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Information technology – Generic cabling for customer premises – Part 9906: Balanced 1-pair cabling channels up to 600 MHz for single pair Ethernet (SPE)

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FOREWORD

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ISO/IEC TR 11801-9906, which is a Technical Report, was prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology.

The list of all currently available parts of the ISO/IEC 11801 series, under the general title *Information technology – Generic cabling for customer premises*, can be found on the IEC and ISO websites.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
JTC1-SC25/2888/DTR	JTC1-SC25/2913/RVDTR

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

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

INTRODUCTION

This document is a compendium of balanced 1-pair cabling channels specifications related to specific applications.

The balanced 1-pair cabling channels support single-pair Ethernet (SPE) applications, according to ISO/IEC/IEEE 8802-3:2017/AMD4, 1000BASE-T1; ISO/IEC/IEEE 8802-3:2017/AMD1, 100BASE-T1; and IEEE 802.3cg, 10BASE-T1.

While the original use case for SPE was automotive applications, this document describes balanced 1-pair cabling channels intended for use in non-automotive, SPE applications, for example:

- industrial automation applications, Industrial Internet of Things (IIoT), Industry 4.0;
- enterprise building applications, Internet of Things (IoT), smart lighting, energy management, and access control;
- other IoT applications, smart building and home automation applications.

SPE cabling channels support bidirectional signal transmission, using one balanced pair, for 1 000 Mbit/s (ISO/IEC/IEEE 8802-3:2017/AMD4) up to 40 m, 100 Mbit/s (ISO/IEC/IEEE 8802-3:2017/AMD1) up to 15 m, or 10 Mbit/s (IEEE 802.3cg) up to 1 000 m, where reach is influenced by cabling channel capacity limitations from signal loss and electromagnetic interference.

SPE channels optionally support power delivery together with the signal delivery over a single balanced pair. Remote powering over balanced 1-pair cabling is addressed in ISO/IEC TS 29125:2017/AMD1[1].

[1] To be published. Stage at the time of publication: ISO/IEC DTS 29125:2017/AMD1:2019.

INFORMATION TECHNOLOGY – GENERIC CABLING FOR CUSTOMER PREMISES –

Part 9906 – Balanced 1-pair cabling channels up to 600 MHz for single pair Ethernet (SPE)

1 Scope

This document covers channel specifications, for channels constructed from balanced 1-pair cabling components, primarily intended for use in industrial automation and process control applications.

The channel specifications are consistent with corresponding IEEE 802.3 single-pair Ethernet (SPE) applications and are referenced from link segment specifications in the following IEEE SPE physical layer specifications:

- ISO/IEC/IEEE 8802-3:2017/AMD4, 1 000 Mb/s: 1000BASE-T1 Type A, ≤ 15 m, 1000BASE-T1 Type B, ≤ 40 m;
- ISO/IEC/IEEE 8802-3:2017/AMD1, 100 Mb/s: 100BASE-T1, ≤ 15 m;
- IEEE 802.3cg, 10 Mb/s: 10BASE-T1S, ≤ 15 m; 10BASE-T1L, ≤ 1 000 m.

The channel component specifications are referenced according to corresponding IEC balanced 1-pair cable and connector specifications.

Channel specifications include IL, RL, TCL, coupling attenuation, and alien crosstalk parameters specifications.

Channel EMC related specifications include electromagnetic isolation levels E_1, E_2 and E_3, which are defined according to the MICE standard environmental characterization system specified in ISO/IEC 11801-1.

2 Normative references

ISO/IEC 11801-1, *Information technology – Generic cabling for customer premises – Part 1: General requirements*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 11801-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
balanced 1-pair cabling channel
cabling channel constructed from balanced 1-pair cables, balanced 1-pair connectors and balanced 1-pair cord to form a cabling channel intended for use in differential-mode signal transmission and power delivery applications

3.1.2
balanced 1-pair cable
cable consisting of a single pair of conductors, optional screen, and overall jacket, primarily intended for use in differential-mode signal transmission and power delivery applications

3.1.3
balanced 1-pair connector
connector intended for use with balanced 1-pair cable in differential-mode signal transmission and power delivery applications

3.1.4
balanced 1-pair cord
cable assembly constructed from a 1-pair cable and 1-pair connectors

3.2 Symbols

V_{pp} peak-to-peak voltage

4 Balanced 1-pair cabling channels

4.1 General

Channel signal transmission specifications for balanced 1-pair cabling are referenced from three physical layer specifications: ISO/IEC/IEEE 8802-3:2017/AMD1, ISO/IEC/IEEE 8802-3:2017/AMD4 and IEEE802.3cg. These cover five link segment specifications: 1000BASE-T1 Type A, 1000BASE-T1 Type B, 100BASE-T1, 10BASE-T1S, and 10BASE-T1L. IEEE SPE link segment specifications and physical layer standards are summarized in Annex C.

The SPE link segment specifications are identified by their corresponding upper frequency specification, i.e. 600 MHz, 66 MHz, and 20 MHz.

The SPE signal transmission functional space covered by the five link segment specifications is given in Table 1.

Table 1 – SPE signal transmission functional space

Upper frequency	Frequency range	Reach	Screen	Data rate	SPE link segment	IEEE physical layer
MHz	MHz	m	**Type**	Mb/s	**Specification**	**Standard**
600	$1 \le f \le 600$	15	Screened and unscreened	1 000	1000BASE-T1 Type A	ISO/IEC/IEEE 8802-3:2017/ AMD4
600	$1 \le f \le 600$	40	Screened	1 000	1000BASE-T1 Type B	ISO/IEC/IEEE 8802-3:2017/ AMD4
66	$0,3 \le f \le 66$	15	Unscreened	100	100BASE-T1	ISO/IEC/IEEE 8802-3:2017/ AMD1
20	$0,1 \le f \le 20$	15	Screened and unscreened	10	10BASE-T1S	802.3cg
20	$0,1 \le f \le 20$	1 000	Screened and unscreened	10	10BASE-T1L	802.3cg

NOTE Limits involving more than 1 pair within a channel; the following parameters are not applicable to balanced 1-pair cabling channels: NEXT, PS NEXT, ACR-F, PS ACR-F, ACR-N, PS ACR-N, delay skew and pair-to-pair resistance unbalance.

4.2 Component specifications

Balanced 1-pair cabling channel characteristics are specified using balanced 1-pair cabling component specifications. Balanced 1-pair cable and connector component specification references are given in Annex A and Annex B, respectively.

The characteristics of a channel are specified between connections to active equipment. The channel comprises only passive sections of cable, connecting hardware and cords. The connections at the hardware interface to active equipment are not taken into account.

Application support depends on channel performance, which in turn depends on cable length, number of connections, connector termination practices, workmanship and performance. It is possible to achieve equivalent channel performance over greater lengths by the use of fewer connections or by using components with higher performance.

Considerations for balanced 1-pair channels bundled in a 4-pair cabling channel are given in Annex D.

4.3 Environmental classifications

ISO/IEC 11801-1 classifies the environments for generic cabling according to three "MICE" levels.

The balanced 1-pair cabling specifications referenced in ISO/IEC/IEEE 8802-3:2017/AMD1, ISO/IEC/IEEE 8802-3:2017/AMD4 and IEEE 802.3cg include channel EMC related specifications for electromagnetic isolation levels E_1, E_2 and E_3, which are defined according to the MICE standard environmental characterization system specified in ISO/IEC 11801-1.

The channel EMC related specifications are unbalance attenuation, coupling attenuation, and alien (exogenous) crosstalk, which are specified for channels and components per E_1, E_2 and E_3.

4.4 Channel reference implementations

The 15 m channel comprises a 2 m cord (50 % derated), attached at each end of a permanent link of 11 m length, and four connectors, based on components specified in Annex A and Annex B.

The 40 m channel comprises a 2 m cord (50 % derated), attached at each end of a permanent link of 36 m length, and four connectors, based on components specified in Annex A and Annex B.

The 1 000 m channel comprises a 2 m cord (50 % derated), attached at each end of a permanent link of 996 m length, and 10 connectors, based on components specified in Annex A and Annex B.

4.5 Balanced 1-pair cabling channel signal transmission specifications

4.5.1 Return loss (RL)

The balanced 1-pair cabling channel return loss (RL) specifications are given, using the formulae in Table 2.

Table 2 – Balanced 1-pair cabling channel return loss (RL)

Upper frequency	Frequency range	RL	Length	Screen type
MHz	MHz	dB	m	
600	$1 \le f \le 10$	19,0	15	Screened and unscreened
	$10 < f \le 40$	$24 - 5 \lg(f)$		
	$40 < f \le 130$	16		
	$130 < f \le 400$	$37 - 10 \lg(f)$		
	$400 < f \le 600$	11		
600	$1 \le f \le 10$	19,0	40	Screened
	$10 < f \le 40$	$24 - 5 \lg(f)$		
	$40 < f \le 130$	16		
	$130 < f \le 400$	$37 - 10 \lg(f)$		
	$400 < f \le 600$	11		
66	$0,3 \le f \le 20$	18,0	15	Unscreened
	$20 < f \le 66$	$31 - 10 \lg(f)$		
20	$0,1 \le f \le 10$	14	15	Screened and unscreened
	$10 < f \le 20$	$14 - 10 \lg(f/10)$		
20	$0,1 \le f \le 0,5$	$9 + 9f$	1 000	Screened and unscreened
	$0,5 < f \le 20$	13,5		

4.5.2 Insertion loss (IL)

The balanced 1-pair cabling channel insertion loss (IL) specifications are given, using the formulae in Table 3.

Table 3 – Balanced 1-pair cabling channel IL

Upper frequency	Frequency range	Channel IL	Length	Screen type	IEC cable
MHz	MHz	dB	m		**61156-x**
600	$1 \le f \le 600$	$0,42\times\left(1,8\sqrt{f}+0,0050f+\frac{0,25}{\sqrt{f}}\right)+4\times0,02\sqrt{f}$	15	Screened and unscreened	-11, -12
600	$1 \le f \le 600$	$0,152\times\left(3,36\sqrt{f}+0,015f+\frac{0,42}{\sqrt{f}}\right)+4\times0,02\sqrt{f}$ [a,b]	40	Screened	-11, -12
66	$0,3 \le f \le 66$	$0,152\times\left(5,06\sqrt{f}+0,059f+\frac{0,53}{\sqrt{f}}\right)+4\times0,02\sqrt{f}$ [a,b]	15	Screened and unscreened	-11, -12
20	$0,1 \le f \le 20$	$0,152\times\left(5,06\sqrt{f}+0,059f+\frac{0,53}{\sqrt{f}}\right)+4\times0,02\sqrt{f}$ [a,b]	15	Screened and unscreened	-13, -14
20	$0,1 \le f \le 20$	$10\times\left(1,23\sqrt{f}+0,01f+\frac{0,2}{\sqrt{f}}\right)+10\times0,02\sqrt{f}$	1 000	Screened and unscreened	-13, -14

[a] This channel was created by rearranging the link segment formula.

[b] The ($a\sqrt{f} + bf + c/\sqrt{f}$) factor in the "cable" IL term, factored from the corresponding link segment IL specifications, see Annex C, is for information, for comparison and modelling purposes.

4.5.3 Unbalance attenuation and coupling attenuation

4.5.3.1 General

Unbalance attenuation parameters, transverse-conversion-loss (TCL) and equal-level-transverse-conversion-transfer-loss (ELTCTL), are used for differential-mode-to-common-mode conversion loss specifications, for unscreened cabling.

Coupling attenuation is used for differential-mode-to-common-mode conversion loss specifications, for screened cabling.

Differential-mode-to-common-mode conversion loss specifications correspond to balanced 1-pair cabling channel EMC specifications per E_1, E_2 and E_3 electromagnetic characterizations.

See ISO/IEC 11801-1 for detailed information on balanced cabling, unbalance attenuation parameters and E_1, E_2 and E_3 environment characterization specifications.

4.5.3.2 Transverse-conversion-loss (TCL)

The balanced 1-pair cabling channel transverse-conversion-loss (TCL) specifications are given using the formulae in Table 4.

Table 4 – Balanced 1-pair cabling channel TCL

Upper frequency	Frequency range	TCL			Length	Screen type
		E_1	E_2	E_3		
MHz	MHz	dB	dB	dB	m	
600	$1 \le f \le 600$	Not specified	Not specified	Not specified	15	Screened and unscreened
600	$1 \le f \le 600$	Not specified	Not specified	Not specified	40	Screened
66	$0{,}3 \le f \le 33$	43,0	Not specified	Not specified	15	Screened and unscreened
	$33 < f \le 200$	$43 - 20 \lg(f/33)$	Not specified	Not specified		
20	$0{,}1 \le f \le 20$	$53 - 15 \lg(f)$	$63 - 15 \lg(f)$	Not specified	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	$53 - 15 \lg(f)$	$63 - 15 \lg(f)$	Not specified	1 000	Screened and unscreened

4.5.3.3 Equal-level-transverse-conversion-transfer-loss (ELTCTL)

The balanced 1-pair cabling channel equal-level-transverse-conversion-transfer-loss (ELTCTL) specifications are given using the formulae in Table 5.

Table 5 – Balanced 1-pair cabling channel ELTCTL

Upper frequency	Frequency range	ELTCTL			Length	Screen type
		E_1	E_2	E_3		
MHz	MHz	dB	dB	dB	m	
600	$1 \le f \le 600$	Not specified	Not specified	Not specified	15	Screened and unscreened
600	$1 \le f \le 600$	Not specified	Not specified	Not specified	40	Screened
66	$0{,}3 \le f \le 33$	Not specified	Not specified	Not specified	15	Screened and unscreened
	$33 < f \le 200$	Not specified	Not specified	Not specified		
20	$0{,}1 \le f \le 20$	Not specified	Not specified	Not specified	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	$30 - 20 \lg(f)$	$40 - 20 \lg(f)$	Not specified	1 000	Screened and unscreened

NOTE While no ELTCTL link segment specifications are given by IEEE 802.3 for these applications, they should be considered for long lengths; these values are implicit from the TCL values and correspond to ISO/IEC 11801-1 values.

4.5.3.4 Coupling attenuation

The balanced 1-pair cabling channel coupling attenuation specifications are given using the formulae in Table 6.

Table 6 – Balanced 1-pair cabling channel coupling attenuation

Upper frequency	Frequency range	Coupling attenuation			Length	Screen type
		E_1	E_2	E_3		
MHz	MHz	dB	dB	dB	m	
600	$1 \le f \le 600$	$72 - 11{,}5 \lg(f)$	Not specified	Not specified	15	Screened and unscreened
600	$1 \le f \le 600$	$80 - 20 \lg(f)$	$90 - 20 \lg(f)$	$100 - 20 \lg(f)$	40	Screened
66	$0{,}3 \le f \le 33$	43	Not specified	Not specified	15	Screened and unscreened
	$33 < f \le 200$	$43 - 20 \lg(f/33)$	Not specified	Not specified		
20	$0{,}1 \le f \le 20$	$53 - 10 \lg(f)$	$63 - 10 \lg(f)$	$73 - 10 \lg(f)$	15	Screened
20	$0{,}1 \le f \le 20$	$53 - 10 \lg(f)$	$63 - 10 \lg(f)$	$73 - 10 \lg(f)$	1 000	Screened

NOTE This corresponds to ISO/IEC 11801-1 values.

4.5.4 Alien (exogenous) crosstalk

4.5.4.1 General

For unscreened cabling alien (exogenous) crosstalk parameters, power-sum alien near-end crosstalk (PS ANEXT) and power-sum alien attenuation to crosstalk ratio far-end (PS AACR-F) are used for differential-mode-to-differential-mode alien noise loss specifications.

For screened cabling, E_1 coupling attenuation specifications, given in 4.5.3.4, may be substituted for alien noise loss specifications; see ISO/IEC 11801-1.

These alien noise loss specifications are based on the 6-around-1 measurement setup according to IEC 61156-1.

4.5.4.2 PS ANEXT

The balanced 1-pair cabling channel PS ANEXT specifications are given using the formulae in Table 7.

Table 7 – Balanced 1-pair cabling channel PS ANEXT

Upper frequency	Frequency range	PS ANEXT	Length	Screen type
MHz	MHz	dB	m	
600	$1 \le f \le 600$	$54 - 10 \lg(f/100)$	15	Screened and unscreened
600	$1 \le f \le 600$	$72{,}8 - 10 \lg(f/100)$	40	Screened
66	$0{,}3 \le f \le 66$	$31{,}5 - 10 \lg(f/100)$	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	$31{,}5 - 10 \lg(f/100)$	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	$37{,}5 - 17 \lg(f/20)$	1 000	Screened and unscreened

4.5.4.3 PS AACR-F

The balanced 1-pair cabling channel PS AACR-F specifications are given using the formulae in Table 8.

Table 8 – Balanced 1-pair cabling channel PS AACR-F

Upper frequency	Frequency range	PS AACR-F	Length	Screen type
MHz	MHz	dB	m	
600	$1 \le f \le 600$	$67 - 20 \lg(f/100)$	15	Screened and unscreened
600	$1 \le f \le 600$	$61 - 20 \lg(f/100)$	40	Screened
66	$0{,}3 \le f \le 66$	$16{,}5 - 20 \lg(f/100)$	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	$16{,}5 - 20 \lg(f/100)$	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	$38 - 18 \lg(f/20)$	1 000	Screened and unscreened

4.5.5 DC loop resistance

The balanced 1-pair cabling channel DC loop resistance specifications are given using the formulae in Table 9.

Table 9 – Balanced 1-pair cabling channel DC loop resistance

Upper frequency	Frequency range	DC loop resistance	Length	Screen type
MHz	MHz	Ω	m	
600	$1 \le f \le 600$	Not specified	15	Screened and unscreened
600	$1 \le f \le 600$	Not specified	40	Screened
66	$0{,}3 \le f \le 66$	Not specified	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	TBD	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	TBD	1 000	Screened and unscreened
TBD to be determined				

4.5.6 Propagation delay

The balanced 1-pair cabling channel propagation delay specifications are given using the formulae in Table 10.

Table 10 – Balanced 1-pair cabling channel propagation delay

Upper frequency	Frequency range	Propagation delay	Length	Screen type
MHz	MHz	ns	m	
600	$1 \le f \le 600$	94	15	Screened and unscreened
600	$1 \le f \le 600$	234	40	Screened
66	$0{,}3 \le f \le 66$	Not specified	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	Not specified	15	Screened and unscreened
20	$0{,}1 \le f \le 20$	8 834	1 000	Screened and unscreened
NOTE 8 834 ns corresponds to 1 485 m of cable, which is the maximum length possible, using 1,6 mm (AWG 14) or larger conductor, while conforming to attenuation requirements.				

Annex A
(informative)

Balanced 1-pair cable specifications

A.1 General

For information regarding balanced 1-pair cables, see the IEC balanced 1-pair cable general standard, IEC 61156-1, and the specific cable standards intended for balanced 1-pair cabling applications, which are listed in Table A.1.

Balanced 1-pair cables are specified in IEC 61156-11 and IEC 61156-12 for the 600 MHz channel and will be specified in future parts (IEC 61156-13 and IEC 61156-14) for the 20 MHz channel.

Table A.1 – Balanced 1-pair cable standards

Upper frequency	Frequency range	Conductor type	Screen type	Balanced 1-pair cable standard	Cable type
MHz	MHz				
600	$1 \le f \le 600$	Solid	Screened	IEC 61156-11	Horizontal
600	$1 \le f \le 600$	Stranded or solid	Screened or unscreened	IEC 61156-12	Work area
20	$0{,}1 \le f \le 20$	Solid	Screened	IEC 61156-13	Horizontal
20	$0{,}1 \le f \le 20$	Stranded or solid	Screened or unscreened	IEC 61156-14	Work area

A.2 Cables using alternative conductor sizes

Cabling channel insertion loss can be reduced for extended reach, by reducing cable IL with larger conductor size, see Annex E; maximum link delay specifications should be taken into consideration.

A.3 Balanced 1-pair cable specifications

A.3.1 Return loss (RL)

The balanced 1-pair cable return loss (RL) specifications are given using the formulae in Table A.2.

Table A.2 – Balanced 1-pair cable RL

Upper frequency	Frequency range	RL	Conductor type	Screen type
MHz	MHz	dB		
600	$1 \le f \le 10$	$20 - 5 \lg(f)$	Solid	Screened
	$10 < f \le 20$	25		
	$20 < f \le 250$	$25 - 7 \lg(f/20)$		
	$250 < f \le 600$	17,3		
600	$1 \le f \le 10$	$20 - 5 \lg(f)$	Stranded or solid	Screened or unscreened
	$10 < f \le 20$	25		
	$20 < f \le 250$	$25 - 8,6 \lg(f/20)$		
	$250 < f \le 600$	15,6		
20	$0,1 \le f \le 10$	$20 - 5 \lg(f)$	Solid	Screened
	$10 < f \le 20$	25		
20	$0,1 \le f \le 10$	$20 - 5 \lg(f)$	Stranded or solid	Screened or unscreened
	$10 < f \le 20$	25		

A.3.2 Insertion loss (IL)

The balanced 1-pair cable insertion loss (IL) specifications are given using the formulae in Table A.3.

Table A.3 – Balanced 1-pair cable IL

Upper frequency	Frequency range	Cable IL	Conductor type	Screen type
MHz	MHz	dB/100 m		
600	$1 \le f \le 600$	$1,8\sqrt{f} + 0,0050f + 0,25/\sqrt{f}$	Solid	Screened
600	$1 \le f \le 600$	$2,7\sqrt{f} + 0,0075f + 0,36/\sqrt{f}$	Stranded or solid	Screened or unscreened
20	$0,1 \le f \le 20$	$1,23\sqrt{f} + 0,01f + 0,2/\sqrt{f}$	Solid	Screened
20	$0,1 \le f \le 20$	$1,84\sqrt{f} + 0,01f + 0,2/\sqrt{f}$	Stranded or solid	Screened or unscreened

A.3.3 Unbalance attenuation and coupling attenuation

A.3.3.1 General

Unbalance attenuation parameters, transverse-conversion-loss (TCL) and equal-level-transverse-conversion-transfer-loss (ELTCTL), are used for differential-mode-to-common-mode conversion loss specifications, for unscreened cabling.

Coupling attenuation is used for differential-mode-to-common-mode conversion loss specifications, for screened cabling.

A.3.3.2 Transverse-conversion-loss (TCL)

The balanced 1-pair cable transverse-conversion-loss (TCL) specifications are given using the formulae in Table A.4.

Table A.4 – Balanced 1-pair cable TCL

Upper frequency	Frequency range	TCL Level 1	TCL Level 2	TCL Level 3	TCL Level 4	Conductor type	Screen type
MHz	MHz	dB	dB	dB	dB		
600	$1 \le f \le 600$	40 max.	Not specified	Not specified	Not specified	Solid	Screened
	$1 < f \le 600$	50 – 15 lg(f)	Not specified	Not specified	Not specified		
600	$1 \le f \le 600$	40 max.	Not specified	Not specified	Not specified	Stranded or solid	Screened or unscreened
	$1 < f \le 600$	50 – 15 lg(f)	Not specified	Not specified	Not specified		
20	$0{,}1 \le f \le 20$	40 max.	50 max.	50 max.	50 max.	Solid	Screened
	$0{,}1 < f \le 20$	40 – 15 lg(f)	50 – 15 lg(f)	60 – 15 lg(f)	70 – 15 lg(f)		
20	$0{,}1 \le f \le 20$	40 max.	50 max.	50 max.	50 max.	Stranded or solid	Screened or unscreened
	$0{,}1 < f \le 20$	40 – 15 lg(f)	50 – 15 lg(f)	60 – 15 lg(f)	70 – 15 lg(f)		

A.3.3.3 Equal-level-transverse-conversion-transfer-loss (ELTCTL)

The balanced 1-pair cable equal-level-transverse-conversion-transfer-loss (ELTCTL) specifications are given using the formulae in Table A.5.

Table A.5 – Balanced 1-pair cable ELTCTL

Upper frequency	Frequency range	ELTCTL Level 1	ELTCTL Level 2	ELTCTL Level 3	ELTCTL Level 4	Conductor type	Screen type
MHz	MHz	dB	dB	dB	dB		
600	$1 \le f \le 600$	5 min.	Not specified	Not specified	Not specified	Solid	Screened
	$1 < f \le 600$	40 – 20lg(f)	Not specified	Not specified	Not specified		
600	$1 \le f \le 600$	5 min.	Not specified	Not specified	Not specified	Stranded or solid	Screened or unscreened
	$1 < f \le 600$	40 – 20lg(f)	Not specified	Not specified	Not specified		
20	$1 \le f \le 20$	5 min.	5 min.	5 min.	5 min.	Solid	Screened
	$1 < f \le 20$	35 – 20lg(f)	35 – 20lg(f)	45 – 20lg(f)	55 – 20lg(f)		
20	$1 \le f \le 20$	5 min.	5 min.	5 min.	5 min.	Stranded or solid	Screened or unscreened
	$1 < f \le 20$	35 – 20lg(f)	35 – 20lg(f)	45 – 20lg(f)	55 – 20lg(f)		

A.3.3.4 Coupling attenuation

The balanced 1-pair cable coupling attenuation specifications are given using the formulae in Table A.6.

Table A.6 – Balanced 1-pair cable coupling attenuation

Upper frequency	Frequency range	Coupling attenuation Type II	Coupling attenuation Type Ib	Coupling attenuation Type I	Conductor type	Screen type
MHz	MHz	dB	dB	dB		
600	$1 \le f \le 100$	55 max.	70 max.	85 max.	Solid	Screened
	$100 < f \le 600$	55 – 20 lg(f/100)	70 – 20lg(f/100)	85 – 20 lg(f/100)		
600	$1 \le f \le 600$	55 max.	70 max.	85 max.	Stranded or solid	Screened or unscreened
	$1 < f \le 600$	55 – 20 lg(f/100)	70 – 20lg(f/100)	85 – 20 lg(f/100)		
20	$1 \le f \le 20$	55 max.	70 max.	85 max.	Solid	Screened
	$1 < f \le 20$	55 – 20 lg(f/100)	70 – 20lg(f/100)	85 – 20 lg(f/100)		
20	$1 \le f \le 20$	55 max.	70 max.	85 max.	Stranded or solid	Screened or unscreened
	$1 < f \le 20$	55 – 20 lg(f/100)	70 – 20lg(f/100)	85 – 20 lg(f/100)		

A.3.4 Alien (exogenous) crosstalk

A.3.4.1 General

For unscreened cabling alien (exogenous) crosstalk parameters, power-sum alien near-end crosstalk (PS ANEXT) and power-sum alien attenuation to crosstalk ratio far-end (PS AACR-F) are used for differential-mode-to-differential-mode alien noise loss specifications.

For screened cabling, E_1 coupling attenuation specifications, given in A.3.3.4, may be substituted for alien noise loss specifications, see ISO/IEC 11801-1.

These alien noise loss specifications are based on the 6-around-1 measurement setup according to IEC 61156-1.

A.3.4.2 PS ANEXT

The balanced 1-pair cable PS ANEXT specifications are given using the formulae in Table A.7.

Table A.7 – Balanced 1-pair cable PS ANEXT

Upper frequency	Frequency range	PS ANEXT	Conductor type	Screen type
MHz	MHz	dB		
600	$1 \le f \le 600$	67,0	Solid	Screened
600	$1 \le f \le 600$	67,0	Stranded or solid	Screened or unscreened
20	$0{,}1 \le f \le 20$	(ffs)	Solid	Screened
20	$0{,}1 \le f \le 20$	(ffs)	Stranded or solid	Screened or unscreened
ffs for further study				

A.3.4.3 PS AACR-F

The balanced 1-pair cable PS AACR-F specifications are given using the formulae in Table A.8.

Table A.8 – Balanced 1-pair cable PS AACR-F

Upper frequency	Frequency range	PS AACR-F	Conductor type	Screen type
MHz	MHz	dB		
600	$1 \le f \le 600$	$103 - 20 \lg(f)$	Solid	Screened
600	$1 \le f \le 600$	$103 - 20 \lg(f)$	Stranded or solid	Screened or unscreened
20	$0{,}1 \le f \le 20$	(ffs)	Solid	Screened
20	$0{,}1 \le f \le 20$	(ffs)	Stranded or solid	Screened or unscreened
ffs for further study				

A.3.5 DC resistance

The balanced 1-pair cable DC resistance specifications are given using the formulae in Table A.9.

Table A.9 – Balanced 1-pair cable DC resistance

Upper frequency	Frequency range	DC loop resistance	Conductor type	Screen type
MHz	MHz	Ω/km		
600	$1 \le f \le 600$	145	Solid	Screened
600	$1 \le f \le 600$	145	Stranded or solid	Screened or unscreened
20	$0{,}1 \le f \le 20$	60,3	Solid	Screened
20	$0{,}1 \le f \le 20$	60,3	Stranded or solid	Screened or unscreened

A.3.6 Propagation delay

The balanced 1-pair cable propagation delay specifications are given using the formulae in Table A.10.

Table A.10 – Balanced 1-pair cable propagation delay

Upper frequency	Frequency range	Propagation delay	Conductor type	Screen type
MHz	MHz	ns		
600	$1 \le f \le 600$	$534 + 36/\sqrt{f}$	Solid	Screened
600	$1 \le f \le 600$	$534 + 36/\sqrt{f}$	Stranded or solid	Screened or unscreened
20	$0{,}1 \le f \le 20$	$534 + 36/\sqrt{f}$	Solid	Screened
20	$0{,}1 \le f \le 20$	$534 + 36/\sqrt{f}$	Stranded or solid	Screened or unscreened

Annex B
(informative)

Balanced 1-pair connector specifications

B.1 General

Information regarding balanced 1-pair connectors will be given in the future IEC balanced 1-pair connector general standard, IEC 63171.

The various transmission specifications for connectors, intended for use in balanced 1-pair cabling applications, are organized according to characteristics arranged in Table B.1.

Table B.1 – Balanced 1-pair connector standards

Upper frequency	Frequency range	Screen type	Balanced 1-pair connector standard
MHz	MHz		
600	0,1 ≤ f ≤ 600	Screened or unscreened	IEC 63171
20	0,1 ≤ f ≤ 20	Screened or unscreened	IEC 63171

B.2 Balanced 1-pair connector specifications

B.2.1 Return loss (RL)

The balanced 1-pair connector return loss (RL) specifications are given using the formulae in Table B.2.

Table B.2 – Balanced 1-pair connector RL

Upper frequency	Frequency range	RL	Screen type
MHz	MHz	dB	
600	0,1 ≤ f ≤ 600	74 – 20 lg(f)	Screened or unscreened
20	0,1 ≤ f ≤ 20	74 – 20 lg(f)	Screened or unscreened

B.2.2 Insertion loss (IL)

The balanced 1-pair connector insertion loss (IL) specifications are given using the formulae in Table B.3.

Table B.3 – Balanced 1-pair connector IL

Upper frequency	Frequency range	IL	Screen type
MHz	MHz	dB	
600	$0,1 \le f \le 600$	$0,02 \sqrt{f}$	Screened or unscreened
20	$0,1 \le f \le 20$	$0,02 \sqrt{f}$	Screened or unscreened

B.2.3 Unbalance attenuation and coupling attenuation

B.2.3.1 General

Unbalance attenuation parameters, transverse-conversion-loss (TCL) and equal-level-transverse-conversion-transfer-loss (ELTCTL), are used for differential-mode-to-common-mode conversion loss specifications, for unscreened cabling.

Coupling attenuation is used for differential-mode-to-common-mode conversion loss specifications, for screened cabling.

B.2.3.2 Transverse-conversion-loss (TCL)

The balanced 1-pair connector transverse-conversion-loss (TCL) specifications are given using the formulae in Table B.4.

Table B.4 – Balanced 1-pair connector TCL

Upper frequency	Frequency range	TCL	Screen type
MHz	MHz	dB	
600	$0,1 \le f \le 600$	$68 - 20 \lg(f)$	Unscreened
20	$0,1 \le f \le 20$	$68 - 20 \lg(f)$	Unscreened

B.2.3.3 Transverse-conversion-transfer-loss (TCTL)

The balanced 1-pair connector transverse-conversion-transfer-loss (TCTL) specifications are given using the formulae in Table B.5.

Table B.5 – Balanced 1-pair connector TCTL

Upper frequency	Frequency range	TCTL	Screen type
MHz	MHz	dB	
600	$0,1 \le f \le 600$	$68 - 20 \lg(f)$	Unscreened
20	$0,1 \le f \le 20$	$68 - 20 \lg(f)$	Unscreened

B.2.3.4 Coupling attenuation

The balanced 1-pair connector coupling attenuation specifications are given using the formulae in Table B.6.

Table B.6 – Balanced 1-pair connector coupling attenuation

Upper frequency	Frequency range	Coupling attenuation	Screen type
MHz	MHz	dB	
600	$0,1 \le f \le 600$	$100 - 20 \lg(f)$	Screened
20	$0,1 \le f \le 20$	$100 - 20 \lg(f)$	Screened

B.2.4 Alien (exogenous) crosstalk

B.2.4.1 General

For unscreened cabling alien (exogenous) crosstalk parameters, power-sum alien near-end crosstalk (PS ANEXT) and power-sum alien attenuation to crosstalk ratio far-end (PS AACR-F) are used for differential-mode-to-differential-mode alien noise loss specifications.

For screened cabling, E_1 coupling attenuation specifications, given in B.2.3.4, may be substituted for alien noise loss specifications, see ISO/IEC 11801-1.

These alien noise loss specifications are based on the 6-around-1 measurement setup according to IEC 61156-1.

B.2.4.2 PS ANEXT

The balanced 1-pair connector PS ANEXT specifications are given using the formulae in Table B.7.

Table B.7 – Balanced 1-pair connector PS ANEXT

Upper frequency	Frequency range	PS ANEXT	Screen type
MHz	MHz	dB	
600	$0,1 \le f \le 600$	$110 - 20 \lg(f)$	Unscreened
600	$0,1 \le f \le 600$	$140 - 20 \lg(f)$	Screened
20	$0,1 \le f \le 20$	$110 - 20 \lg(f)$	Unscreened
20	$0,1 \le f \le 20$	$140 - 20 \lg(f)$	Screened

B.2.4.3 PS AACR-F

The balanced 1-pair connector PS AACR-F specifications are given using the formulae in Table B.8.

Table B.8 – Balanced 1-pair connector PS AACR-F

Upper frequency	Frequency range	PS AACR-F	Screen type
MHz	MHz	dB	
600	$0,1 \le f \le 600$	$107 - 20 \lg(f)$	Unscreened
600	$0,1 \le f \le 600$	$120 - 20 \lg(f)$	Screened
20	$0,1 \le f \le 20$	$107 - 20 \lg(f)$	Unscreened
20	$0,1 \le f \le 20$	$120 - 20 \lg(f)$	Screened

B.2.5 DC resistance (DCR)

The balanced 1-pair connector DCR specifications are given using the formulae in Table B.9.

Table B.9 – Balanced 1-pair connector DCR

Upper frequency	Frequency range	DCR	Screen type
MHz	MHz	mΩ	
600	$0,1 \leq f \leq 600$	50	Screened or unscreened
20	$0,1 \leq f \leq 20$	50	Screened or unscreened

B.2.6 Propagation delay (delay)

The balanced 1-pair connector delay specifications are given using the formulae in Table B.10.

Table B.10 – Balanced 1-pair connector delay

Upper frequency	Frequency range	Delay	Screen type
MHz	MHz	ns	
600	$0,1 \leq f \leq 600$	2,5	Screened or unscreened
20	$0,1 \leq f \leq 20$	2,5	Screened or unscreened

Annex C
(informative)

Link segment specifications

C.1 General

IEEE 802.3 single-pair Ethernet (SPE) link segment characteristics are summarized here.

NOTE IEEE 802.3cg changed the limit line from PS AACRF to PS AFEXT and is valid under all circumstances, for example, a short disturber disturbing a long cable.

C.2 Return loss (RL)

C.2.1 1000BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD4

See Table C.1.

Table C.1 – Return loss limits for 15 m and 40 m link segment

Frequency MHz	Minimum return loss dB
$1 < f \leq 10$	19,0
$10 < f \leq 40$	$24 - 5 \lg(f)$
$40 < f \leq 130$	16
$130 < f \leq 400$	$37 - 10 \lg(f)$
$400 < f \leq 600$	11

C.2.2 100BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD1

See Table C.2.

Table C.2 – Return loss limits for 15 m link segment

Frequency	Minimum return loss
MHz	dB
$1 < f \leq 20$	18,0
$20 < f \leq 66$	$18 - 10 \lg(f/20)$

C.2.3 10BASE-T1S, IEEE 802.3cg

See Table C.3.

Table C.3 – Return loss limits for 15 m link segment

Frequency MHz	Minimum return loss dB
$0,3 < f < 10$	14
$10 \leq f \leq 40$	$14 - 10 \lg(f/10)$

C.2.4 10BASE-T1L, IEEE 802.3cg

See Table C.4.

Table C.4 – Return loss limits for 1 000 m link segment

Frequency MHz	Minimum return loss dB
$0,1 < f < 0,5$	$9,0 + 8\,f$
$0,5 \le f \le 20$	13,0

C.3 Insertion loss (IL)

C.3.1 1000BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD4

See Table C.5.

Table C.5 – Insertion loss limits of a 15 m and 40 m link segment

Frequency range $1 < f \le 600$ MHz	Insertion loss dB
15 m	$\left(0,5907\sqrt{f} + 0,0023\,f + 0,0639/\sqrt{f}\right)$
40 m	$0,7131\sqrt{f} + 0,004\,f + (0,11/\sqrt{f}) + 0,08\sqrt{f} + 0,018\sqrt{f}$

C.3.2 100BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD1

C.3.2.1 General

See Table C.6.

NOTE This link segment includes the mating connectors at the end.

Table C.6 – Insertion loss limits for a 15 m link segment

Frequency MHz	Maximum insertion loss dB
$1 < f \le 10$	$1,0 + 1,6 \times \frac{f-1}{9}$
$10 < f \le 33$	$2,6 + 2,3 \times \frac{f-10}{23}$
$33 < f \le 66$	$4,9 + 2,3 \times \frac{f-33}{33}$

C.3.2.2 10BASE-T1S, IEEE 802.3cg

See Table C.7.

Table C.7 – Insertion loss limits for a 15 m link segment

Frequency MHz	Maximum insertion loss dB
$1 < f \leq 10$	$1{,}0 + 1{,}6 \times \frac{f-1}{9}$
$10 < f \leq 33$	$2{,}6 + 2{,}3 \times \frac{f-10}{23}$
$33 < f \leq 40$	$4{,}9 + 2{,}3 \times \frac{f-33}{33}$

NOTE These specifications are the same as for 100BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD1.

C.3.2.3 10BASE-T1L, IEEE 802.3cg

See Table C.8.

Table C.8 – Insertion loss limits for a 1 000 m link segment

Frequency MHz	Maximum insertion loss dB	1000BASE-T1L
$0{,}1 < f \leq 20$	$10 \times \left(1{,}23\sqrt{f} + 0{,}01f + 0{,}2/\sqrt{f}\right) + 10 \times 0{,}02\sqrt{f}$	For PHY in normal operation
$0{,}1 < f \leq 20$	$5{,}9 \times \left(1{,}23\sqrt{f} + 0{,}01f + 0{,}2/\sqrt{f}\right) + 10 \times 0{,}02\sqrt{f}$	For PHY in the 1,0 V_{pp} operation

C.4 TCL - 10BASE-T1L, IEEE 802.3cg

See Table C.9.

Table C.9 – TCL for a 1 000 m link segment

Frequency MHz	TCL for E_1 dB	TCL for E_2 dB	TCL for E_3 dB
$0{,}1 \leq f \leq 10$	≥ 50	≥ 50	Not specified
$10 \leq f \leq 20$	≥ 50 – 20lg(f/10)	≥ 50 – 20lg(f/10)	Not specified

NOTE Specifications are for 1 V_{pp} operating mode.

C.5 ELTCTL - 10BASE-T1L, IEEE 802.3cg

See Table C.10.

Table C.10 – ELTCTL for a 1 000 m link segment

Frequency MHz	ELTCTL for E_1 dB	ELTCTL for E_2 dB	ELTCTL for E_3 dB
$0{,}1 \le f \le 20$	Not specified	Not specified	Not specified

NOTE Specifications are for 1 V_{pp} operating mode.

C.6 PS ANEXT

C.6.1 1000BASE-T1, Type A, ISO/IEC/IEEE 8802-3:2017/AMD4

See Table C.11.

Table C.11 – PS ANEXT for a 15 m link segment

Frequency MHz	PS ANEXT dB
$1 \le f \le 600$	$54 - 10 \lg(f/100)$

C.6.2 1000BASE-T1, Type B, ISO/IEC/IEEE 8802-3:2017/AMD4

See Table C.12.

Table C.12 – PS ANEXT for a 40 m link segment

Frequency MHz	PS ANEXT dB
$1 \le f \le 600$	65

C.6.3 100BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD1

See Table C.13.

Table C.13 – PS ANEXT for a 15 m link segment

Frequency MHz	PS ANEXT dB
$1 \le f \le 100$	$31{,}5 - 10 \lg(f/100)$

C.6.4 10BASE-T1S, IEEE 802.3cg

See Table C.14.

Table C.14 – PS ANEXT for a 15 m link segment

Frequency MHz	PS ANEXT dB
$1 \le f \le 100$	$31{,}5 - 10 \lg(f/100)$

NOTE These specifications are the same as for 100BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD1.

C.6.5 10BASE-T1L, IEEE 802.3cg

See Table C.15.

Table C.15 – PS ANEXT for a 1 000 m link segment

Frequency MHz	PS ANEXT dB
$0{,}1 \le f \le 20$	$37{,}5 - 20 \lg(f/20)$

C.7 PS AACR-F

C.7.1 1000BASE-T1, Type A, ISO/IEC/IEEE 8802-3:2017/AMD4

See Table C.16.

Table C.16 – PS AACR-F for a 15 m link segment

Frequency MHz	PS AACR-F dB
$1 \le f \le 600$	$67 - 20 \lg(f/100)$

C.7.2 1000BASE-T1, Type B, ISO/IEC/IEEE 8802-3:2017/AMD4

See Table C.17.

Table C.17 – PS AACR-F for a 40 m link segment

Frequency MHz	PS AACR-F dB
$1 \le f \le 600$	$61 - 20 \lg(f/100)$

C.7.3 100BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD1

See Table C.18.

Table C.18 – PS AACR-F for a 15 m link segment

Frequency MHz	PS AACR-F dB
$1 \le f \le 100$	$16{,}5 - 20 \lg(f/100)$

C.7.4 10BASE-T1S, IEEE 802.3cg

See Table C.19.

Table C.19 – PS AACR-F for a 15 m link segment

Frequency MHz	PS AACR-F dB
$1 \le f \le 100$	$16{,}5 - 20 \lg(f/100)$

NOTE These specifications are the same as for 100BASE-T1, ISO/IEC/IEEE 8802-3:2017/AMD1.

C.7.5 10BASE-T1L, IEEE 802.3cg

See Table C.20.

Table C.20 – PS AACR-F for a 1 000 m link segment

Frequency MHz	PS AACR-F dB
$0{,}1 \le f \le 20$	$38 - 18 \lg(f/20)$

C.8 Coupling attenuation

C.8.1 1000BASE-T1, Type A, ISO/IEC/IEEE 8802-3:2017/AMD4

See Table C.21.

Table C.21 – Coupling attenuation for a 15 m link segment

Frequency MHz	Coupling attenuation for E_1 dB	Coupling attenuation for E_2 dB	Coupling attenuation for E_3 dB
$10 \le f \le 600$	$72 - 11{,}51 \lg(f)$	Not specified	Not specified