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	$1 \le f \le 100$	$-20\lg\left(10^{\frac{65,3-15\lg(f)}{-20}} + 2\times 10^{\frac{83-20\lg(f)}{-20}}\right)$ [a]
E	$1 \le f \le 250$	$-20\log\left(10^{\frac{74,3-15\lg(f)}{-20}} + 2\times 10^{\frac{94-20\lg(f)}{-20}}\right)$ [b]
F	$1 \le f \le 600$	$-20\lg\left(10^{\frac{102,4-15\lg(f)}{-20}} + 2\times 10^{\frac{102,4-15\lg(f)}{-20}}\right)$ [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	$1 \le f \le 100$	$-20\lg\left(10^{\frac{62,3-15\lg(f)}{-20}} + 2\times 10^{\frac{80-20\lg(f)}{-20}}\right)$ [a]
E	$1 \le f \le 250$	$-20\lg\left(10^{\frac{72,3-15\lg(f)}{-20}} + 2\times 10^{\frac{90-20\lg(f)}{-20}}\right)$ [b]
F	$1 \le f \le 600$	$-20\lg\left(10^{\frac{99,4-15\lg(f)}{-20}} + 2\times 10^{\frac{99,4-15\lg(f)}{-20}}\right)$ [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:

$$ACR_{ik} = NEXT_{ik} - IL_k \quad (2)$$

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:

$$PS\,ACR_k = PS\,NEXT_k - IL_k \tag{3}$$

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:

$$ELFEXT_{ik} = FEXT_{ik} - IL_k \tag{4}$$

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	$1 \le f \le 100$	$-20\lg\left(10^{\frac{60,8-20\lg(f)}{-20}} + 4\times 10^{\frac{72,1-20\lg(f)}{-20}}\right)$ [b]
E	$1 \le f \le 250$	$-20\lg\left(10^{\frac{64,8-20\lg(f)}{-20}} + 4\times 10^{\frac{80,1-20\lg(f)}{-20}}\right)$ [c]
F	$1 \le f \le 600$	$-20\lg\left(10^{\frac{91-20\lg(f)}{-20}} + 4\times 10^{\frac{87-15\lg(f)}{-20}}\right)$ [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	$0{,}1 \le f \le 1$	5,000
C	$1 \le f \le 16$	$0{,}534 + 0{,}036/\sqrt{f} + 4 \times 0{,}002\,5$
D	$1 \le f \le 100$	$0{,}534 + 0{,}036/\sqrt{f} + 4 \times 0{,}002\,5$
E	$1 \le f \le 250$	$0{,}534 + 0{,}036/\sqrt{f} + 4 \times 0{,}002\,5$
F	$1 \le f \le 600$	$0{,}534 + 0{,}036/\sqrt{f} + 4 \times 0{,}002\,5$

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.