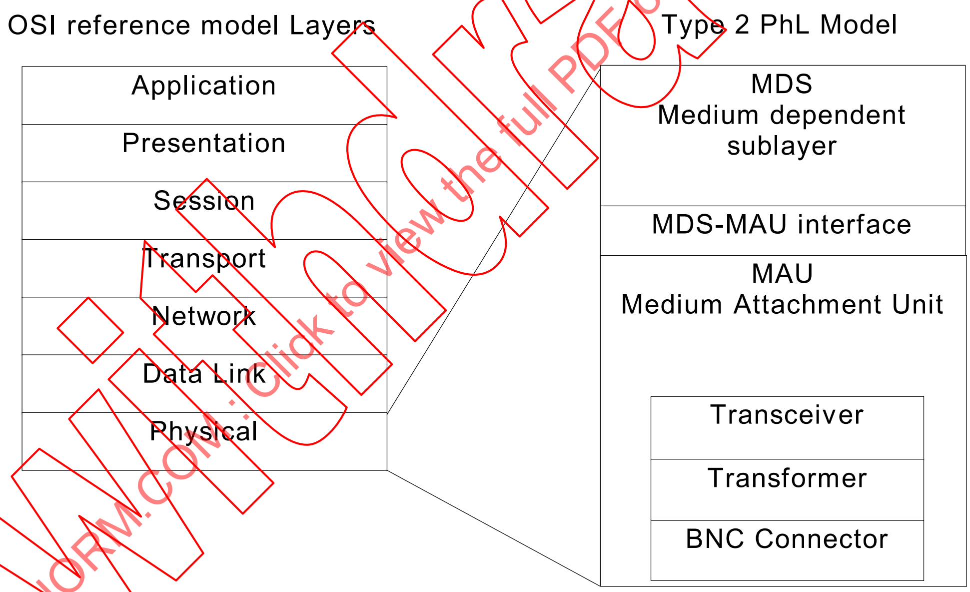

Figure 84 – Components of 5 Mbit/s, voltage-mode, coaxial wire PhL variant

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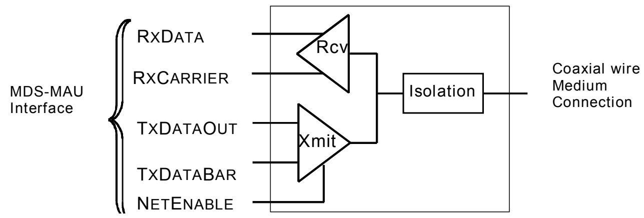
18.2 Transceiver: 5 Mbit/s, voltage-mode, coaxial wire

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 85.

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 85 – Coaxial wire MAU block diagram

Figure 86 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.

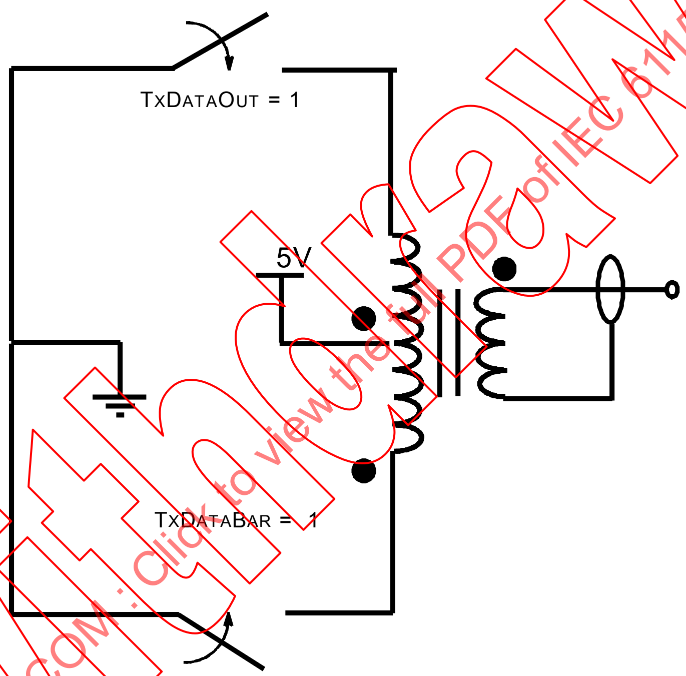


Figure 86 – Coaxial wire MAU transmitter

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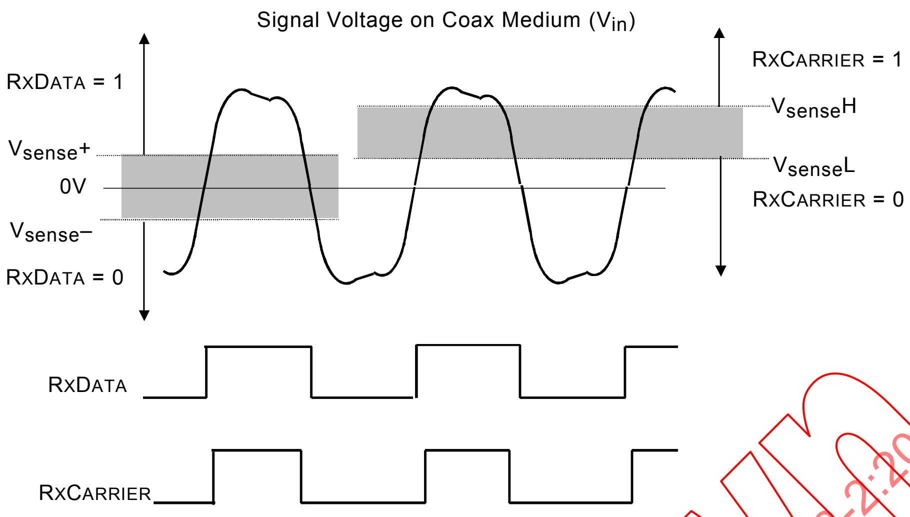
Three signals shall be available at the MDS-MAU interface for controlling transmission onto the medium, TxDataOut, TxDataBar, and NetEnable. These three transmit signals, when connected to the transceiver, shall define the physical symbols on the wire. The relationship between these transceiver request 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 87 – 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 87 shall be defined as the voltage as measured between the coaxial cable centre conductor and the coaxial shield. All polarities shall be defined in terms of the voltage on the coaxial cable centre 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.

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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 88
Transmit level asymmetry (between 0 and 1)	< 450 mV max [b, d]	
Transmit signal distortion (over voltage, droop, ring)	± 10 % [a, e]	see Figure 88
Total transmit jitter (Tx Jitter)	< 5 ns	see Figure 88
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 88
Rise / fall limit (10 % to 90 % of peak-to-peak)	30 ns max [a]	see Figure 88

[a] This shall be a peak to peak voltage as measured into a 37,5 Ω load from 0 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 to 20 MHz.

[e] Levels shall be a function of the actual measured transmit voltage.

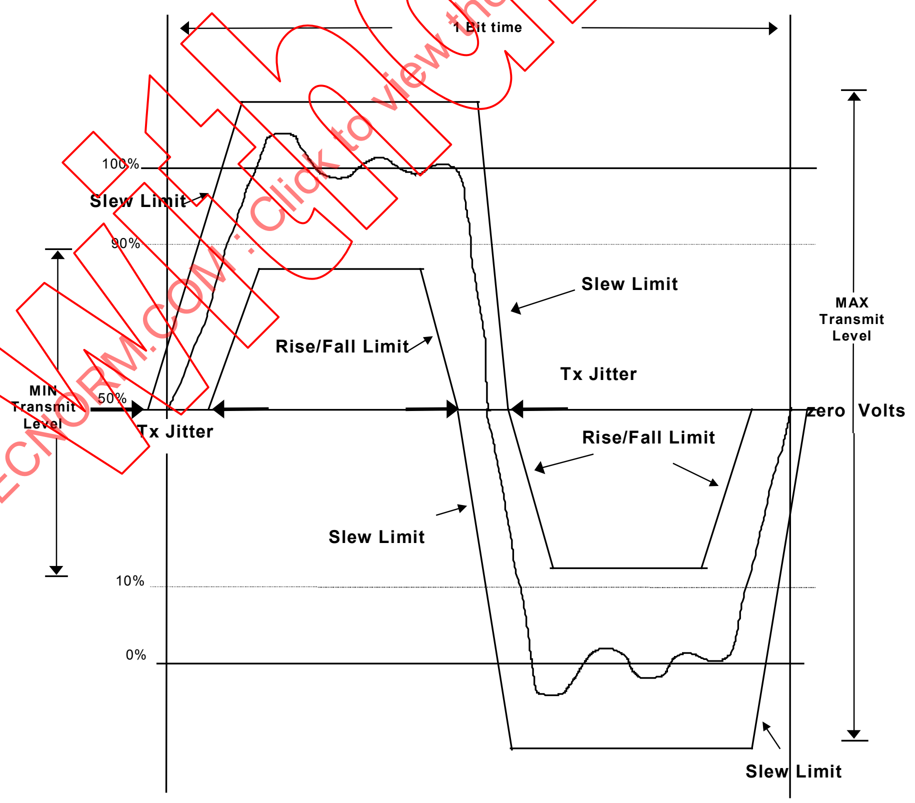

Figure 88 – Coaxial wire MAU transmit mask

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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 89
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_{senseL})	+ 23 mV	allows for hysteresis and tolerance
High carrier sensitivity limit (V_{senseH})	+ 255 mV	allows for hysteresis and tolerance
`RxData` pattern jitter (peak-to-peak) for Vin > 510 mV	< 40 ns	inside of eye pattern as shown in Figure 89 shall be true when V_{in} > Minimum Receive Signal Level

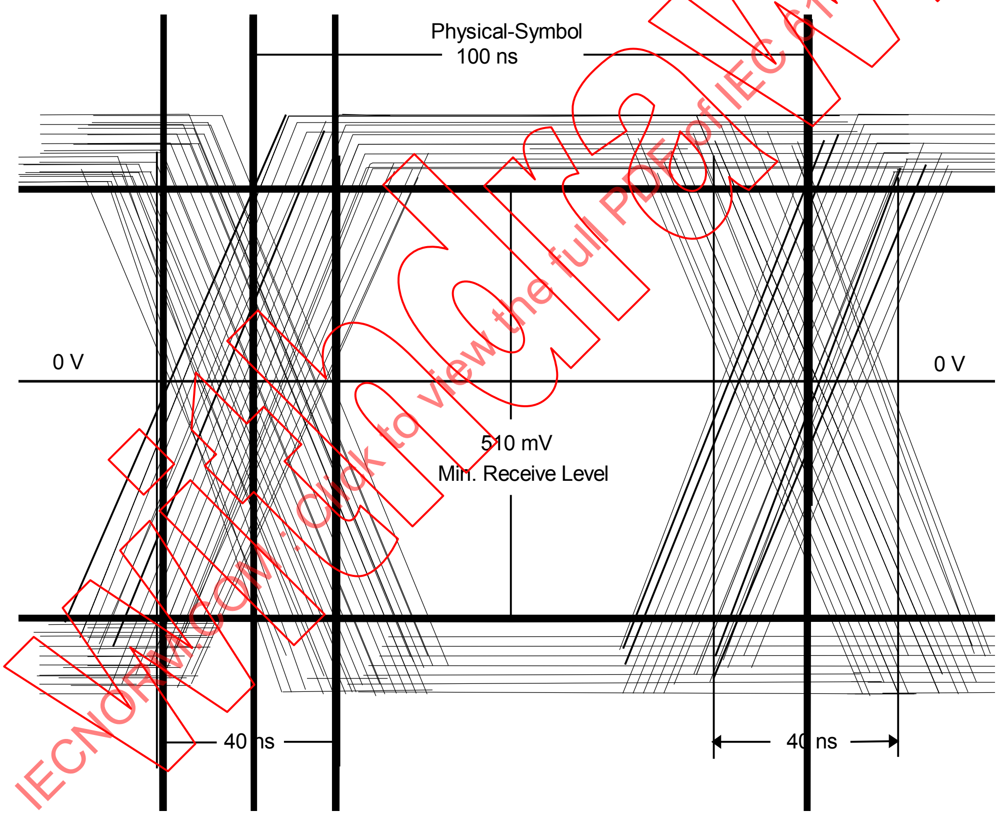

Figure 89 – Coaxial wire MAU receive mask

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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 93) 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	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 90 shows the schematic symbol for the transformer.

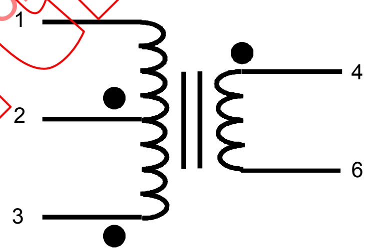

Figure 90 – Transformer symbol

Coupling transformers shall conform to the requirements specified in Table 89.

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Table 89 – 5 Mbit/s, voltage-mode, coaxial wire transformer electrical specifications

Specification	Minimum	Typical	Maximum
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 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 91 shows a topology example.

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NOTE 2 In this example, two segments are connected by a repeater to form a seven node link.

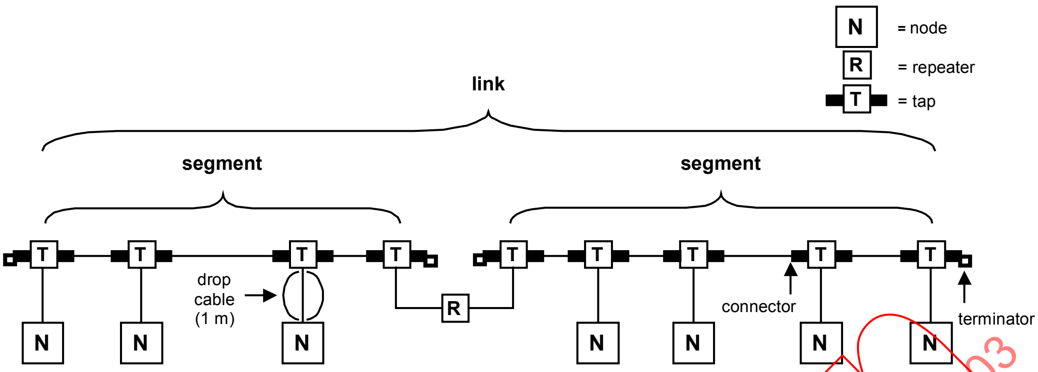

Figure 91 – 5Mbit/s, voltage-mode, coaxial wire topology example

Topology limits are shown in Figure 92. Up to 48 nodes can be connected to a segment of length up to 1000 m as shown in Figure 92. The trade-off between distance and number of nodes is shown in Figure 92. 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 92 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 92.

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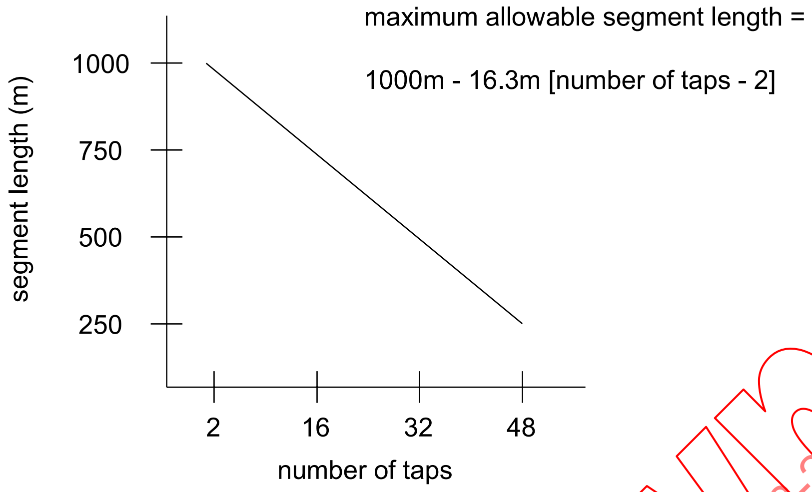

Figure 92 – Coaxial wire medium topology limits

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 tap shall provide BNC jack connections at the trunk and a 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 of IEC 61158-2.

The transmission and reflection requirements shall be as shown in Figure 93. 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 93.

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NOTE 2 The tap is a reciprocal device (S11=S22, S12=S21) so trunk port orientation is arbitrary.

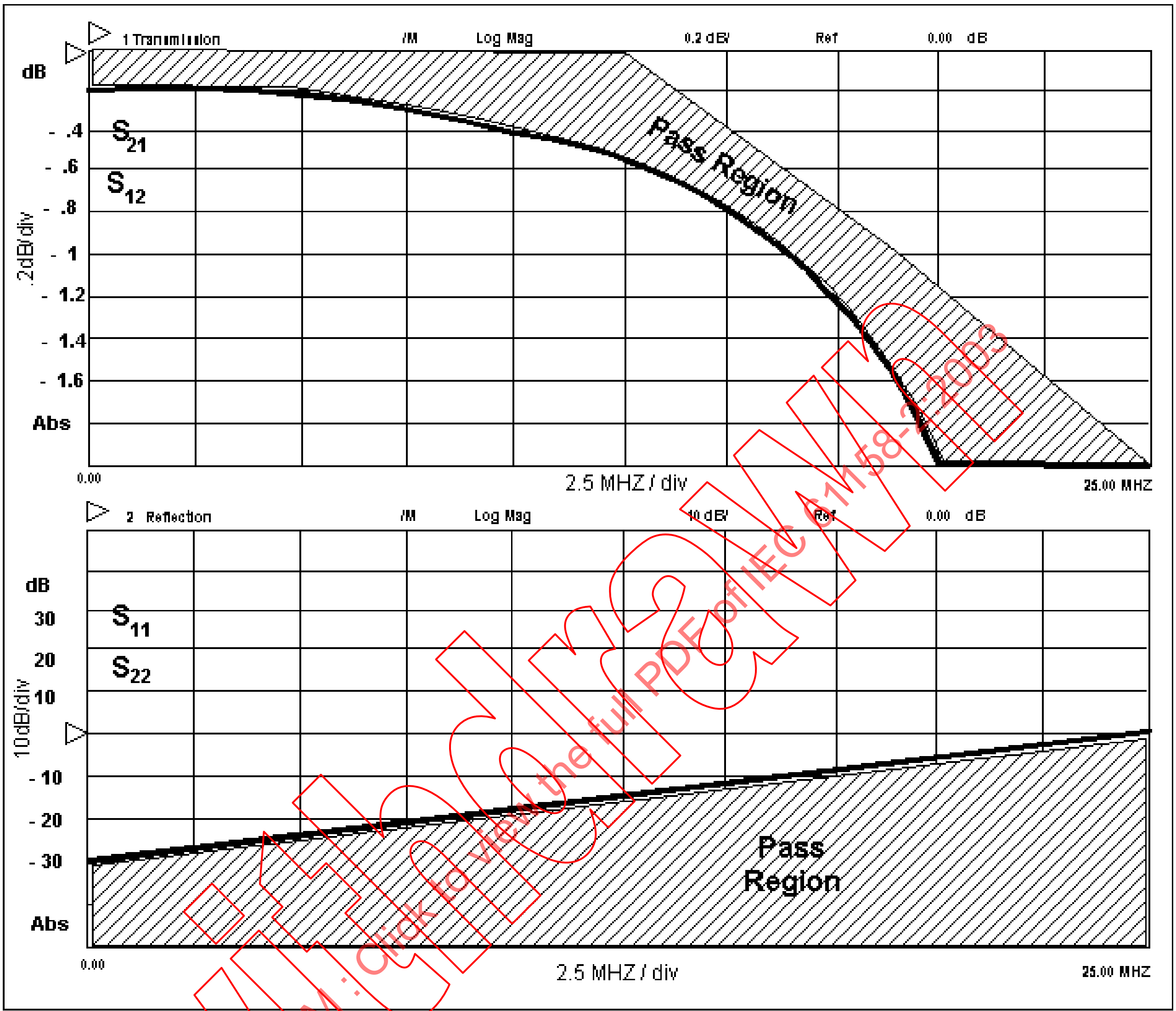

Figure 93 – Coaxial wire medium tap electrical characteristics

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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
Electrical specifications	
Shielding	Dual shield
Impedance	75 Ω ± 3 Ω
Nominal inductance	304,5 nH/m
Nominal capacitance	54,13 pF/m
Delay	4,06 ns/m ± 0,1 ns/m
Attenuation (dB/100 m) @	
1 MHz	1,21
5 MHz	2,88
10 MHz	4,13
50 MHz	9,71
Structural return loss	26 dB minimum from 5 to 50 MHz
Conductor DC resistance	83,7 Ω/km nominal
Shield DC resistance	10,49 Ω/km nominal
Mechanical specifications	
Center conductor material and diameter	solid copper 0,51 mm
Dielectric material and diameter	Foam polyethylene 2,43 mm
Shield type (dual) diameter	1st layer 0,1 mm gauge strands, 95% coverage tin coated copper braid 2nd layer 0,1 mm gauge strands, 95% coverage tin coated copper braid
Jacket diameter	3,94 mm

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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
Electrical specifications	
Shielding	Quad shield
Impedance	75 Ω ± 3 Ω
Nominal inductance	318,24 nH/m
Nominal capacitance	53,15 pF/m
Delay	4,16 ns/m ± 0,1 ns/m
Attenuation (dB/100 m) @	
1 MHz	1,18
2 MHz	1,25
5 MHz	1,48
10 MHz	1,94
20 MHz	2,82
50 MHz	4,53
Structural Return Loss	23 dB minimum from 5 to 50 MHz
Conductor DC Resistance	92 Ω/km nominal
Shield DC Resistance	11,8 Ω/km nominal
Mechanical specifications	
Centre Conductor Material & Diameter	solid Bare Copper Covered Steel 1,0 mm ± 0,0197mm
Dielectric Material & Diameter	Foam Polyethylene 7,086 mm ± 0,197 mm
Shield Type (quad)	1st layer bonded foil 2nd layer 60% coverage braid 3rd layer foil 4th layer 40% coverage braid
Jacket Diameter	11,81 mm ± 0,197 mm

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18.7.2 Connectors

The trunk connection shall use a BNC 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 fibre medium attachment method defines three fibre media and PhL variants. The first variant covers fibre media and PhL requirements for a short-range system for distances of up to 300 m (nominal), the second variant covers fibre media and PhL requirements for a medium-range system for distances of up to 7km (nominal), and the last variant covers fibre media and PhL requirements for a long-range system for distances of up to 20km (nominal).

The fibre 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 fibres.

For all variants, the fibre 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.

The fibre medium MAU shall consist of the fibre transceiver and fibre 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 fibre connectors.

19.2 Transceiver 5 Mbit/s, optical medium

To support a fibre medium, a fibre 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 signalling 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 94, a functional block diagram depicting the MAU components.

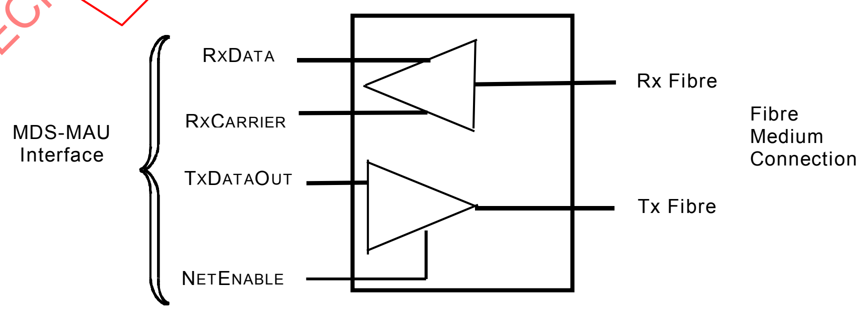

Figure 94 – MAU block diagram 5 Mbit/s, optical fibre medium

The transmit signals shall be as shown in Table 92.

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Table 92 – Transmit control line definitions 5 Mbit/s, optical fibre medium

TxDataOut	NetEnable	Physical symbol	Signal on fibre 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 fibre interface transmit and receive limits shall be as shown in Table 93.

Table 93 – Fibre 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 fibre 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, Type 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 fibre 5 Mbit/s, optical medium

The trunk fibre shall meet the requirements specified in 19.6 for the appropriate fibre 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 fibre PhL variants.

19.6 Fibre specifications 5 Mbit/s, optical medium

The signal characteristics for fibre media and PhL variant at 25°C shall be as shown in Table 94, Table 95 and Table 96.

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Table 94 – Fibre signal specification 5 Mbit/s, optical medium, short range

Specification	Min	Nom	Max
Fibre			
Distance	0 m	300 m	
Fibre Attenuation @ λ		6 dB/ km	
Fibre 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			
Wave Length 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 – Fibre signal specification 5 Mbit/s, optical medium, medium range

Specification	Min	Nom	Max
Fibre			
Distance	0 m	7 km	
Fibre Attenuation @ λ		1,5 dB/ km	
Fibre 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			
Wave Length λ	1270 nm	1300 nm	1370 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

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Specification	Min	Nom	Max
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 – Fibre signal specification 5 Mbit/s, optical medium, long range

Specification	Min	Nom	Max
Fibre			
Distance			20 km
Fibre Attenuation @ λ		0,5 dB/km	
Fibre Technology	Graded Index, Single Mode		
Core / Cladding	10/125 µm		
Numerical Aperture	0,1		
System			
BER	1 in 10^9		
Power Budget	10 dB		
Transmitter			
Wave Length λ	1270 nm	1300 nm	1370 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

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20 Type 2: Medium Attachment Unit: Network Access Port (NAP)

20.1 General

Figure 95 shows the location of the network access port (NAP) PhL and Medium within the ISO/OSI reference model.

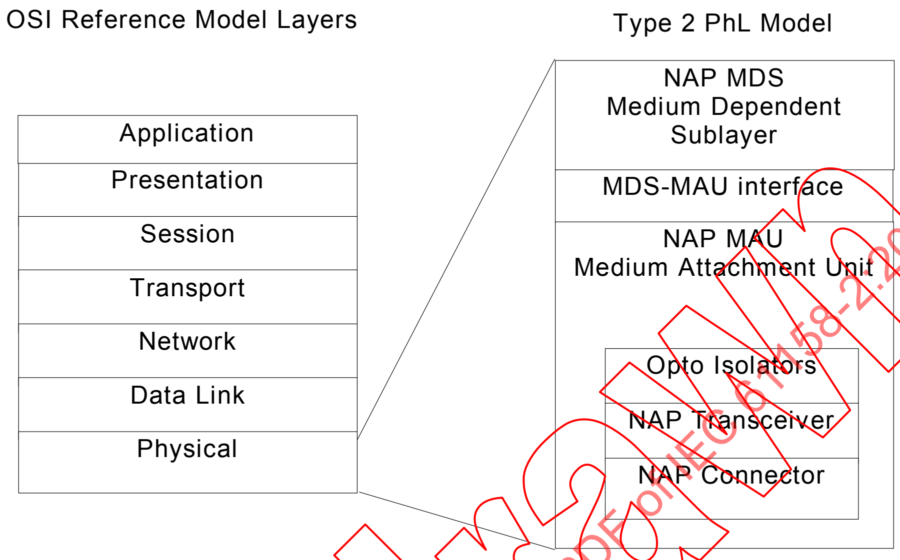

Figure 95 – NAP reference model

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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 96. A permanent node shall function as a transient node when no other PhL medium is connected as shown in Figure 96.

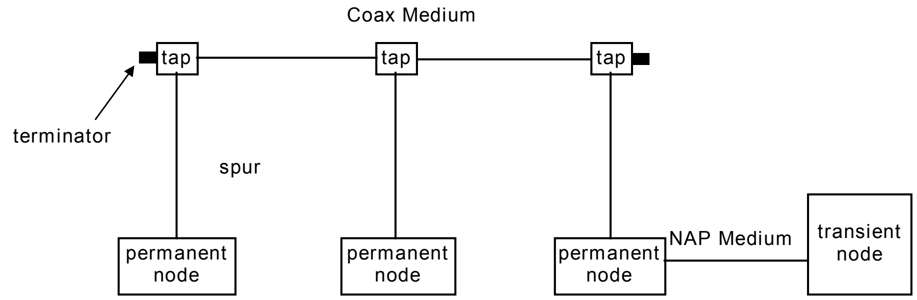

Figure 96 – Example of transient and permanent nodes

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 Signalling

The signalling 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

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20.3 Transceiver

The NAP MAU block diagram shown in Figure 97 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).

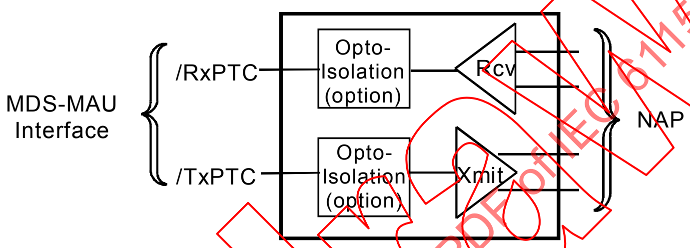

Figure 97 – NAP transceiver

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 98.

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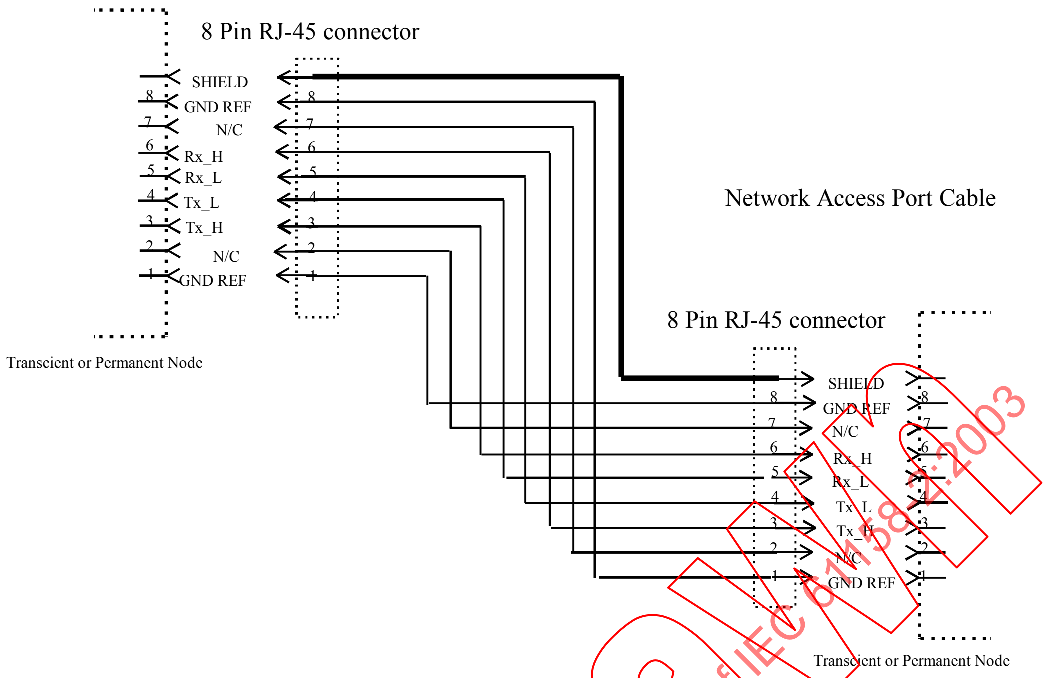

NOTE The NAP cable connectors are installed so that the signal lines are reversed to allow the correct connection. This allows the equipment to use the same pinout independent of function.

Figure 98 – 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.

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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

See 12.3.1

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.

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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 of IEC 61158-2 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 of IEC 61158-2 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 T_{bit}.

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.

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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):

$$\left|\frac{Z - Z_0}{Z + Z_0}\right| \leq 0,2$$

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 59 (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 Output level requirements

See 12.4.3

21.4.4 Output timing requirements

See 12.4.4.

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21.4.5 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.

This part of IEC 61158 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 98 and Table 99.

Table 98 – 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 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.	

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Table 99 – 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 99
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 of IEC 61158-2 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 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 of IEC 61158-2 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 99.

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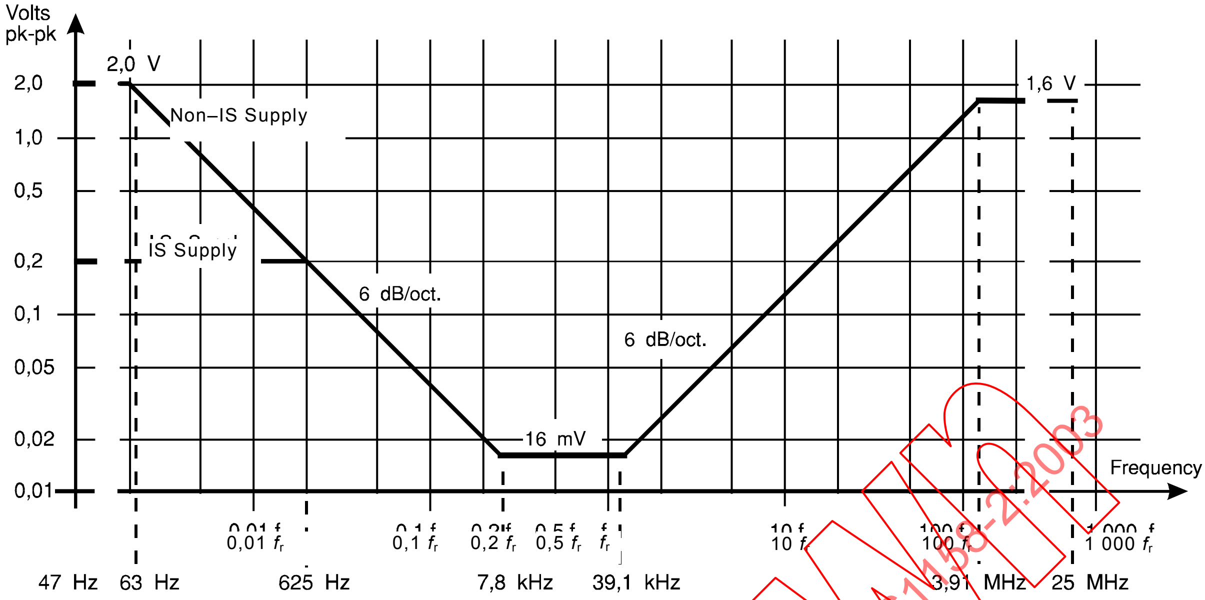

Figure 99 – Power supply ripple and noise

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: 1) when transmitting, 2) within the first 10 ms after the connection of the device to an operating network, 3) within the first 10 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 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.

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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 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 of IEC 61158-2 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.

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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 centre 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 part of IEC 61158 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.

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NOTE The barrier can appear as a shunt impedance as low as 460 Ω at the signalling 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.

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22 Type 3: Medium Attachment Unit: Asynchronous Transmission, wire medium

22.1 Electrical characteristics

This MAU specification describes a balanced line transmission corresponding to ANSI TIA/EIA-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 22.2.2).

NRZ bit encoding is combined with ANSI TIA/EIA-485-A signalling 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).

Topology: Linear bus, terminated at both ends, stubs ≤ 0,3 m, no branches;

In contrast to the ANSI TIA/EIA-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

It shall be taken into consideration that the total line length includes the sum of the stub lengths.

Medium: Shielded twisted pair cable recommended, see "Medium specifications"

Line Length: ≤ 1 200 m, depending on the data rate and cable type

Number of stations: 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.

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 100) and assuming a conductor cross-sectional are of 0,22 mm^2, the maximum permissible topology is as follows:

1 repeater: 2,4 km and 62 stations

2 repeater: 3,6 km and 92 stations (see Figure 100 below)

3 repeater: 4,8 km and 122 stations

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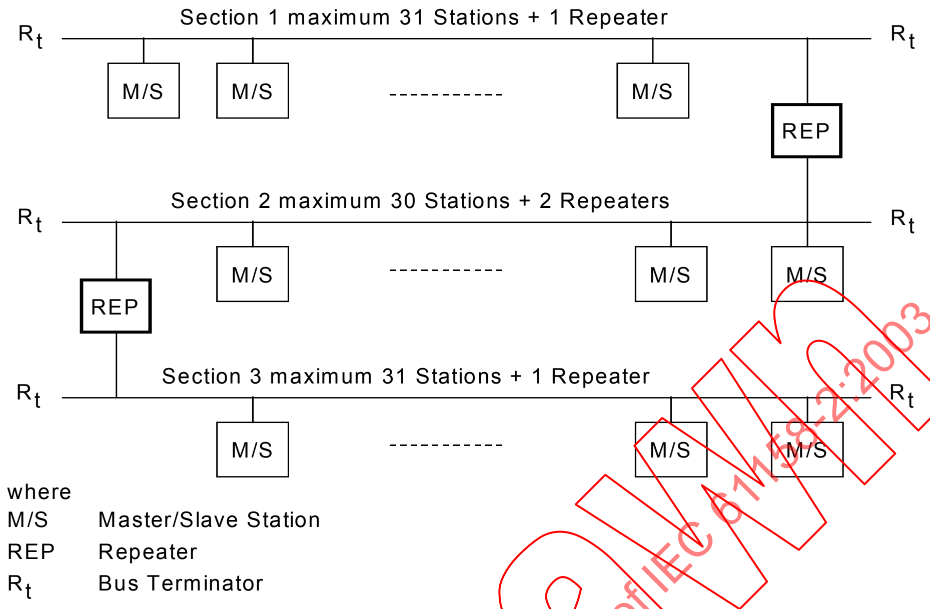

Figure 100 – Repeater in linear bus topology

In a tree topology, for example, as in Figure 101, 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.

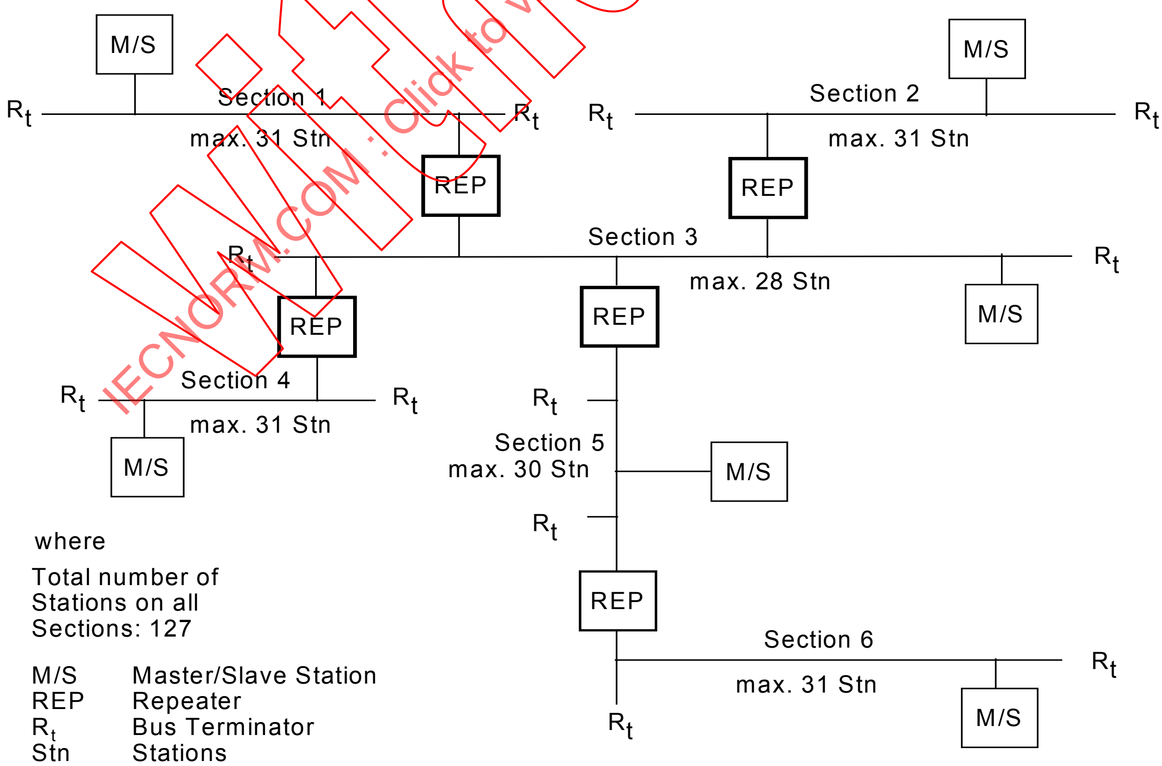

Figure 101 – Repeater in tree topology

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22.2 Medium specifications

22.2.1 Connector

The connector is specified in Annex I.2.

22.2.2 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-485-A.

Two types of cables are defined, as specified in Table 100.

Table 100 – 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 sheath IS	blue	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 101 shows the maximum length of cable type A and cable type B for the different transmission speeds.

Table 101 – 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	1200	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 102, shows the integration of inductances L1 to L4 in the connector.

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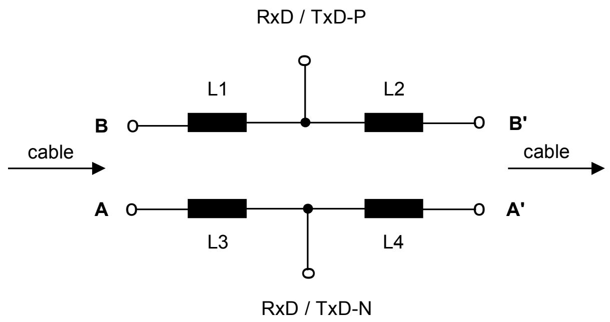

Figure 102 – Example for a connector with integrated inductance

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-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 103.

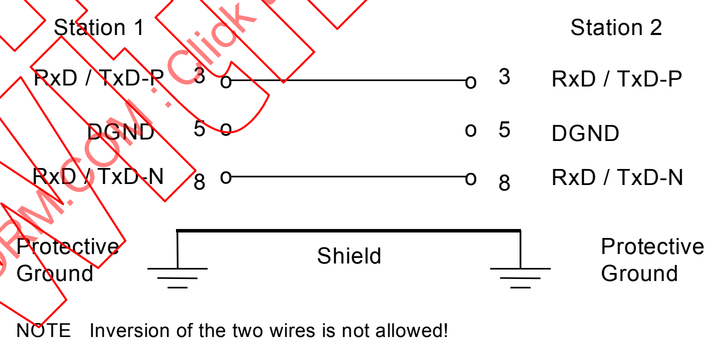

Figure 103 – Interconnecting wiring

The wiring shown in Figure 103 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.

22.2.3 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.

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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.

22.2.4 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-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 104. 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.

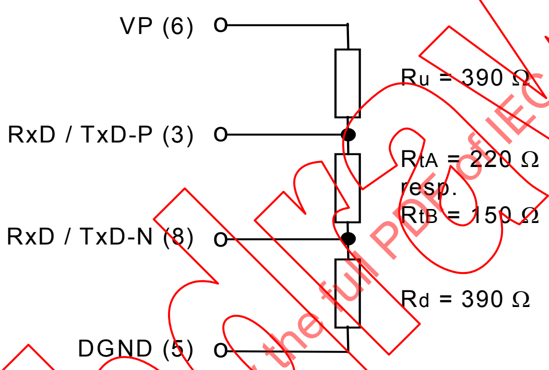

Figure 104 – Bus Terminator

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.

22.3 Transmission method

22.3.1 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.

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22.3.2 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.

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23 Type 3: Medium Attachment Unit: Asynchronous Transmission, optical medium

23.1 Characteristic features of optical data transmission

Table 102 shows the characteristic features of an optical data transmission.

Table 102 – Characteristic Features

Item	Feature
Transfer medium	Fibre 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 } with or without retiming Opto-electrical converter
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 fibre optic cable (multimode) : - 3 400m (independent of the number of nodes) EXAMPLE 2 Network segment with 1 active star coupler and plastic fibre optic cable: - 88m (independent of the number of nodes) NOTE Increasing of ranges and numbers of nodes is possible through linking network segments

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Figure 105 shows the optical MAU beside an ANSI TIA/EIA-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-485-A MAU. The mentioned interface is described in 5.4.2.

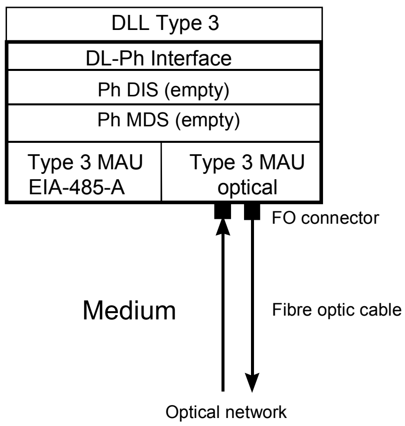

Figure 105 – Connection to the optical network

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 fibre 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 fibre optics to bridge large distances at high transmission speeds
– Simple and economical installation of shorter networks based on plastic fibres
– Low weight
– No corrosion
– Simplified standard cabling of buildings through identical reference fibres 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 106 shows the principal structure of an optical network.

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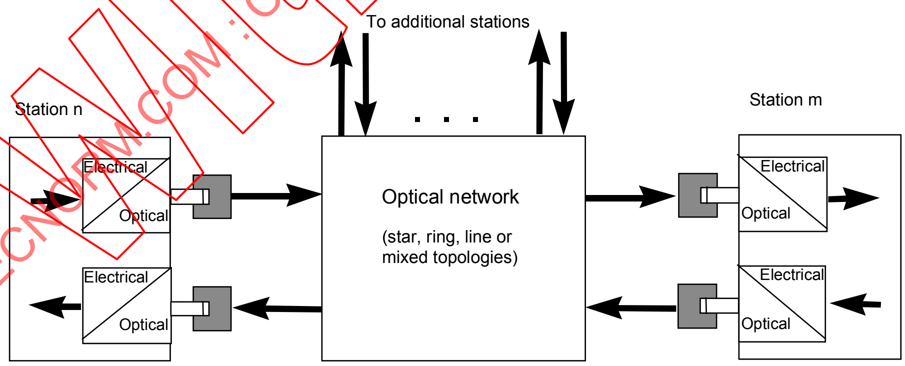

Figure 106 – Principle structure of optical networking

Electrical-optical converters with a specific signal level budget that take into account of the physical differences between glass and plastic fibres are specified for each fibre 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 107.

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 108);

– A passive optical link consisting of a fibre 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.

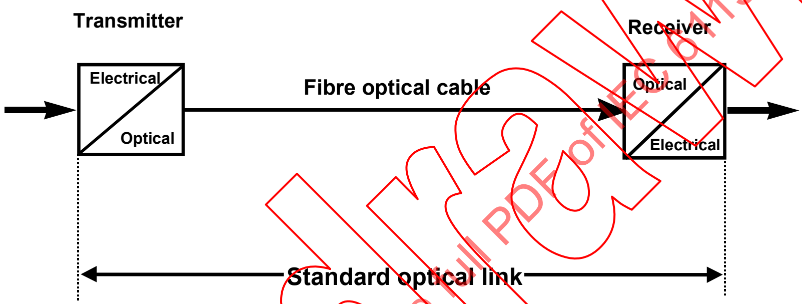

Figure 107 – Definition of the standard optical link

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-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.

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23.7 Optical signal level

23.7.1 General

Taking into account the physical differences between glass and plastic fibres, a specific level budget is applicable for both fibre 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 fibre optic cable or a 0,5 m long plastic fibre optic cable and measured with a large detector area. Cladding modes must not be included in the measured value. The fibre 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 103 to Table 106 are based on the shape of the transmit signal specified by the signal template in Figure 108. The technical terms used in the table (peak wavelength, etc.) are explained in IEC 60050-731:1991.

Table 103 – Characteristics of optical transmitters for multi-mode glass fibre

Quantity	Value	Unit
Peak wavelength	790 to 910	nm
Spectral width	≤ 75	nm
Operating temperature	0 to 70	°C
Test fibre (graded index) (see note)	62,5/125	µm
NA (numerical aperture of the test fibre)	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 fibre as specified in IEC 60 793-2:1998, Type A1b		

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Table 104 – Characteristics of optical transmitters for single-mode glass fibre

Quantity	Value	Unit
Peak wavelength	1 260 to 1 380	nm
Spectral width	≤ 120	nm
Operating temperature	0 to 70	°C
Test fibre (graded index) (see note)	9/125	µm
NA (numerical aperture of the test fibre)	0,113 ± 0,02	
$P_{\text{Smax“0“}}$ (max. transmit power for binary “0“)	-10	dBm
$P_{\text{Smin“0“}}$ (min. transmit power for binary "0“)	-20	dBm
$P_{\text{Smax“1“}}$ (max. transmit power for binary “1“)	-40	dBm
P_{Sost} (max. overshoot, tx power for “0“)	-8,8	dBm
NOTE Test fibre as specified in IEC 60 793-2:1998, Type B1.1, B3		

Table 105 – Characteristics of optical transmitters for plastic fibre

Quantity	Value		Unit
Peak wavelength	640 to 675		nm
Spectral width	≤ 35		nm
Operating temperature	0 to 70		°C
Test fibre (graded index) (see note)	980/1 000		µm
NA (numerical aperture of the test fibre)	0,5 ± 0,15		
Transmitter power level	standard	increased	
$P_{\text{Smax“0“}}$ (max. transmit power for binary “0“)	-5,0	0	dBm
$P_{\text{Smin“0“}}$ (min. transmit power for binary “0“)	-11	-6	dBm
$P_{\text{Smax“1“}}$ (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 fibre as specified in IEC 60 793-2:1998, Type A4a			

Table 106 – Characteristics of optical transmitters for 200/230 glass fibre

Quantity	Value	Unit
Peak wavelength	640 to 675	nm
Spectral width	≤ 35	nm
Operating temperature	0 to 70	°C
Test fibre (stepped index) (see note)	200/230	µm
NA (numerical aperture of the test fibre)	0,37 ± 0,02	
$P_{\text{Smax“0“}}$ (max. transmit power for binary “0“)	-8	dBm
$P_{\text{Smin“0“}}$ (min. transmit power for binary “0“)	-17	dBm
$P_{\text{Smax“1“}}$ (max. transmit power for binary “1“)	-44	dBm
P_{Sost} (max. overshoot, transmit power for binary “0“)	-6,8	dBm
NOTE Test fibre in IEC 60 793-2:1998, Type A3c: NA = 0,4 ± 0,04		

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23.7.3 Characteristics of optical receivers

The input sensitivity of receivers is also specified in dBm see Table 107 to Table 110 The input sensitivity is measured at the end of the specified reference fibre 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 108.

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 107 – Characteristics of optical receivers for multi-mode glass fibre

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 108 – Characteristics of optical receivers for single-mode glass fibre

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 109 – Characteristics of optical receivers for plastic fibre

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

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Table 110 – Characteristics of optical receivers for 200/230 glass fibre

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 111.

Table 111 – 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 102.

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 108, with parameters as given in Table 112.

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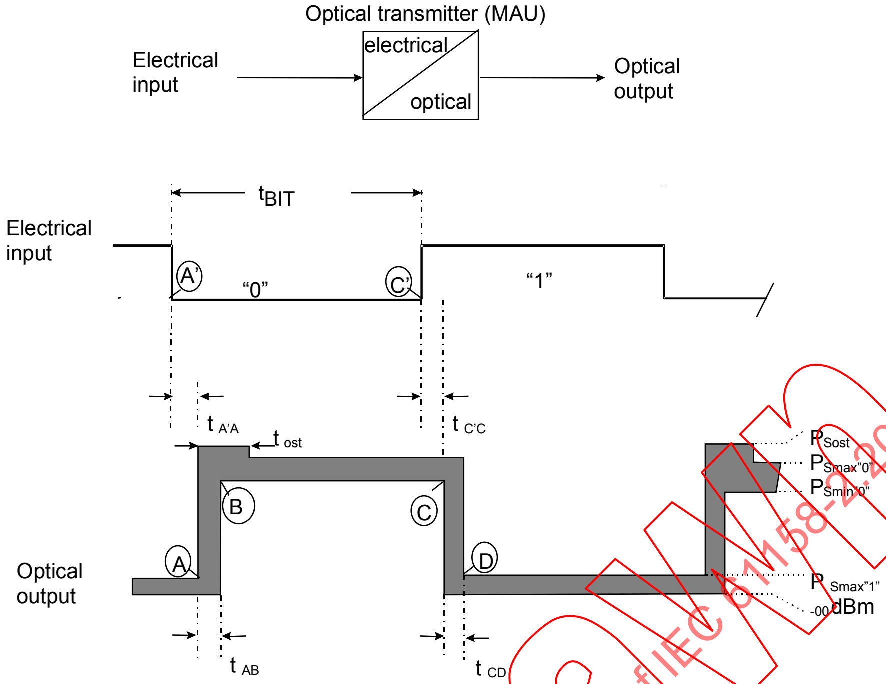

where

- 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 108 – Signal template for the optical transmitter

The optical transmitter shall meet the template specifications at ≤ 1,5 Mbit/s and 3 to 12 Mbit/s as shown in Table 112.

Table 112 – Permissible signal distortion due to the optical transmitter

Time	≤ 1,5 Mbit/s	3 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 113. This applies to the entire input level range specified in 23.7.3.

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Table 113 – Permissible signal distortion due to the optical receiver

Time	≤ 1,5 Mbit/s	3 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-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 114.

Table 114 – Permissible signal influence due to internal electronic circuits of a coupling component

Time	≤ 1,5 Mbit/s	3 to 12 Mbit/s	Unit
t_{log} (see note 1)	-0 to 10	-0 to 10	ns
t_{delay} (see note 1)	≤ 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 115. 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 115.

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Table 115 – 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 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 fibre optic cable

The connectors are specified in Annex I.3.

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.

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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 1200 m, and the Baud rate can be 9600, 19200, 38400 or 76800.

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 116.

Table 116 – 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 1200 m.

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24.5 Electrical Specification

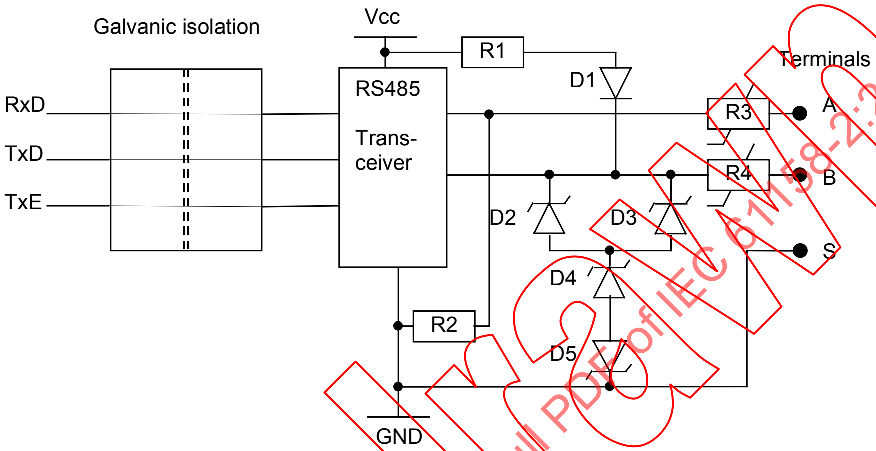
The voltage levels of the transmitter and receiver can be taken from ANSI TIA/EIA-485-A.

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 109.



R1, R2	15k1
R3, R4	PTC, max 13 Ohm, hold current 100 mA
D1	100 mA small signal diode
D2, D3, D4, D5	3.9 V / 1 W Voltage regulator diode

Figure 109 – Recommended interface circuit

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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 9600, 19200, 38400, 76800 or 230400.

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 117.

Table 117 – 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.

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26 Type 6: Medium Attachment Unit: RS-485

26.1 General

The Type 6-485-PhL specification describes a balanced line transmission corresponding to ANSI TIA/EIA-485-A, named RS-485 throughout the remainder of this clause. Terminators, located at both ends of the twisted-pair cable, enable the PhL to support higher speed transmission.

26.2 Transmission method

The transmission method used by the RS-485 PhL is differential bipolar signalling with Manchester encoding

26.3 Differential signal levels

In the RS-485 PhL Manchester encoded data from the MDS is transmitted via a twisted pair cable. A High level (Manchester_symbol = "HI"), as described in 9.7.4, is represented by a positive differential voltage between pin 3 (RxD/ TxD-P, B/B') and pin 8 (RxD/ TxD-N, A/A') of the bus connector, a Low level (Manchester_symbol = "LO") is represented by a negative differential voltage.

When a device is not transmitting (MDS output = "SILENCE"), as described in 5.6.3 and 9.7.3, the transmitter output shall be disabled and shall present a high impedance (≥ 10 kΩ) to the line.

During the idle periods, that is, when no data is transmitted by any device, the receive line signal will represent a Manchester "HI", since the segment terminator forces the differential voltage between connector pins 3 and 8 to be positive when all transmitters are disabled.

The line receivers shall always be enabled, therefore during idle a Manchester "HI" signal is received by every device.

26.4 Additional specifications for the communication element

The rated data rate for the RS-485 transceiver shall be at least twice the data rate of the bus.

Short Circuit Protection is recommended:

Driver Current <= 250 mA

Receiver Current <= 95 mA

Thermal Overload protection is recommended.

Electrostatic discharge protection is recommended per IEC 61000-4-2

≥ 15 kV -Air Gap,

≥ 8 kV -Contact

NOTE The specifications given in this subclause are in addition to those contained in the RS-485 specification.

26.5 Galvanic isolation

Galvanic isolation of the communication element is not required, but see the requirements of 26.12 for bus data-rates of 1,25 Mbit/s or higher.

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26.6 Minimum InterFrameGap settings

The minimum required values of InterFrameGap, versus the number of repeaters, is shown in Table 118.

Table 118 – Minimum setting of the InterFrameGap parameter for RS-485 wire PhL

	InterFrameGap (bit-periods)			
	6	12	18	24
number of repeaters	0	1	2	3

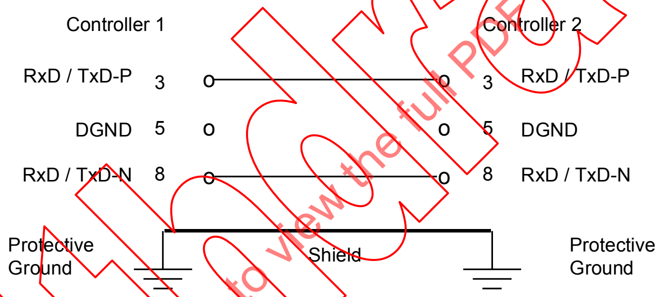
NOTE Theoretically the minimum value of InterFrameGap is
{[4 + (4* number-of-repeaters)] * bit-period + 6 µs/Km of cable in the longest path}.
This condition is satisfied by the simplified rule given in Table 118 for the topologies supported by Type 6.

26.7 Connector

The connector type and pinout is shown in Annex L.

26.8 Signal conveyance requirements

The minimum wiring between two communicating devices is shown in Figure 103.



NOTE Inversion of the two wires is not allowed!

Figure 110 – Minimum interconnecting wiring

The wiring shown in Figure 103 allows for a common mode voltage between the two communicating devices (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 (DGND) shall be installed.

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 device 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.

26.9 Ph-segment termination network and excitation voltage

The termination network of Figure 111 is required at each end of each Ph—segment.

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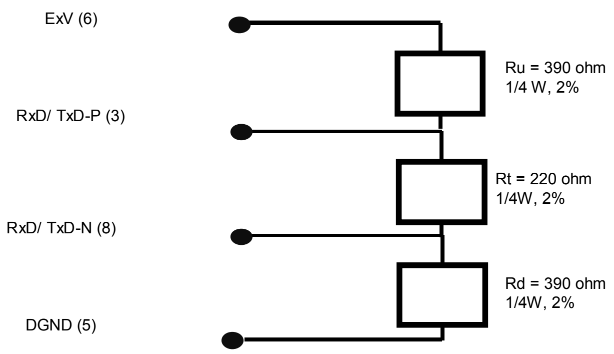

Figure 111 – RS-485 Ph—segment termination network

Excitation voltage (ExV) of + 5 V with respect to DGND (C/C') must be supplied to the terminator at each end of each Ph-segment.

The specifications of the terminator components are:

a) Ru +5 V to RxD/ TxD-P= 390 Ω, 0,25 W ± 2 %

b) Rt RxD/ TxD-P to RxD/ TxD-N = 220 Ω, 0,25 W ± 2 %

c) Rd RxD/ TxD-N to DGND = 390 Ω, 0,25 W ± 2 %

26.10 Data rates

The max-allowed-data-rate is a conformance-class issue. Its range is 78,125 kbit/s to max-data-rate by powers of 2. The range of max-data-rate is 78,125 kbit/s to 5 Mbit/s by powers of 2.

The max-permitted-data-rate for any logical link is limited by the length of the longest Ph-segment on this link, as described in Table 120.

The configured-data-rate per logical link may be 78,125 kbit/s to MIN[max-allowed-data-rate, max-permitted-data-rate].

NOTE The system-manager configures the configured-data-rate of all nodes on one logical link to be the same value.

26.11 Maximum topologies

The maximum number of nodes per Ph-segment is 32.

Assuming 32 nodes are attached to each Ph-segment, the maximum number of nodes per logical link is:

– 123 for a linear bus topology

– 32 x 31 = 992 for a star topology

26.12 Specifications of Ph-segments

Each Ph-segment is a linear "bus", terminated in its characteristic impedance at each end of the Ph-segment.

No branches are allowed in the trunk cable

The Stub cable connecting each node to the trunk cable must be shorter than 0,3 m.

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The total length of all stubs is included in computation of the Ph-segment's cable effective length.

The maximum total stub capacitance versus Data-rate for all stubs on a Ph-segment is specified in Table 119.

Table 119 – Maximum stub capacitance per Ph-segment versus bus data rate

Data rate	**Maximum stub capacitance** (nF)
5 Mbit/s	0,05
2,5 Mbit/s	0,05
1,25 Mbit/s	0,05
625 kbit/s	0,25
312,5 kbit/s	0,5
156,25 kbit/s	1,0
78,125 kbit/s	2,0

For data rates equal or less than 625 kbit/s the sum of the stub lengths (total of the capacities of all stubs) is specified in Table 119. For example at 625 kbit/s the maximum total stub length is 8,3 m.

At 1,25 Mbit/s and higher data rates the total capacities of all stubs shall less than 0,05 nF. 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 112, shows the integration of the inductance in the connector.

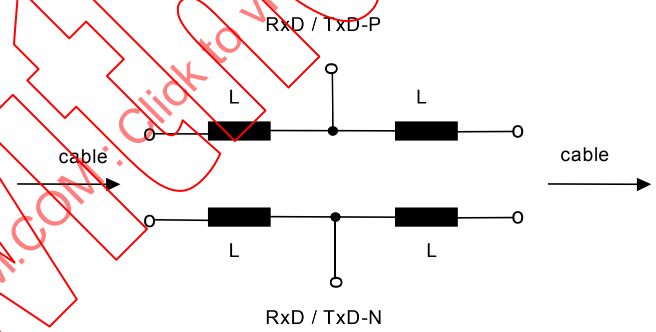

Figure 112 – Example for a connector with integrated inductance

The inductance shall have the value of 110 nH when the typical capacity of each communication element (connector, cable to RS-485-Transceivers, RS-485 Transceivers itself and other parts) is between 15 to 25 pF.

NOTE 1 The calculation of the inductance includes the contribution of the connected device. In case of disconnection of such connectors wiring reflections may occur which cause distortion on the segment.

The maximum cable length per Ph-segment versus Data-rate is specified in Table 120.

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Table 120 – Maximum cable length per Ph-segment versus bus data rate

Data rate	Maximum cable length (m)
5 Mbit/s	100
2,5 Mbit/s	100
1,25 Mbit/s	100
625 kbit/s	225
312,5 kbit/s	350
156,25 kbit/s	600
78,125 kbit/s	1200

The dependency of the permissible data rate upon the logical link expanse (maximum distance between two communicating devices) is shown in Figure 2-A.1 of the ANSI TIA/EIA-422-B.

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.

26.13 Signal cable specifications

The medium of each bus segment 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).

26.13.1 Signal pair specifications

The characteristic impedance of the cable shall be in the range between 135 and 165 Ω (3-20 MHz), the cable capacity (conductor - conductor) should be less than 30 pF/m, resistance shall be less than 110 Ω/km, and the conductor cross sectional area should be equal or greater than 0,34 mm^2.

Cable selection criteria are included in the appendix of EIA/TIA-485A.

26.14 Example single Ph-segment topology

A maximum single Ph-segment bus topology is shown in Figure 113.

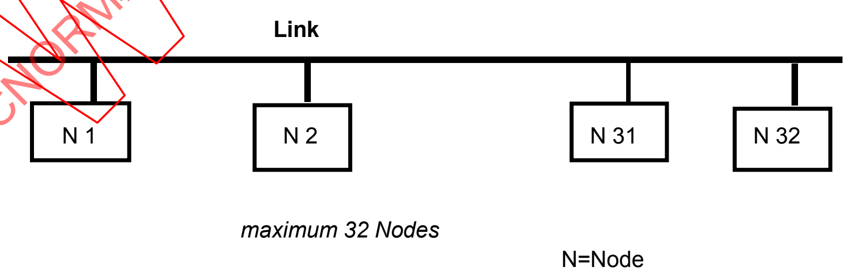

Figure 113 – Maximum single Ph-segment bus topology

26.15 Multi-segment topologies

RS-485 repeaters are used for logical links consisting of multiple Ph-segments.

The configuration rules for multi-segment topologies are:

a) Maximum Ph-segments in series = 4

b) Maximum repeaters in any signal path = 3

c) Each repeater counts as a node on all the Ph-segments it connects.

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26.15.1 Linear bus

The maximum linear bus topology, which has four Ph-segments, is shown in Figure 114.

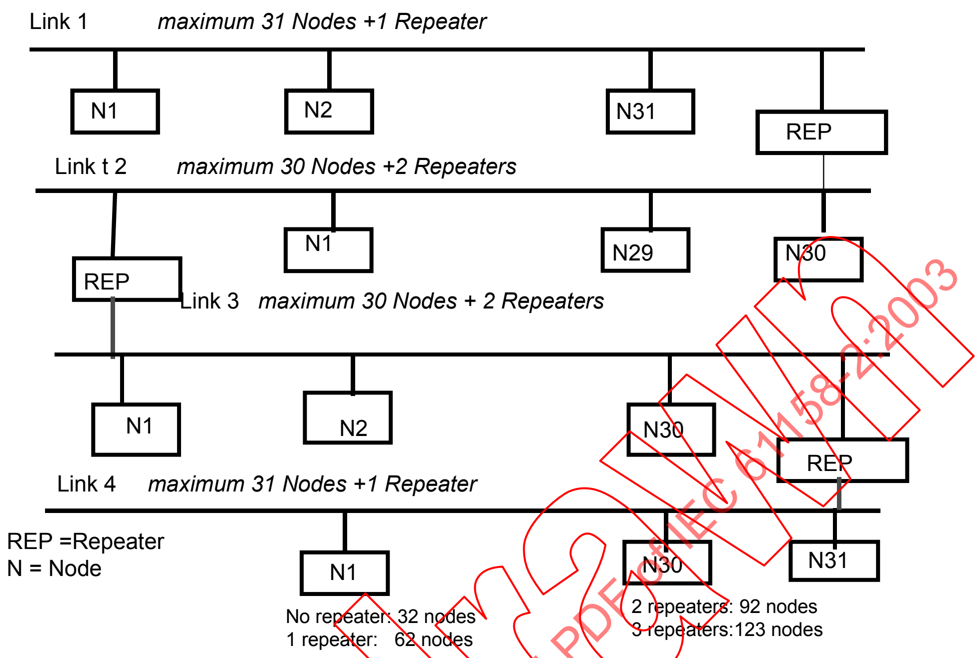

Figure 114 – Example maximum linear bus topology with four Ph-segments

26.15.2 Star

An example star (tree) topology with six Ph-segments is shown in Figure 115.

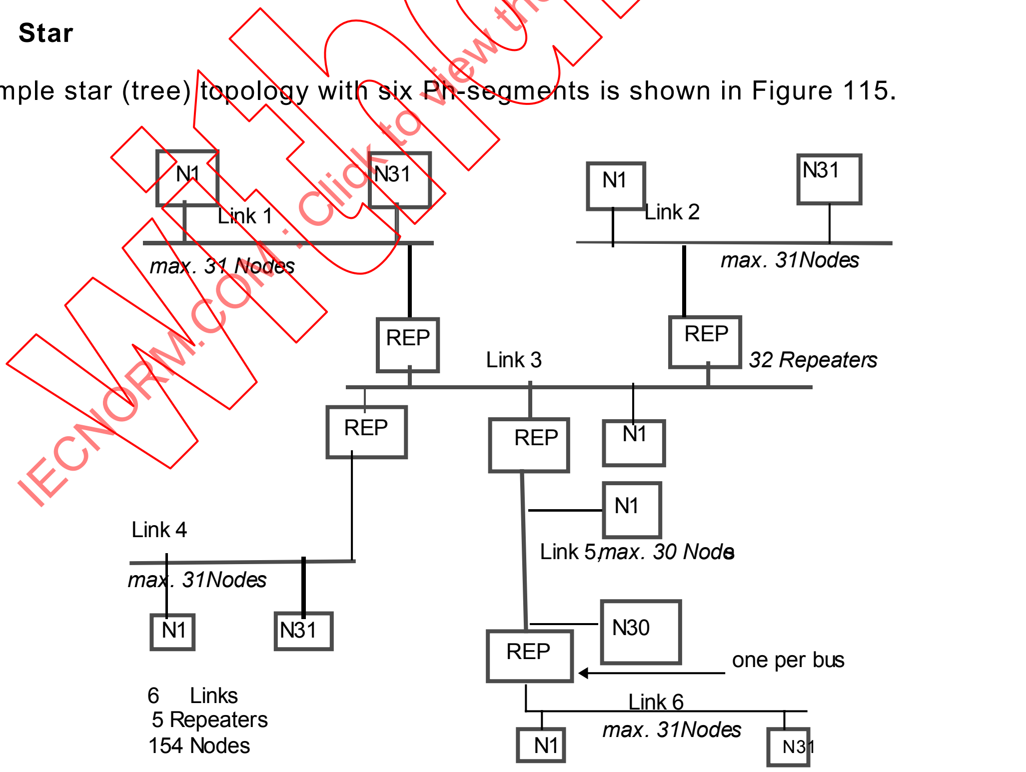

Figure 115 – Example star topology with six Ph-segments

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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 116 and Figure 117.

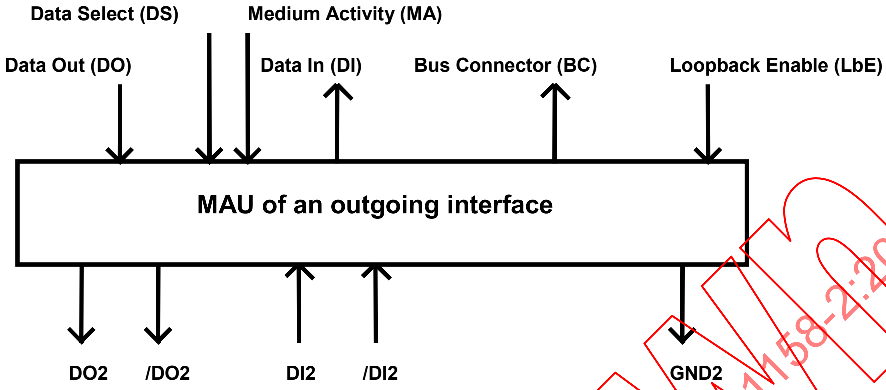

Figure 116 – MAU of an outgoing interface

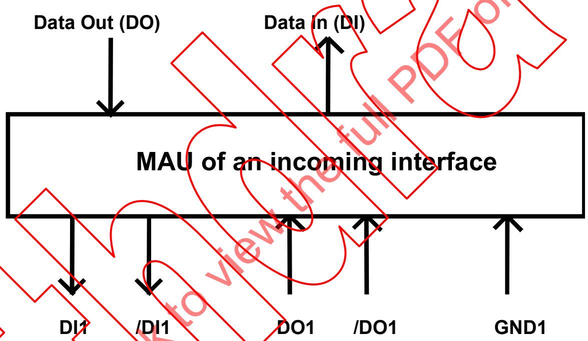

Figure 117 – MAU of an incoming interface

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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 121 defines the bit rates and bit rate dependent quantities.

Table 121 – 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 118) consists of two point-to point connections. The connections are unidirectional. Thus each MAU has one transmitter and one receiver.

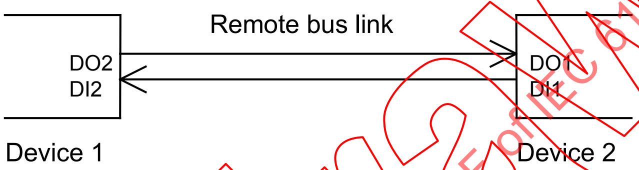

Figure 118 – Remote bus link

A remote bus link shall be between 0 and the maximum length for a given bit rate (see Table 121).

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 119).

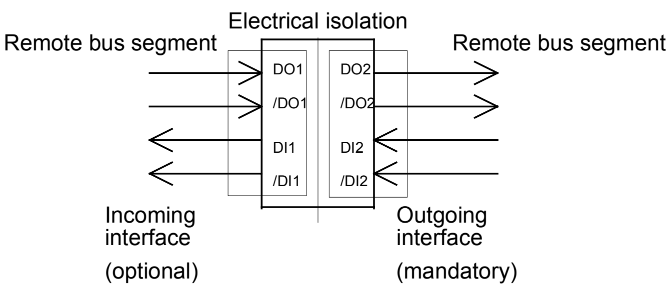

Figure 119 – Interface to the transmission medium

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