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Customer Premises Cabling
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Liaison report to IEEE 802.3 on 10G Developments

Date: 2003-February-14
To: IEEE 802.3
From: ISO/IEC JTC 1/SC 25/WG 3
Subject: Liaison Report from ISO/IEC JTC 1/SC 25/WG 3 to IEEE 802.3 on 10G Developments

ISO/IEC JTC 1/SC 25/WG 3 has been following with interest your progress towards the definition of a PAR for 10GBASE-T. We reviewed this at our Wellington, New Zealand meeting of February 10-14, and would like to offer the following comments.

1. We note that initial discussions regarding the PAR for 10GBASE-T centre around the use of channels “Category 5 / Class D or better”
2. We would like to advise you that the “Category 5 / Class D” specifications in ISO/IEC 11801 have recently been updated to be equivalent to TIA/EIA 568B.1 Category 5e, and the installed base also commonly referred to as “Category 5” will have significant variations, as these are not verified for the additional requirements specified in the 2nd Edition of ISO/IEC 11801.
3. We would also advise you that the lowest common denominator found in the installed base is equivalent to the first edition of ISO/IEC 11801 from 1995. Please refer to this ISO/IEC document for a definition of the installed base of Category 5 / Class D cabling.
4. This Working Group has re-engineered and specified the Category 5 / Class D Channel to accommodate the needs of IEEE 802.3, which we agreed to do in the lack of higher specified classes of transmission. We presently have a number of active projects under way and would find it difficult to justify any further work on “Category 5 / Class D” specifications, due to its anticipated obsolescence.
5. The strategic decision to develop higher performance cabling, Classes E and F, to accommodate future applications was based on the increasing channel performance trend required by Ethernet as it has evolved.
6. The recently published ISO/IEC 11801 2nd Edition (2002), specifies channel and link Classes E and F based on higher performance components to support the development and implementation of future applications
7. We would like to note that the installed base of Category 6 / Class E and Category 7 / Class F channels, currently specified up to 250 MHz and 600 MHz respectively, has been growing rapidly since 1997, and Category 6 / Class E channels are expected to become a significant share of the installed base by the time your standard is expected to be completed.

In light of the above observations we strongly urge you to focus on the support of 10GBASE-T over channels “Category 6 / Class E or better”, in order that we may co-operate with you in the most expedient manner.

Respectfully submitted

ISO/IEC JTC 1/SC 25/WG 3

Annex 1 Excerpt from ISO/IEC 11801: 1995,

NOTE 1 - This edition was approved for publication 1994 and published 1995-07-15.

NOTE 2 – The effect of equipment and work area cords need to be added to the link values specified in clause 7 of edition 1 of ISO/IEC 11801 to arrive at channels values. Edition 2:2002 specifies the channels including such cords.

7 Link specifications

This clause defines the performance requirements of installed generic cabling. The performance of the cabling is specified for individual links and for two different media types (balanced cables and optical fibre). A tutorial on the material in this clause is provided in annex F.

The design rules of clause 6 can be used to create generic cabling links containing components specified in clauses 8 and 9. The link specifications in this clause allow for the transmission of defined classes of applications over distances other than those of clause 6, and/or using media and components with different transmission performance than those of clauses 8 and 9.

The performance requirements described in this clause may be used as verification tests for any implementation of this International Standard, using the test methods defined, or referred to, by this clause. Additionally, they can be used for qualification of existing cabling, diagnosis at the cabling link level, and as the basis for an alternative implementation.

Care should be exercised in the interpretation of any results obtained from alternative test methods or practices. When needed, correlation factors should be identified and applied.

The performance of a cabling link is specified at and between interfaces to the link. The cabling comprises only passive sections of cable, connecting hardware, and patch cords. Active and passive application specific hardware is not addressed by this International Standard. Figure 11 shows an example of terminal equipment in the work area connected to a host using two links; an optical fibre link and a balanced cable link. The two links are connected together using an optical fibre to balanced cable converter. There are four link interfaces; one at each end of the copper link, and one at each end of the optical fibre link.

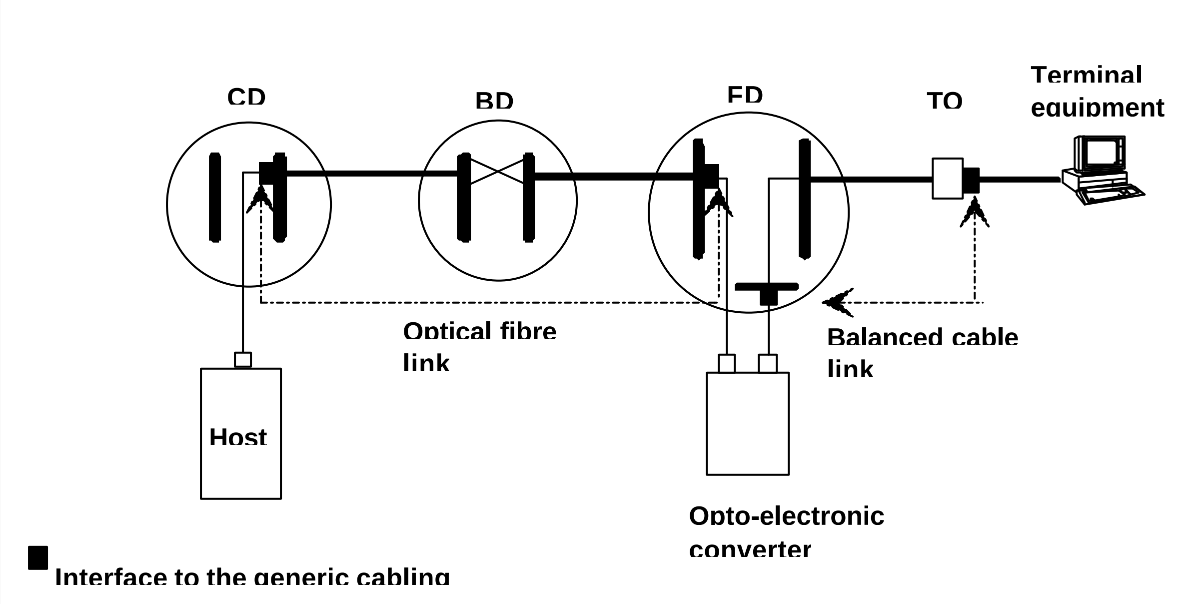

Figure 11 - Example of a system showing the location of cabling interfaces and extent of associated links

Interfaces to the cabling are at each end of a link. Interfaces to the cabling are specified at the TO and at any point where application specific equipment is connected to the cabling; the work area and equipment cabling are not included in the link.

The link performance requirements specified in this clause shall be met at each interface specified for each medium. It is not necessary to measure every parameter specified in this clause as conformance may also be proved by suitable design.

Link performance specifications shall be met for all temperatures at which the cabling is intended to operate. Performance testing may be carried out at ambient temperature, but there shall be adequate margins to account for temperature dependence of cabling components as per manufacturer's specifications. The effects of ageing should also be taken into account. In particular, consideration should be given to measuring performance at worst case temperatures, or calculating worst case performance based on measurements made at other temperatures.

7.1 Classification of applications and links

7.1.1 Application classification

Five application classes for cabling have been identified for the purposes of this International Standard. This ensures that the limiting requirements of one system do not unduly restrict other systems.

The application classes are:

Class A applications include speech band and low frequency applications. Copper cabling links supporting class A applications are specified up to 100 kHz.

Class B applications include medium bit rate data applications. Copper cabling links supporting class B applications are specified up to 1 MHz.

Class C applications include high bit rate data applications. Copper cabling links supporting class C applications are specified up to 16 MHz.

Class D applications include very high bit rate data applications. Copper cabling links supporting class D applications are specified up to 100 MHz.

Optical class applications include high and very high bit rate data applications. Optical fibre cabling links are specified at 10 MHz and above. Bandwidth is generally not a limiting factor in the customer's premises.

Annex G gives examples of applications that fall within the various classes.

7.1.2 Link classification

Generic cabling, when configured to support particular applications, comprises one or more links

For copper cabling links, a class A link is specified so that it will provide the minimum transmission performance to support class A applications. Similarly, class B, C and D links provide the transmission performance to support class B, C and D applications respectively. Links of a given class will support all applications of a lower class. Class A is regarded as the lowest class.

Optical parameters are specified for singlemode and multimode optical fibre links. For optical fibre cabling links, the link is specified so that the minimum transmission performance is supported for applications specified at 10 MHz and above.

Class C and D links correspond to full implementations of category 3 and category 5 horizontal cabling subsystems respectively, as specified in 6.1.

Table 2 relates the link classes to the cabling categories of clauses 8 and 9. This table indicates the

channel length over which the various applications may be supported.

The distances presented are based on crosstalk loss (for copper cables), bandwidth (for optical fibre cables), and attenuation limits for various classes. Other characteristics of applications, for example propagation delay, may further limit these distances.

Table 2 - Channel lengths achievable with different categories and types of cabling

Medium	Channel length				
	Class A	Class B	Class C	Class D	Optical class
Category 3 balanced cable (8.1)	2 km	200 m	100 m [1)]	-	-
Category 4 balanced cable (8.1)	3 km	260 m	150 m [3)]	-	-
Category 5 balanced cable (8.1)	3 km	260 m	160 m [3)]	100 m [1)]	-
150 Ω balanced cable (8.2)	3 km	400 m	250 m [3)]	150 m [3)]	-
Multimode optical fibre (8.4)	N/A	N/A	N/A	N/A	2 km
Singlemode optical fibre (8.5)	N/A	N/A	N/A	N/A	3 km [2)]

NOTES

1) The 100 m distance includes a total allowance of 10 m of flexible cable for patch cords / jumpers, work area and equipment connections. Link specifications are consistent with 90 m horizontal cable, 7,5 m electrical length of patch cable and three connectors of the same category. Support for applications is assumed, provided that no more than an additional 7,5 m electrical length of combined work and equipment area cable is used (see figure 7).

2) 3 km is a limit defined by the scope of the International Standard and not a medium limitation.

3) For distances greater than 100 m of balanced cable in the horizontal cabling subsystem, the applicable application standards should be consulted.

Consideration should be given, when specifying and designing cabling, to the possible future connection of cabling subsystems to form longer links. The performance of these longer links will be lower than that of any of the individual subsystem links from which they are constructed. Measurement of links should be made initially, upon installation of each cabling subsystem. Testing of combined subsystems should be performed as required by the application.

7.2 Balanced cabling links

The parameters specified in this subclause apply to cabling links with shielded or unshielded cable elements, with or without an overall shield, unless explicitly stated otherwise. Unless stated otherwise, outline test configurations for all measurements on balanced cabling are given in annex A. Specialised test instruments are required for high frequency field measurements on balanced cabling. The maximum application frequencies are based on required link characteristics, and are not indicated by the maximum specified frequency for the cabling.

7.2.1 Characteristic impedance

The nominal differential characteristic impedance of a cabling link shall be 100 Ω, 120 Ω, or 150 Ω at frequencies between 1 MHz and the highest specified frequency for the cabling class.

The tolerance of the characteristic impedance in a given link shall not exceed the chosen nominal impedance by more than ±15 Ω (f.f.s.) from 1 MHz up to the highest specified frequency for that class.

The variation of the characteristic impedance of a cabling link is characterised by the return loss. The nominal characteristic impedance of cables used in a cabling link shall be in accordance with the requirements of clause 8.

The measurement of these values on installed cabling systems is under study. Verification of the characteristic impedance of cabling links should be made by a suitable design, and the appropriate choice of cables and connecting hardware.

7.2.2 Return loss

The return loss of the cabling, measured at any interface, shall meet or exceed the values shown in table 3. The remote end of the link should be terminated with a resistor of value equal to the nominal impedance of the cabling during the test.

Table 3 - Minimum return loss at each cabling interface

Frequency MHz	**Minimum return loss** dB	
	Class C	**Class D**
1 ≤ f ≤ 10	18 (f.f.s.)	18 (f.f.s.)
10 ≤ f ≤ 16	15 (f.f.s.)	15 (f.f.s.)
16 ≤ f ≤ 20	N/A	15 (f.f.s.)
20 ≤ f ≤ 100	N/A	10 (f.f.s.)

7.2.3 Attenuation

The attenuation of a link shall not exceed the values shown in table 4, and shall be consistent with the design values of cable length and cabling materials used. The attenuation of the link shall be measured according to 3.3.2 of IEC 1156-1, except that the measured attenuation shall not be scaled to a standard length. For class D links, the ACR requirements in 7.2.5 may require lower attenuation than that shown in table 4. Class D links should comprise cables which closely follow the square root of frequency attenuation characteristic above 1 MHz.

The values in table 4 are based on the requirements of the applications listed in annex G.

Table 4 - Maximum attenuation values

Frequency MHz	**Maximum attenuation** dB			
	Class A	**Class B**	**Class C**	**Class D**
0,1	16	5,5	N/A	N/A
1,0	N/A	5,8	3,7	2,5
4,0	N/A	N/A	6,6	4,8
10,0	N/A	N/A	10,7	7,5
16,0	N/A	N/A	14,0	9,4
20,0	N/A	N/A	N/A	10,5
31,25	N/A	N/A	N/A	13,1
62,5	N/A	N/A	N/A	18,4
100,0	N/A	N/A	N/A	23,2

For attenuation measurements that include equipment and work area cables on both ends of a cabling link, the values in table 4 should not be exceeded by more than the attenuation of the equipment and work area cables used.

7.2.4 Near-end crosstalk loss

The near-end crosstalk loss of a link shall meet or exceed the values shown in table 5, and shall be consistent with the design values of cable length and cabling materials used. The crosstalk loss shall be measured according to 3.3.4 of IEC 1156-1 except that the measured near-end crosstalk loss shall not be adjusted for length. The NEXT shall be measured from both ends of the cabling segment to allow a correct evaluation of the cabling link. See also A.1.1. For class D links, the ACR in 7.2.5 may require better near-end crosstalk loss performance than that shown in table 5.

The values in table 5 are based on the near-end crosstalk loss requirements of the applications listed in annex G.

Table 5 - Minimum NEXT loss

Frequency MHz	**Minimum crosstalk loss** dB			
	Class A	**Class B**	**Class C**	**Class D**
0,1	27	40	N/A	N/A
1,0	N/A	25	39	54
4,0	N/A	N/A	29	45
10,0	N/A	N/A	23	39
16,0	N/A	N/A	19	36
20,0	N/A	N/A	N/A	35
31,25	N/A	N/A	N/A	32
62,5	N/A	N/A	N/A	27
100,0	N/A	N/A	N/A	24

For NEXT loss measurements that include equipment and work area cables on both ends of a cabling link, the NEXT loss in table 5 should be met. Equipment connectors are not accounted for in this table and may contribute to additional crosstalk degradation.

Crosstalk is not the only source of noise in a transmission system. An assumption has been made that noise from all other sources is at least 10 dB less than the crosstalk noise power at all application frequencies of interest.

7.2.5 Attenuation to crosstalk loss ratio

This is the difference between the crosstalk loss and the attenuation of the link in dB. It is related to, but distinct from, the signal to crosstalk ratio (SCR) which accommodates the transmit and receive signal levels of an application. By applying the requirements of 7.2.3, 7.2.4 and 7.2.5, the transmission requirements of the applications listed in annex G will be met. The ACR of a link is calculated by:

$$ACR(dB) = a_N(dB) - a(dB)$$

where:

ACR is the attenuation to crosstalk loss ratio

a_N is the crosstalk loss, measured between any two pairs of a link. The crosstalk attenuation shall be measured according to 3.3.4 of IEC 1156-1, except that the measured crosstalk shall not be adjusted for length.

a is the attenuation of the link when measured according to 3.3.2 of IEC 1156-1, except that the measured attenuation shall not be scaled to a standard length.

The ACR is based on the most severe requirements of the applications listed in annex G. The ACR for links of class A, B and C is identical to the values which can be calculated directly from the attenuation and crosstalk loss values shown in tables 4 and 5 respectively. For class D links, the ACR is more demanding than the direct calculation from tables 4 and 5. For class D links, the ACR shall be better than the limits shown in table 6. This provides some flexibility in the choice of cabling components, allowing some limited trade-offs between attenuation (cable length) and crosstalk performance of the cabling.

Table 6 - Minimum ACR values

Frequency MHz	**Minimum ACR** dB
	Class D
1,0	-
4,0	40
10,0	35
16,0	30
20,0	28
31,25	23
62,5	13
100,0	4

For ACR calculations that include equipment and work area cables on both ends of a link, the ACR values in table 6 should not be degraded by more than the attenuation of the equipment and work area cables used.

7.2.6 DC resistance

The loop resistance of pairs shall be less than the values given in table 7 for each class of application. These figures are derived from application requirements. The d.c. loop resistance shall be measured according to 5.1 of IEC 189-1. A short circuit is applied at the remote end of the pair and the loop resistance is measured at the near end. The measured value should be consistent with the length and diameter of the conductors used in the cable.

Table 7 - Maximum d.c. loop resistance

Link class	**Class A**	**Class B**	**Class C**	**Class D**
Maximum loop resistance Ω	560	170	40	40

7.2.7 Propagation delay

The propagation delay, measured as shown in annex A, shall be less than the limits given in table 8. These limits are derived from system requirements. Any measured or calculated values should be consistent with the lengths and materials used in the cabling.

Table 8 - Maximum propagation delay

Measurement Frequency MHz	**Class**	**Delay** µs
0,01	A	20,0
1	B	5,0
10	C	1,0
30	D	1,0

The maximum propagation delay in the horizontal cabling subsystem shall not exceed 1 µs.

7.2.8 Longitudinal to differential conversion loss (balance)

The longitudinal conversion loss, measured as LCL and as LCTL according to ITU-T Recommendation G.117, should exceed the values shown in table 9.

Table 9 - Longitudinal to differential conversion loss

Frequency MHz	**Minimum longitudinal to differential conversion loss** dB			
	Class A	**Class B**	**Class C**	**Class D**
0,1	30	45	35	40
1,0	N/A	20	30	40
4,0	N/A	N/A	f.f.s.	f.f.s.
10,0	N/A	N/A	25	30
16,0	N/A	N/A	f.f.s.	f.f.s.
20,0	N/A	N/A	f.f.s.	f.f.s.
100,0	N/A	N/A	N/A	f.f.s.

The measurement of these values on installed systems is not yet well established. It is sufficient to verify the values by design.

7.2.9 Transfer impedance of shield

This parameter applies to shielded cabling only. The measurement of transfer impedance for installed cabling is not well developed. Connector termination practices may be verified by laboratory measurements of representative samples of short lengths of terminated cable. The transfer impedance requirements for shielded cables and connectors in clauses 8 and 9 should be applied. See clause 10 for guidance on the use of shielded cabling.

Annex 2 Excerpt from ISO/IEC 11801: 2002,

NOTE 1 - This edition was approved for publication 2002 and published 2002-09-30.

NOTE 2 - Equipment and work area are part of the channel.

NOTE 3 – The page numbers 37 to 50 are those of ISO/IEC 11801:2002.

NOTE 4 – This Annex is COPYRIGHTED MATERIAL

6 Performance of balanced cabling

6.1 General

This clause specifies the minimum performance of generic balanced cabling. The performance of balanced cabling is specified for channels, permanent links and CP links (see Figure 10).

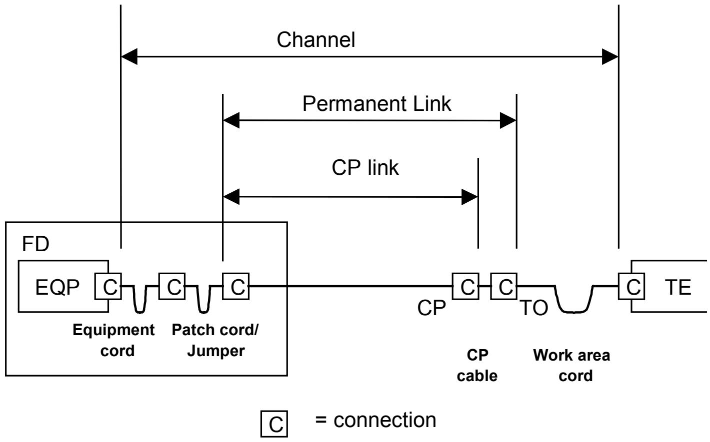

Figure 10 – Channel, permanent link and CP link of a balanced cabling

In the case of cable sharing, additional requirements should be taken into account for balanced cabling. The additional crosstalk requirements for balanced cables are specified in 9.3.

The performance specifications are separated into six classes (A to F) for balanced cabling. This allows the successful transmission of applications over channels according to Annex F which lists the applications and the minimum class required.

The channel performance requirements described in this clause may be used for the design and verification of any implementation of this International Standard. Where required, the test methods defined or referred to by this clause, shall apply. In addition, these requirements can be used for application development and troubleshooting.

The permanent link and CP link performance requirements described in Annex A may be used for acceptance testing of any implementation of this International Standard. Where required, the test methods defined or referred to by Annex A, shall apply.

The specifications in this clause allow for the transmission of defined classes of applications over distances other than those of 7.2, and/or using media and components with different performances than those specified in Clauses 9, 10 and 13.

The channel, permanent link and CP link performance specification of the relevant class shall be met for all temperatures at which the cabling is intended to operate.

There shall be adequate margins to account for temperature dependence of cabling components as per relevant standards and suppliers' instructions. In particular, consideration should be given to measuring performance at worst case temperatures, or calculating worst case performance based on measurements made at other temperatures.

Compatibility between cables used in the same channel or permanent link shall be maintained throughout the cabling system. For example, connections between cables with different nominal impedance shall not be made.

6.2 Layout

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

Application support depends on channel performance only, which in turn depends on cable length, number of connections, connector termination practices and 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 (see also Annex G).

The performance limits for balanced cabling channels are given in 6.4. These limits are derived from the component performance limits of Clause 9 and 10 assuming the channel is composed of 90 m of solid conductor cable, 10 m of cord(s) and four connections (see Figure 10).

Most class F channels are implemented with two connections only. Additional information concerning this implementation is given in Annex H.

Figure 11 shows an example of terminal equipment in the work area connected to transmission equipment using two different media channels, which are cascaded. In fact there is an optical fibre channel (see Clause 8) connected via an active component in the FD to a balanced cabling channel. There are four channel interfaces; one at each end of the balanced channel, and one at each end of the optical fibre channel.

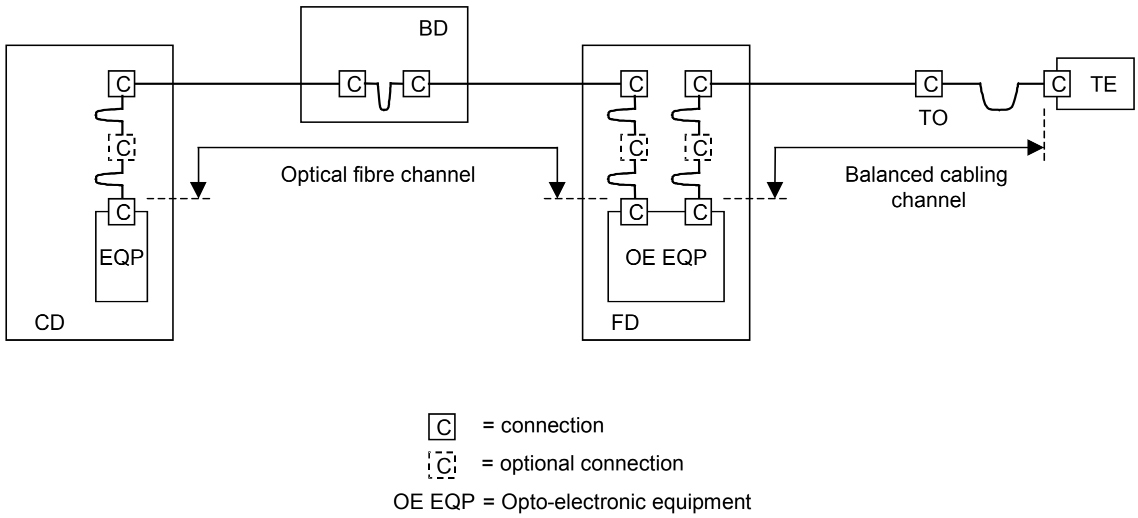

Figure 11 – Example of a system showing the location of cabling interfaces and extent of associated channels

The performance of a permanent link is specified for horizontal cabling at and between the TO and the first patch panel at the other side of the horizontal cable; it may contain a CP. The performance of a CP link is specified for horizontal cabling at and between the CP and the first patch panel at the other side of the horizontal cable. For backbone cabling the permanent link is specified at and between the patch panels at each side of the backbone cable. The permanent link and CP link comprise only passive sections of cable and connecting hardware.

The performance limits for balanced cabling permanent links and CP links are given in Annex A.

The performance limits for balanced cabling permanent links with maximum implementation are also given in Annex A. These limits are derived from the component performance limits of Clauses 9 and 10 assuming the permanent link is composed of 90 m of solid conductor cable and three connections (see Figure 10).

Most class F permanent links are implemented with two connections only. Additional information concerning this implementation is given in Annex H.

6.3 Classification of balanced cabling

This standard specifies the following classes for balanced cabling.

Class A is specified up to 100 kHz.

Class B is specified up to 1 MHz.

Class C is specified up to 16 MHz.

Class D is specified up to 100 MHz.

Class E is specified up to 250 MHz.

Class F is specified up to 600 MHz.

A Class A channel is specified so that it will provide the minimum transmission performance to support Class A applications. Similarly, Class B, C, D, E and F channels provide the transmission performance to support Class B, C, D, E and F applications respectively. Links and channels of a given class will support all applications of a lower class. Class A is regarded as the lowest class.

Channels, permanent links and CP links in the horizontal cabling shall be installed to provide a minimum of Class D performance.

Annex F lists known applications by classes.

6.4 Balanced cabling performance

6.4.1 General

The parameters specified in this subclause apply to channels with screened or unscreened cable elements, with or without an overall screen, unless explicitly stated otherwise.

The nominal impedance of channels is 100 Ω. This is achieved by suitable design and appropriate choice of cabling components (irrespective of their nominal impedance).

The requirements in this subclause are given by limits computed to one decimal place, using the equation for a defined frequency range. The limits for the propagation delay and delay skew are computed to three decimal places. The additional tables are for information only and have limits derived from the relevant equation at key frequencies.

6.4.2 Return loss

The return loss requirements are applicable only to Classes C, D, E and F.

The return loss (*RL*) of each pair of a channel shall meet the requirements derived by the equation in Table 2.

The return loss requirements shall be met at both ends of the cabling. Return loss (*RL*) values at frequencies where the insertion loss (*IL*) is below 3,0 dB are for information only.

When required, the return loss (*RL*) shall be measured according to IEC 61935-1. Terminations of 100 Ω shall be connected to the cabling elements under test at the remote end of the channel.

Table 2 – Return loss for channel

Class	**Frequency** MHz	**Minimum return loss** dB
C	$1 \le f \le 16$	15,0
D	$1 \le f < 20$	17,0
	$20 \le f \le 100$	$30 - 10\,\lg(f)$
E	$1 \le f < 10$	19,0
	$10 \le f < 40$	$24 - 5\,\lg(f)$
	$40 \le f \le 250$	$32 - 10\,\lg(f)$
F	$1 \le f < 10$	19,0
	$10 \le f < 40$	$24 - 5\,\lg(f)$
	$40 \le f < 251{,}2$	$32 - 10\,\lg(f)$
	$251{,}2 \le f \le 600$	8,0

Table 3 – Informative return loss values for channel at key frequencies

Frequency MHz	**Minimum return loss** dB			
	Class C	**Class D**	**Class E**	**Class F**
1	15,0	17,0	19,0	19,0
16	15,0	17,0	18,0	18,0
100	N/A	10,0	12,0	12,0
250	N/A	N/A	8,0	8,0
600	N/A	N/A	N/A	8,0

6.4.3 Insertion loss/attenuation

Previous editions of this standard use the term “attenuation”, which is still widely used in the cable industry. However, due to impedance mismatches in cabling systems, especially at higher frequencies, this characteristic is better described as “insertion loss”. In this edition, the term “insertion loss” is adopted throughout to describe the signal attenuation over the length of channels, links and components. Unlike attenuation, insertion loss does not scale linearly with length.

The term “attenuation” is maintained for the following parameters:

- attenuation to crosstalk ratio (ACR) – see 6.4.5;
- unbalanced attenuation – see 6.4.14;
- coupling attenuation – see 6.4.15.

For the calculation of *ACR, PS ACR, ELFEXT* and *PS ELFEXT*, the corresponding value for insertion loss (*IL*) shall be used.

The insertion loss (*IL*) of each pair of a channel shall meet the requirements derived by the equation in Table 4.

When required, the *insertion loss* shall be measured according to IEC 61935-1.

Table 4 – Insertion loss for channel

Class	Frequency MHz	Maximum insertion loss [a] dB
A	$f = 0,1$	16,0
B	$f = 0,1$	5,5
	$f = 1$	5,8
C	$1 \le f \le 16$	$1{,}05 \times \left(3{,}23\sqrt{f}\right) + 4 \times 0{,}2$
D	$1 \le f \le 100$	$1{,}05 \times \left(1{,}910\,8\sqrt{f} + 0{,}022\,2 \times f + 0{,}2/\sqrt{f}\right) + 4 \times 0{,}04 \times \sqrt{f}$
E	$1 \le f \le 250$	$1{,}05 \times \left(1{,}82\sqrt{f} + 0{,}016\,9 \times f + 0{,}25/\sqrt{f}\right) + 4 \times 0{,}02 \times \sqrt{f}$
F	$1 \le f \le 600$	$1{,}05 \times \left(1{,}8\sqrt{f} + 0{,}01 \times f + 0{,}2/\sqrt{f}\right) + 4 \times 0{,}02 \times \sqrt{f}$

[a] Insertion loss (*IL*) at frequencies that correspond to calculated values of less than 4,0 dB shall revert to a maximum requirement of 4,0 dB.

Table 5 – Informative insertion loss values for channel at key frequencies

Frequency MHz	Maximum insertion loss dB					
	Class A	Class B	Class C	Class D	Class E	Class F
0,1	16,0	5,5	N/A	N/A	N/A	N/A
1	N/A	5,8	4,2	4,0	4,0	4,0
16	N/A	N/A	14,4	9,1	8,3	8,1
100	N/A	N/A	N/A	24,0	21,7	20,8
250	N/A	N/A	N/A	N/A	35,9	33,8
600	N/A	N/A	N/A	N/A	N/A	54,6

6.4.4 NEXT

6.4.4.1 Pair-to-pair NEXT

The *NEXT* between each pair combination of a channel shall meet the requirements derived by the equation in Table 6.

The *NEXT* requirements shall be met at both ends of the cabling. *NEXT* values at frequencies where the insertion loss (*IL*) is below 4,0 dB are for information only.

When required, the *NEXT* shall be measured according to IEC 61935-1.

Table 6 – NEXT for channel

Class	Frequency MHz	Minimum NEXT dB
A	$f = 0{,}1$	27,0
B	$0{,}1 \le f \le 1$	$25 - 15\lg(f)$
C	$1 \le f \le 16$	$39{,}1 - 16{,}4\lg(f)$
D	$1 \le f \le 100$	$-20\lg\left(10^{\frac{65{,}3-15\lg(f)}{-20}} + 2\times10^{\frac{83-20\lg(f)}{-20}}\right)$ [a]
E	$1 \le f \le 250$	$-20\log\left(10^{\frac{74{,}3-15\lg(f)}{-20}} + 2\times10^{\frac{94-20\lg(f)}{-20}}\right)$ [b]
F	$1 \le f \le 600$	$-20\lg\left(10^{\frac{102{,}4-15\lg(f)}{-20}} + 2\times10^{\frac{102{,}4-15\lg(f)}{-20}}\right)$ [b]

[a] *NEXT* at frequencies that correspond to calculated values of greater than 60,0 dB shall revert to a minimum requirement of 60,0 dB.

[b] *NEXT* at frequencies that correspond to calculated values of greater than 65,0 dB shall revert to a minimum requirement of 65,0 dB.

Table 7 – Informative NEXT values for channel at key frequencies

Frequency MHz	Minimum channel NEXT dB					
	Class A	Class B	Class C	Class D	Class E	Class F
0,1	27,0	40,0	N/A	N/A	N/A	N/A
1	N/A	25,0	39,1	60,0	65,0	65,0
16	N/A	N/A	19,4	43,6	53,2	65,0
100	N/A	N/A	N/A	30,1	39,9	62,9
250	N/A	N/A	N/A	N/A	33,1	56,9
600	N/A	N/A	N/A	N/A	N/A	51,2

6.4.4.2 Power sum NEXT (PS NEXT)

The *PS NEXT* requirements are applicable only to Classes D, E and F.

The *PS NEXT* of each pair of a channel shall meet the requirements derived by the equation in Table 8.

The PS NEXT requirements shall be met at both ends of the cabling. *PS NEXT* values at frequencies where the insertion loss (*IL*) is below 4,0 dB are for information only.

$PS\ NEXT_k$ of pair k is computed as follows:

$$PS\ NEXT_k = -10\lg \sum_{i=1, i \neq k}^{n} 10^{\frac{-NEXT_{ik}}{10}} \qquad (1)$$

where

i is the number of the disturbing pair;

k is the number of the disturbed pair;

n is the total number of pairs;

$NEXT_{ik}$ is the near end crosstalk loss coupled from pair i into pair k.

Table 8 – PS NEXT for channel

Class	**Frequency** MHz	**Minimum PS NEXT** dB
D	$1 \leq f \leq 100$	$-20\lg\left(10^{\frac{62{,}3-15\lg(f)}{-20}} + 2\times 10^{\frac{80-20\lg(f)}{-20}}\right)$ [a]
E	$1 \leq f \leq 250$	$-20\lg\left(10^{\frac{72{,}3-15\lg(f)}{-20}} + 2\times 10^{\frac{90-20\lg(f)}{-20}}\right)$ [b]
F	$1 \leq f \leq 600$	$-20\lg\left(10^{\frac{99{,}4-15\lg(f)}{-20}} + 2\times 10^{\frac{99{,}4-15\lg(f)}{-20}}\right)$ [b]

[a] *PS NEXT* at frequencies that correspond to calculated values of greater than 57,0 dB shall revert to a minimum requirement of 57,0 dB.

[b] *PS NEXT* at frequencies that correspond to calculated values of greater than 62,0 dB shall revert to a minimum requirement of 62,0 dB.

Table 9 – Informative PS NEXT values for channel at key frequencies

Frequency MHz	**Minimum PS NEXT** dB		
	Class D	**Class E**	**Class F**
1	57,0	62,0	62,0
16	40,6	50,6	62,0
100	27,1	37,1	59,9
250	N/A	30,2	53,9
600	N/A	N/A	48,2

6.4.5 Attenuation to crosstalk ratio (ACR)

The *ACR* requirements are applicable only to Classes D, E and F.

6.4.5.1 Pair-to-pair ACR

Pair-to-pair *ACR* is the difference between the pair-to-pair *NEXT* and the insertion loss (*IL*) of the cabling in dB.

The *ACR* of each pair combination of a channel shall meet the difference of the *NEXT* requirement of Table 6 and the insertion loss (*IL*) requirement of Table 4 of the respective class.

The *ACR* requirements shall be met at both ends of the cabling.

ACR_{ik} of pairs *i* and *k* is computed as follows:

$$ACR_{ik} = NEXT_{ik} - IL_k \tag{2}$$

where

i is the number of the disturbing pair;

k is the number of the disturbed pair;

$NEXT_{ik}$ is the near end crosstalk loss coupled from pair *i* into pair *k*;

IL_k is the insertion loss of pair *k*. When required, it shall be measured according to IEC 61935-1.

Table 10 – Informative ACR values for channel at key frequencies

Frequency MHz	**Minimum ACR** dB		
	Class D	**Class E**	**Class F**
1	56,0	61,0	61,0
16	34,5	44,9	56,9
100	6,1	18,2	42,1
250	N/A	–2,8	23,1
600	N/A	N/A	–3,4

6.4.5.2 Power sum ACR (PS ACR)

The *PS ACR* of each pair of a channel shall meet the difference of the *PS NEXT* requirement of Table 8 and the insertion loss (*IL*) requirement of Table 4 of the respective class.

The *PS ACR* requirements shall be met at both ends of the cabling.

PS ACR_k of pair *k* is computed as follows:

$$PS\,ACR_k = PS\,NEXT_k - IL_k \quad (3)$$

where

k is the number of the disturbed pair;

PS $NEXT_k$ is the power sum near end crosstalk loss of pair *k*;

IL_k is the insertion loss of pair *k*. When required, it shall be measured according to IEC 61935-1.

Table 11 – Informative PS ACR values for channel at key frequencies

Frequency MHz	**Minimum PS ACR** dB		
	Class D	**Class E**	**Class F**
1	53,0	58,0	58,0
16	31,5	42,3	53,9
100	3,1	15,4	39,1
250	N/A	–5,8	20,1
600	N/A	N/A	–6,4

6.4.6 ELFEXT

The *ELFEXT* requirements are applicable only to Classes D, E and F.

6.4.6.1 Pair-to-pair ELFEXT

The *ELFEXT* of each pair combination of a channel shall meet the requirements derived by the equation in Table 12.

$ELFEXT_{ik}$ of pairs *i* and *k* is computed as follows:

$$ELFEXT_{ik} = FEXT_{ik} - IL_k \quad (4)$$

where

i is the number of the disturbed pair;

k is the number of the disturbing pair;

$FEXT_{ik}$ is the far end crosstalk loss coupled from pair *i* into pair *k*. When required, it shall be measured according to IEC 61935-1.

IL_k is the insertion loss of pair *k*. When required, it shall be measured according to IEC 61935-1.

NOTE The ratio of the insertion loss (*IL*) of the disturbed pair to the input-to-output *FEXT* is relevant for the signal-to-noise-ratio consideration. The results computed in accordance with the formal definition above cover all possible combinations of insertion loss of wire pairs and corresponding input-to-output *FEXT*.

Table 12 – ELFEXT for channel

Class	**Frequency** MHz	**Minimum ELFEXT** [a] dB
D	$1 \le f \le 100$	$-20\lg\left(10^{\frac{63{,}8-20\lg(f)}{-20}}+4\times10^{\frac{75{,}1-20\lg(f)}{-20}}\right)$ [b]
E	$1 \le f \le 250$	$-20\lg\left(10^{\frac{67{,}8-20\lg(f)}{-20}}+4\times10^{\frac{83{,}1-20\lg(f)}{-20}}\right)$ [c]
F	$1 \le f \le 600$	$-20\lg\left(10^{\frac{94-20\lg(f)}{-20}}+4\times10^{\frac{90-15\lg(f)}{-20}}\right)$ [c]

[a] *ELFEXT* at frequencies that correspond to measured *FEXT* values of greater than 70,0 dB are for information only.

[b] *ELFEXT* at frequencies that correspond to calculated values of greater than 60,0 dB shall revert to a minimum requirement of 60,0 dB.

[c] *ELFEXT* at frequencies that correspond to calculated values of greater than 65,0 dB shall revert to a minimum requirement of 65,0 dB.

Table 13 – Informative ELFEXT values for channel at key frequencies

Frequency MHz	**Minimum ELFEXT** dB		
	Class D	**Class E**	**Class F**
1	57,4	63,3	65,0
16	33,3	39,2	57,5
100	17,4	23,3	44,4
250	N/A	15,3	37,8
600	N/A	N/A	31,3

6.4.6.2 Power sum ELFEXT (PS ELFEXT)

The *PS ELFEXT* of each pair of a channel shall meet the requirements derived by the equation in Table 14.

$PS\ ELFEXT_k$ of pair *k* is computed as follows:

$$PS\ ELFEXT_k = -10\lg \sum_{i=1, i \neq k}^{n} 10^{\frac{-ELFEXT_{ik}}{10}} \qquad (5)$$

where

i is the number of the disturbing pair;

k is the number of the disturbed pair;

N is the total number of pairs;

$ELFEXT_{ik}$ is the equal level far end crosstalk loss coupled from pair *i* into pair *k*.

Table 14 – PS ELFEXT for channel

Class	Frequency MHz	Minimum PS ELFEXT [a] dB
D	$1 \le f \le 100$	$-20\lg\left(10^{\frac{60,8-20\lg(f)}{-20}} + 4\times10^{\frac{72,1-20\lg(f)}{-20}}\right)$ [b]
E	$1 \le f \le 250$	$-20\lg\left(10^{\frac{64,8-20\lg(f)}{-20}} + 4\times10^{\frac{80,1-20\lg(f)}{-20}}\right)$ [c]
F	$1 \le f \le 600$	$-20\lg\left(10^{\frac{91-20\lg(f)}{-20}} + 4\times10^{\frac{87-15\lg(f)}{-20}}\right)$ [c]

[a] *PS ELFEXT* at frequencies that correspond to measured *FEXT* values of greater than 70,0 dB are for information only.

[b] *PS ELFEXT* at frequencies that correspond to calculated values of greater than 57,0 dB shall revert to a minimum requirement of 57,0 dB.

[c] *PS ELFEXT* at frequencies that correspond to calculated values of greater than 62,0 dB shall revert to a minimum requirement of 62,0 dB.

Table 15 – Informative PS ELFEXT values for channel at key frequencies

Frequency MHz	Minimum PS ELFEXT dB		
	Class D	Class E	Class F
1	54,4	60,3	62,0
16	30,3	36,2	54,5
100	14,4	20,3	41,4
250	N/A	12,3	34,8
600	N/A	N/A	28,3

6.4.7 Direct current (d.c.) loop resistance

The d.c. loop resistance of each pair of a channel shall meet the requirements in Table 16.

When required, the d.c. loop resistance shall be measured according to IEC 61935-1.

Table 16 – Direct current (d.c.) loop resistance for channel

Maximum d.c. loop resistance Ω					
Class A	Class B	Class C	Class D	Class E	Class F
560	170	40	25	25	25

6.4.8 Direct current (d.c.) resistance unbalance

The d.c. resistance unbalance between the two conductors within each pair of a channel shall not exceed 3 % for all classes. This shall be achieved by design.

6.4.9 Current carrying capacity

The minimum current carrying capacity for channels of Classes D, E and F shall be 0,175 A d.c. per conductor for all temperatures at which the cabling will be used. This shall be achieved by an appropriate design.

6.4.10 Operating voltage

The channels of classes D, E and F shall support an operating voltage of 72 V d.c. between any conductors for all temperatures at which the cabling is intended to be used.

6.4.11 Power capacity

The channels of classes D, E and F shall support the delivery of a power of 10 W per pair for all temperatures at which the cabling is intended to be used.

6.4.12 Propagation delay

The propagation delay of each pair of a channel shall meet the requirements derived by the equation in Table 17.

When required, the propagation delay shall be measured according to IEC 61935-1.

Table 17 – Propagation delay for channel

Class	**Frequency** MHz	**Maximum propagation delay** µs
A	$f = 0,1$	20,000
B	$0,1 \leq f \leq 1$	5,000
C	$1 \leq f \leq 16$	$0,534 + 0,036/\sqrt{f} + 4 \times 0,002\,5$
D	$1 \leq f \leq 100$	$0,534 + 0,036/\sqrt{f} + 4 \times 0,002\,5$
E	$1 \leq f \leq 250$	$0,534 + 0,036/\sqrt{f} + 4 \times 0,002\,5$
F	$1 \leq f \leq 600$	$0,534 + 0,036/\sqrt{f} + 4 \times 0,002\,5$

Table 18 – Informative propagation delay values for channel at key frequencies

Frequency MHz	Maximum propagation delay µs					
	Class A	**Class B**	**Class C**	**Class D**	**Class E**	**Class F**
0,1	20,000	5,000	N/A	N/A	N/A	N/A
1	N/A	5,000	0,580	0,580	0,580	0,580
16	N/A	N/A	0,553	0,553	0,553	0,553
100	N/A	N/A	N/A	0,548	0,548	0,548
250	N/A	N/A	N/A	N/A	0,546	0,546
600	N/A	N/A	N/A	N/A	N/A	0,545

6.4.13 Delay skew

The delay skew between all pairs of a channel shall meet the requirements in Table 19.

When required, the delay skew shall be measured according to IEC 61935-1.

Table 19 – Delay skew for channel

Class	**Frequency** MHz	**Maximum delay skew** µs
A	$f = 0{,}1$	N/A
B	$0{,}1 \leq f \leq 1$	N/A
C	$1 \leq f \leq 16$	0,050 [a]
D	$1 \leq f \leq 100$	0,050 [a]
E	$1 \leq f \leq 250$	0,050 [a]
F	$1 \leq f \leq 600$	0,030 [b]

[a] This is the result of the calculation 0,045 + 4 × 0,001 25.

[b] This is the result of the calculation 0,025 + 4 × 0,001 25.

6.4.14 Unbalance attenuation

The unbalance attenuation near end (longitudinal to differential conversion loss (*LCL*) or transverse conversion loss (*TCL*)) of a channel shall meet the requirements derived by the equation in Table 20.

The unbalance attenuation requirements shall be met at both ends of the cabling.

The unbalance attenuation performance shall be achieved by the appropriate choice of cables and connecting hardware.

Table 20 – Unbalance attenuation for channel

Class	Frequency MHz	Maximum unbalance attenuation dB
A	$f = 0{,}1$	30
B	$f = 0{,}1$ and 1	45 at 0,1 MHz; 20 at 1 MHz
C	$1 \le f \le 16$	$30 - 5\lg(f)$ f.f.s.
D	$1 \le f \le 100$	$40 - 10\lg(f)$ f.f.s.
E	$1 \le f \le 250$	$40 - 10\lg(f)$ f.f.s.
F	$1 \le f \le 600$	$40 - 10\lg(f)$ f.f.s.

6.4.15 Coupling attenuation

The measurement of coupling attenuation for installed cabling is under development. Coupling attenuation of a sample installation may be assessed by laboratory measurements of representative samples of channels assembled, using the components and connector termination practices in question.

7 Reference implementations for balanced cabling

7.1 General

This clause describes implementations of generic balanced cabling that utilise components and assemblies referenced in Clauses 9, 10 and 13. These reference implementations meet the requirements of Clause 5 and, when installed in accordance with ISO/IEC TR 14763-2, comply with the channel performance requirements of Clause 6.

7.2 Balanced cabling

7.2.1 General

Balanced components referenced in Clauses 9 and 10 are defined in terms of impedance and category. In the reference implementations of this clause, the components used in each cabling channel shall have the same nominal impedance, i.e. 100 Ω for Classes D to F and 100 Ω or 120 Ω for Class A to Class C.

The implementations are based on component performance at 20 °C. The effect of temperature on the performance of cables shall be accommodated by derating length as shown in Table 21 and Table 22.

Cables and connecting hardware of different categories may be mixed within a channel. However, the resultant cabling performance will be determined by the category of the lowest performing component.

7.2.2 Horizontal cabling

7.2.2.1 Component choice

The selection of balanced cabling components will be determined by the class of applications to be supported. Refer to Annex F for guidance.