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Information technology – Assessment and mitigation of installed balanced cabling channels in order to support 10GBASE-T

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INFORMATION TECHNOLOGY – ASSESSMENT AND MITIGATION OF INSTALLED BALANCED CABLING CHANNELS IN ORDER TO SUPPORT 10GBASE-T

FOREWORD

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

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The main task of IEC and ISO technical committees is to prepare International Standards. In exceptional circumstances, ISO/IEC JTC 1 or a subcommittee may propose the publication of a technical report of one of the following types:

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where, for any other reason, there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when the technical committee has collected data of a different kind from that which is normally published as an International Standard, for example 'state of the art'.

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/IEC 24750, which is a technical report of type 2, was prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology.

This document is issued in the type 2 technical report series of publications (according to 16.2.2 of the Procedures for the technical work of ISO/IEC JTC 1 (5th edition, 2004)) as a prospective standard for provisional application in the field of balanced cabling channels, because there is an urgent requirement for guidance on how standards in this field should be used.

This document is not to be regarded as an International Standard. It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to IEC Central Office.

A review of this type 2 technical report will be carried out not later than three years after its publication with the option of extension for a further three years, conversion into an International Standard or withdrawal.

ISO/IEC TR 24750 should be read in conjuction with IEEE802.3AN.

This Technical Report has been approved by vote of the member bodies, and the voting results may be obtained from the address given on the second title page.

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

INTRODUCTION

This Technical Report provides guidance whether an installed Class E channel will support 10GBASE-T. The Technical Report also provides mitigation procedures to improve the performance of Class E channels to the point where the application is supported. Class F according to ISO/IEC 11801:2002 will support 10GBASE-T without mitigation up to 100 m.

The support of 10GBASE-T includes additional parameters and an extended frequency range beyond Class E. Conformance of installed cabling beyond the original cabling specifications should be determined on a case-by-case basis, and is primarily needed due to new external noise requirements. Whether these requirements are met by a specific channel is influenced by the components and installation practices used. As 10GBASE-T uses frequencies above those specified for Class E of ISO/IEC 11801, input from supplier and installer may be helpful to evaluate the performance of installed Class E channels.

This Technical Report takes into account the design goals for 10GBASE-T equipment such as:

1) frequency signal range up to 500 MHz;
2) meet EMC limits specified for CISPR/FCC Class A;

NOTE While ISO/IEC 8802-3 (see bibliography) will specify an application to meet Class A on unshielded cabling, meeting Class B may require application specific equipment and/or cabling that exceeds the requirements of ISO/IEC 8802-3 and this TR respectively.

3) support a bit error rate of 10^{-12};
4) support operation over 4-connector, four-pair balanced cabling.

It is expected that 10GBASE-T will be supported by the following cabling channels specified in ISO/IEC 11801:2002.

- Class F channels will support 10GBASE-T to distances of at least 100 m.
- Class E channels using screened Category 6 components and assessed and mitigated according to the guidelines in this Technical Report will support 10GBASE-T to distances up to 100 m.
- Class E channels assessed and mitigated according to the guidelines in this Technical Report are expected to support 10GBASE-T to distances from 55 m to 100 m using unscreened Category 6 components.

In order to provide normative cabling specifications in explicit support of 10GBASE-T, work on an amendment to ISO/IEC 11801:2002 has been started. This amendment will provide new channel specifications that will include all characteristics needed to meet and/or exceed the 10GBASE-T requirements.

NOTE (Class E_A and Class F_A). Completion is expected in 2007.

INFORMATION TECHNOLOGY – ASSESSMENT AND MITIGATION OF INSTALLED BALANCED CABLING CHANNELS IN ORDER TO SUPPORT 10GBASE-T

1 Scope

This Technical Report

- specifies the transmission performance for channels to support 10GBASE-T,
- specifies the methods to assess whether installed Class E and Class F channels meet 10GBASE-T requirements,
- provides mitigation techniques to improve the performance of an existing installation to meet the 10GBASE-T requirements.

NOTE 1 The channel transmission performance specified in this TR is derived from IEEE 802.3AN.

NOTE 2 IEEE 802.3AN specifies requirements beyond the frequency range specified for Class E of ISO/IEC 11801:2002 and additional parameters to those specified for Class E and Class F cabling in ISO/IEC 11801:2002.

NOTE 3 This Technical Report does not re-specify Class E and Class F cabling of ISO/IEC 11801:2002.

2 Normative references

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

IEC 61935-1, *Testing of balanced communication cabling in accordance with ISO/IEC 11801 – Part 1: Installed cabling*[1]

ISO/IEC 11801:2002, *Information technology – Generic cabling systems*

IEEE802.3AN-2006, *IEEE Standard for information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications*

Amendment 1, *Physical Layer and Management Parameters for 10 Gb/s Operation, Type 10GBASE-T (IEEE802.3 10GBASE_Tan)*

NOTE 10GBASE-T refers to IEEE802.3AN, including its amendment.

3 Terms, definitions and abbreviations

For the purposes of this Technical Report the following definitions apply in addition to those of ISO/IEC 11801:2002.

3.1 Terms and definitions

3.1.1
alien (exogenous) crosstalk
signal coupling from a disturbing pair of a channel to a disturbed pair of another channel

3.1.2
alien (exogenous) far-end crosstalk loss (AFEXT)
signal isolation between a disturbing pair of a channel and a disturbed pair of another channel, measured at the far-end

[1] Third edition under consideration.

3.1.3
alien (exogenous) near-end crosstalk loss (ANEXT)
signal isolation between a disturbing pair of a channel and a disturbed pair of another channel, measured at the near-end

3.1.4
attenuation to alien (exogenous) crosstalk ratio at the far-end (AACR-F)
difference, in dB, between the alien far-end crosstalk loss from a disturbing pair of a channel and the insertion loss of a disturbed pair in another channel

3.1.5
attenuation to alien (exogenous) crosstalk ratio at the near-end (AACR-N)
difference, in dB, between the alien near-end crosstalk loss from a disturbing pair of a channel and the insertion loss of a disturbed pair in another channel

3.1.6
attenuation to crosstalk ratio at the far-end (ACR-F)
difference, in dB, between the far-end crosstalk loss from a disturbing pair of a channel and the insertion loss of a disturbed pair of the same channel

3.1.7
attenuation to crosstalk ratio at the near-end (ACR-N)
difference, in dB, between the near-end crosstalk loss from a disturbing pair of a channel and the insertion loss of a disturbed pair of the same channel

3.1.8
average alien (exogenous) near-end crosstalk loss
calculated average of the alien near-end crosstalk loss of the pairs of a disturbed channel

3.1.9
average power sum alien (exogenous) near-end crosstalk loss
calculated average of the power sum alien near-end crosstalk loss of the pairs of a disturbed channel

3.1.10
average power sum attenuation to alien (exogenous) crosstalk ratio far-end
calculated average of the power sum attenuation to alien crosstalk ratio at the far-end of the pairs of a disturbed channel

3.1.11
equal level far-end crosstalk ratio (ELFEXT)
difference, in dB, between the far-end crosstalk loss from a disturbing pair of a channel and the insertion loss of a disturbing pair of the same channel

3.1.12
power sum alien (exogenous) far-end crosstalk loss (PS AFEXT)
power sum of the signal isolation between multiple disturbing pairs of one or more channels and a disturbed pair of another channel, measured at the far-end

3.1.13
power sum alien (exogenous) near-end crosstalk loss (PS ANEXT)
power sum of the signal isolation between multiple disturbing pairs of one or more channels and a disturbed pair of another channel, measured at the near-end

3.1.14
power sum attenuation to alien (exogenous) crosstalk ratio at the far-end (PS AACR-F)
difference, in dB, between the power sum alien far-end crosstalk loss from multiple disturbing pairs of one or more channels and the insertion loss of a disturbed pair in another channel

3.1.15
power sum attenuation to alien (exogenous) crosstalk ratio at the near-end (PS AACR-N)
difference, in dB, between the power sum alien near-end crosstalk loss from multiple disturbing pairs of one or more channels and the insertion loss of a disturbed pair in another channel

3.1.16
power sum attenuation to crosstalk ratio at the far-end (PS ACR-F)
difference, in dB, between the power sum far-end crosstalk loss from multiple disturbing pairs of a channel and the insertion loss of a disturbed pair in the same channel

3.1.17
power sum attenuation to crosstalk ratio at the near-end (PS ACR-N)
difference, in dB, between the power sum near-end crosstalk loss from multiple disturbing pairs of a channel and the insertion loss of a disturbed pair in the same channel

3.1.18
power sum equal level far-end crosstalk ratio (PS ELFEXT)
power sum of all disturbing pairs of a channel, of the difference, in dB, between the far-end crosstalk loss and the insertion loss of each disturbing pair

3.2 Abbreviations

For the purposes of this technical report the following abbreviations apply in addition to those of ISO/IEC 11801:2002.

AACR-F	attenuation to alien crosstalk ratio at the far-end
AACR-N	attenuation to alien crosstalk ratio at the near-end
ACR-F	attenuation to crosstalk ratio at the far-end
ACR-N	attenuation to crosstalk ratio at the near-end
AFEXT	alien far-end crosstalk loss
ANEXT	alien near-end crosstalk loss
ELFEXT	equal level far-end crosstalk ratio
PS AACR-F	power sum attenuation to alien crosstalk ratio at the far-end
PS AACR-N	power sum attenuation to alien crosstalk ratio at the near-end
PS ACR-F	power sum attenuation to crosstalk ratio at the far-end
PS ACR-N	power sum attenuation to crosstalk ratio at the near-end
PS AFEXT	power sum alien far-end crosstalk loss
PS ANEXT	power sum alien near-end crosstalk loss
PS ELFEXT	power sum equal level far-end crosstalk ratio

NOTE 1 See Table 1 for equivalence between abbreviations used in this Technical Report and their equivalents in ISO/IEC 11801:2002.

NOTE 2 The list of abbreviations does not include Annex B.

4 New parameters needed for generic cabling for the support of 10GBASE-T

ISO/IEC 11801, amendment 1, defines *ACR* as "the difference, in dB, between the cross talk loss from a disturbing pair of a channel and the insertion loss of a disturbed pair of the same channel" and *ELFEXT* as "the difference, in dB, between the far end crosstalk loss from a disturbing pair of a channel and the insertion loss of a disturbing pair of the same channel". These definitions in ISO/IEC 11801 are correct for cabling.

10GBASE-T gives a slightly different definition: The S/N ratio of the noise in the disturbed pair to the signal in the disturbed pair. This is, of course, the definition of importance for electrical systems.

For equally long channels the values of both definitions are nearly the same, but if the channels have different lengths the values based on IEEE 802.3 10GBASE-T and ISO/IEC 11801 are different.

In this Technical Report the terms and definitions of some noise related items are different from those in ISO/IEC 11801, in order to align with 10GBASE-T. The limits remain the same so backward compatibility with ISO/IEC 11801 is assured (Table 1 gives a summary).

Crosstalk and power sum crosstalk are well defined in ISO/IEC 11801:2002. As cables are laid in trays, ducts and/or are bundled together, the noise from one cable can couple into other cables. This can happen between telecommunications cables of the same category, but also between cables with different categories or even between signal or power line cables and telecommunications cables.

This type of noise is well known in telephony and existing versions of Ethernet over balanced cabling. It has not been a major issue for the systems in use up to now. However, the increased frequency range and sensitivity of the 10GBASE-T transmission cannot neglect this external noise any more.

Only the power sum of the noise is of importance and therefore *PS ANEXT* and *PS AACR-F* are specified. Since it is irrelevant which external pairs or cables the noise is coming from *ANEXT* and *AACR-F* are not specified. The noise from external sources cannot be compensated for within the specific application addressed here. The power sum computation assumes that the noise is generated by other channels using the same protocol. Disturbances that are created by other protocols (like TV distribution) using the other channels are handled as background noise. To determine alien crosstalk noise, the transmitter shall therefore be known.

In a channel as specified in ISO/IEC 11801, and measured in accordance with IEC 61935-1, the near-end (where the measurement transmitter is) and the far-end (where the measurement receiver is) are known and the terms *NEXT* and *FEXT* are easy to define.

For alien crosstalk the term *ANEXT* or *AFEXT* can be ambiguous. Therefore, new definitions for power sum alien crosstalk noise (near-end and far-end) are introduced (see definitions). It appears that the worst case situation is when a short channel runs in parallel at either end of a long channel. The short channel with high signals will disturb the long channel receiver where receiving signals have been attenuated due to the insertion loss of the long channel. For this case 10GBASE-T introduces power backoff strategies. The idea is that a system detects the length of the channel by receiving signal amplitude and reduces the transmitter voltage to decrease alien noise.

10GBASE-T defines two limits for each of *ANEXT* and *AFEXT* that have to be met concurrently (for values see 5.7.1).

- The first limit applies to every pair individually within the disturbed channel.
- The second limit applies to the average of all four pairs within the disturbed channel.

— *PS ANEXT* average limit is 2,25 dB more stringent than the *PS ANEXT* limit for each pair within the disturbed channel

— *PS ACR-F* average is 4 dB more stringent than the *PS ACR-F* limit for each pair within the disturbed channel.

If these two limits are not met concurrently tradeoffs can be calculated as explained in 5.7.4 and Annex B.

Table 1 – Changes and additions to definitions in ISO/IEC 11801:2002

Abbreviation used in ISO/IEC 11801:2002	Abbreviation used in this Technical Report	Definition	Requirement
ACR	ACR-N	Revised	No change
PS ACR	PS ACR-N	Revised	No change
ELFEXT	ACR-F	Revised	No change
PS ELFEXT	PS ACR-F	Revised	No change
-	PS ANEXT	New	New
-	PS AACR-F	New	New

5 Channel requirements

5.1 General

This clause discusses the 10GBASE-T requirements in relation to the minimum performance channels Class E and Class F as specified in ISO/IEC 11801:2002.

All requirements of this clause are met by Class F.

To support 10GBASE-T applications the channel performance limits of Class E of ISO/IEC 11801:2002 have been extended here to higher frequencies and two new characteristics have been added:

- *PS ANEXT* (5.7.2)
- *PS AACR-F* (5.7.3).

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

NOTE The term "attenuation" is used for definitions as it is common usage within the cabling industry. However, the correct term is insertion loss which includes the effect of impedance variations both with and between the cabling components in the channel.

For a balanced cabling installation to conform to this technical report:

- the channel performance shall meet the requirements of this clause;
- the interfaces to the cabling shall conform to the requirements of Clause 9 of ISO/IEC 11801:2002 with respect to mating interfaces;
- local regulations concerning safety and EMC shall be met as applicable to the location of the installation.

Measuring the link performance of an installed permanent link can be used to assess whether the permanently installed cabling has the potential to be used as part of a balanced cabling channel to support 10GBASE-T. This assessment does not assure conformance to this technical report, and shall not be used instead of the channel qualification procedure described in this clause. Annex A contains balanced cabling permanent link performance guidelines.

5.2 Return loss

The variation of the input impedance of a channel is characterised by the return loss. To support 10GBASE-T the return loss for each pair of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 2. The limits shown in Table 3 are derived from the equations at key frequencies.

When required, the return loss shall be measured according to IEC 61935-1. Terminations of 100 Ω shall be connected to the cabling elements under test at the far-end of the channel. The return loss requirements shall be met at both ends of the cabling.

Table 2 – Equations for return loss limits for a channel

Frequency MHz	**Minimum return loss** dB
$1 \leq f < 10$	19,0
$10 \leq f < 40$	$24 - 5\lg(f)$
$40 \leq f < 400$	$32 - 10\lg(f)$
$400 \leq f \leq 500$	6,0

Table 3 – Informative return loss limits for a channel at key frequencies

Frequency MHz	**Minimum return loss** dB
1,0	19,0
16,0	18,0
100,0	12,0
250,0	8,0
500,0	6,0

Values of return loss at frequencies for which the measured channel insertion loss is below 3,0 dB are for information only.

5.3 Insertion loss

To support 10GBASE-T, the insertion loss of each pair of a channel shall not exceed the limits computed, to one decimal place, using the equation of Table 4. The limits shown in Table 5 are derived from the equation at key frequencies.

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

Table 4 – Equation for insertion loss limits for a channel

Frequency MHz	**Maximum insertion loss** dB
$1 \leq f \leq 500$	$1{,}05\left(1{,}82\sqrt{f} + 0{,}0169 f + 0{,}25/\sqrt{f}\right) + 4 \times 0{,}02\sqrt{f}$
NOTE Values below 4 dB revert to 4 dB.	

Table 5 – Informative insertion loss limits for a channel at key frequencies

Frequency MHz	**Maximum insertion loss** dB
1,0	4,0
16,0	8,3
100,0	21,7
250,0	35,9
500,0	53,4

Also see 5.7 for insertion loss to alien crosstalk ratios.

5.4 Near-end crosstalk loss (NEXT)

5.4.1 Pair-to-pair NEXT

To support 10GBASE-T the pair-to-pair *NEXT* between each pair combination of a channel shall meet the limits computed, to one decimal place, using the equations of Table 6. The limits shown in Table 7 are derived from the equations at key frequencies.

When required, *NEXT* shall be measured according to IEC 61935-1. *NEXT* requirements shall be met at both ends of the cabling.

Table 6 – Equations for NEXT limits for a channel

Frequency MHz	**Minimum NEXT** dB
$1 \le f < 330$	$-20\lg\left(10^{\frac{74{,}3-15\lg(f)}{-20}}+2\times10^{\frac{94-20\lg(f)}{-20}}\right)$
$330 \le f \le 500$	$31-50\lg(f/330)$
NOTE Values larger than 65 dB revert to 65 dB.	

Table 7 – Informative NEXT limits for a channel at key frequencies

Frequency MHz	**Minimum NEXT** dB
1,0	65,0
16,0	53,2
100,0	39,9
250,0	33,1
500,0	22,0

Values of *NEXT* at frequencies for which the measured channel insertion loss is below 4,0 dB are for information only.

5.4.2 Power sum NEXT (PS NEXT)

To support 10GBASE-T the *PS NEXT* for each pair of a channel shall meet the limits computed, to one decimal place, using the equations of Table 8. The limits shown in Table 9 are derived from the equations at key frequencies.

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

PS NEXT$_k$ of pair *k* is computed as follows:

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

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 – Equations for PS NEXT limits for a channel

Frequency MHz	**Minimum PS NEXT** dB
$1 \le f < 330$	$-20\lg\left(10^{\frac{72{,}3-15\lg(f)}{-20}} + 2\times 10^{\frac{90-20\lg(f)}{-20}}\right)$
$330 \le 500$	28-42lg(f/330)
NOTE Values larger than 62 dB revert to 62 dB.	

Table 9 – Informative PS NEXT limits for a channel at key frequencies

Frequency MHz	**Minimum return loss** dB
1,0	62,0
16,0	50,6
100,0	37,1
250,0	30,2
500,0	20,4

Values of *PS NEXT* at frequencies for which the measured channel insertion loss is below 4,0 dB are for information only.

5.5 Attenuation to crosstalk loss ratio near-end (ACR-N)

5.5.1 Pair-to-pair ACR-N

The *ACR-N* for each pair combination of a channel shall meet the limits computed according to equation (2), to one decimal place. The limits shown in Table 10 are derived from the equation (2) at key frequencies. The requirement is automatically satisfied when both insertion loss and *NEXT* requirements are met.

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

ACR-N$_{ik}$ of pairs *i* and *k* is computed as follows:

$$ACR\text{-}N_{ik} = NEXT_{ik} - IL_k \ \text{dB} \tag{2}$$

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 disturbed pair k. When required, it shall be measured according to IEC 61935-1.

Table 10 – Informative ACR-N limits for a channel at key frequencies

Frequency MHz	**Minimum ACR-N** dB
1,0	61
16,0	44,9
100,0	18,2
250,0	-2,8
500,0	-31,4

5.5.2 Power sum ACR-N (PS ACR-N)

The *PS ACR* for each pair of a channel shall meet the limits computed according to equation (3), to one decimal place. The limits shown in Table 11 are derived with equation (3) at key frequencies. The requirement is automatically satisfied when both insertion loss and *PS NEXT* requirements are met.

$PS\ ACR\text{-}N_k$ of pair k is computed as follows:

$$PS\ ACR\text{-}N_k = PS\ NEXT_k - IL_k \text{ dB} \qquad (3)$$

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.

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

Table 11 – Informative PS ACR-N limits for a channel at key frequencies

Frequency MHz	**Minimum PS ACR-N** dB
1,0	58,0
16,0	42,3
100,0	15,4
250,0	-5,8
500,0	-33,0

5.6 Attenuation to crosstalk loss ratio far-end (ACR-F)

5.6.1 Pair-to-pair ACR-F

To support 10GBASE-T the *ACR-F* for each pair combination of a channel shall meet the limits computed, to one decimal place, using the equations of Table 12. The limits shown in Table 13 are derived from the equations at key frequencies.

$ACR\text{-}F_{ik}$ of pairs i and k is computed as follows:

$$ACR\text{-}F_{ik} = FEXT_{ik} - IL_k \ \text{dB} \tag{4}$$

where

i	is the number of the disturbing pair;
k	is the number of the disturbed pair;
$FEXT_{ik}$	is the far-end crosstalk loss coupled from disturbing pair i into disturbed 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.

Table 12 – Equation for ACR-F limits for a channel

Frequency MHz	**Minimum ACR-F** dB
$1 \le f \le 500$	$-20\lg\left(10^{\frac{67{,}8-20\lg(f)}{-20}} + 4 \times 10^{\frac{83{,}1-20\lg(f)}{-20}}\right)$

ACR-F values at frequencies that correspond to measured *FEXT* values of greater than 70,0 dB are for information only.

Table 13 – Informative ACR-F limits for a channel at key frequencies

Frequency MHz	**Minimum ACR-F** dB
1,0	63,3
16,0	39,2
100,0	23,3
250,0	15,3
500,0	9,3

5.6.2 Power sum ACR-F (PS ACR-F)

To support 10GBASE-T the *PS ACR-F* for each pair of a channel shall meet the limits computed, to one decimal place, using the equation of Table 14. The limits shown in Table 15 are derived from the equation at key frequencies.

PS ACR-F$_k$ of pair k is computed as follows:

$$PS\,ACR\text{-}F_k = -10\lg\left[\sum_{i=1,i\neq k}^{n} 10^{\frac{-FEXT_{ik}}{10}} - IL_k\right] \text{dB} \tag{5}$$

where

i	is the number of the disturbing pair;
k	is the number of the disturbed pair;
n	is the total number of pairs;
$FEXT_{ik}$	is the far-end crosstalk loss coupled from pair i into pair k.

Table 14 – Equation for PS ACR-F limits for a channel

Frequency MHz	**Minimum PS ACR-F** dB
$1 \le f \le 500$	$-20\lg\left(10^{\frac{64{,}8-20\lg(f)}{-20}}+4\times10^{\frac{80{,}1-20\lg(f)}{-20}}\right)$

PS ACR-F values at frequencies that correspond to measured *FEXT* values of greater than 70,0 dB are for information only.

Table 15 – Informative PS ACR-F limits for a channel at key frequencies

Frequency MHz	**Minimum PS ACR-F** dB
1,0	60,3
16,0	36,2
100,0	20,3
250,0	12,3
500,0	6,3

5.7 Alien crosstalk

5.7.1 General

Power sum alien NEXT (PS ANEXT) and Power-Sum attenuation to alien crosstalk ratio far-end (PS AACR-F), in accordance with 10GBASE-T, are specified in 5.7.2 and 5.7.3.

NOTE 1 Equations used in 5.7.2 and 5.7.3 for alien crosstalk limits are numerically different from those currently used in 10GBASE-T; however, they are technically equivalent, more concise and better suited for a cabling document.

NOTE 2 For alien field measurements, see IEC 61935-1 (third edition, currently under consideration).

Where the limits of either subclause 5.7.2 or subclause 5.7.3 are not met, compliance with 10GBASE-T requirements can be achieved by meeting alien crosstalk margins as stated in Annex B.

5.7.2 Power sum alien NEXT (PS ANEXT)

The following limits shall be met (see also clause 4).

- One limit, *PS ANEXT*, shall be met by each pair of the disturbed channel.
- A second limit, *PS ANEXT* average, which is 2,25 dB more stringent than the limit for each pair, shall be met by the average of all pairs of the disturbed channel. Average *PS ANEXT* is calculated by averaging the individual *PS ANEXT* calculations in decibels at each frequency point.

The allowable *PS ANEXT* is inter-related to the insertion loss of the channel and is based upon the calculated or measured insertion loss at 250 MHz as detailed below.

To support 10GBASE-T the *PS ANEXT* for each pair in a channel shall meet the limits computed, to one decimal place, using the equations of Table 16. The limits shown in Table 17 are derived from the equations at key frequencies.

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

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

$$PS\ ANEXT_k = -10\lg\left[\sum_{l=1}^{N}\sum_{i=1}^{n} 10^{\frac{-ANEXT_{l,i,k}}{10}}\right] \text{ dB} \quad (6)$$

where

k	is the number of the disturbed pair in the disturbed channel;
i	is the counter of the disturbing pairs in the disturbing channel l;
l	is the summing counter of the disturbing channels;
N	is the number of disturbing channels
n	is the number of disturbing pairs in each of the N channels;
$ANEXT_{l,i,k}$	is the alien near-end crosstalk loss coupled from pair i of disturbing channel l to the pair k of the disturbed channel.

NOTE Alien crosstalk is coupled from the pairs of surrounding cables into the pairs of the considered channel.

The average *PS ANEXT* of all pairs is computed by averaging the values of the four pairs of the disturbed channel expressed in dB as in equation (7).

$$PS\ ANEXT_{\text{avg}} = \frac{1}{4}\sum_{k=1}^{4} PS\ ANEXT_k \text{ dB} \quad (7)$$

Table 16 – Equations for PS ANEXT limits for a channel

Frequency MHz	**Minimum PS ANEXT** dB	
$1 \le f \le 100$	$27{,}48 + IL_{250}/1{,}04 - 10\lg(f/100)$	For each pair of the disturbed channel.
$100 < f \le 500$	$27{,}48 + IL_{250}/1{,}04 - 15\lg(f/100)$	
$1 \le f \le 100$	$29{,}73 + IL_{250}/1{,}04 - 10\lg(f/100)$	For the average of the 4 pairs within the disturbed channel.
$100 < f \le 500$	$29{,}73 + IL_{250}/1{,}04 - 15\lg(f/100)$	
where IL_{250} is the channel insertion loss at 250 MHz in dB rounded to one decimal place, IL_{250} values less then 6,3 dB revert to a value of 6,3 dB, calculated values greater than 67 dB revert to a minimum requirement of 67,0 dB.		

Table 17 – Informative PS ANEXT limits for a channel at key frequencies

	Minimum PS ANEXT dB					
Frequency MHz	1,0	16,0	100,0	250,0	500,0	
IL_{250}= 20,3 dB	67,0	55,0	**47,0**	41,0	36,5	For each pair of the disturbed channel.
IL_{250}= 33,8 dB	67,0	67,0	**60,0**	54,0	49,5	
IL_{250}= 35,9 dB	67,0	67,0	**62,0**	56,0	51,5	
IL_{250}= 20,3 dB	67,0	57,3	49,3	43,3	38,8	For the average of the 4 pairs within the disturbed channel.
IL_{250}= 33,8 dB	67,0	67,0	62,3	55,3	51,8	
IL_{250}= 35,9 dB	67,0	67,0	64,3	58,3	53,8	
NOTE The 10GBASE-T *PS ANEXT* constants are shown in bold.						

Values of *PS ANEXT* at frequencies for which the measured channel insertion loss is below 4,0 dB are for information only.

5.7.3 Power sum attenuation to alien crosstalk ratio far-end (PS AACR-F)

To support 10GBASE-T the following limits shall be met (see also clause 4).

- One limit, *PS AACR-F*, to be met by each pair of the disturbed channel.
- A second limit, *PS AACR-F* average, which is 4 dB more stringent than the limit for each pair, shall be met by the average of all pairs of the disturbed channel. Average *PS AACR-F* is calculated by averaging the individual PS calculations in decibels at each frequency point.

The *PS AACR-F* for each pair combination of a channel shall meet the limits computed, to one decimal place, using the equations of Table 18. The limits shown in Table 19 are derived from the equations at key frequencies.

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

If

$$IL_k > IL_{l,i}\ \text{dB} \tag{8a}$$

then

$$PS\ AFEXT_k = -10\lg\left[\sum_{l=1}^{N}\sum_{i=1}^{n}10^{\frac{-\left\{AFEXT_{l,i,k}+IL_k-IL_{l,i}+10\lg\left(\frac{IL_{l,i}}{IL_k}\right)\right\}}{10}}\right]\ \text{dB} \tag{8b}$$

else

$$PS\ AFEXT_k = -10\lg\left[\sum_{l=1}^{N}\sum_{i=1}^{n}10^{\frac{-AFEXT_{l,i,k}}{10}}\right]\ \text{dB} \tag{8c}$$

where

k is the number of the disturbed pair in the disturbed channel;

i is the counter of the disturbing pairs in the disturbing channel *l*;

l is the summing counter of the disturbing channels;

N is the number of disturbing channels;

n is the number of disturbing pairs in each of the N channels;

$AFEXT_{l,i,k}$ is the alien far-end crosstalk loss coupled from disturbing pair i of channel l to the disturbed pair k;

IL_k is the insertion loss of the disturbed pair k;

$IL_{l,i}$ is the insertion loss of disturbing pair i of disturbing channel l.

$PS\ AACR\text{-}F_k$ of pair k is computed as follows:

$$PS\ AACR-F_k = PS\ AFEXT_k - IL_{avg} \text{ dB} \quad (9)$$

where

i is the counter of the disturbing pair;

k is the counter of the disturbed pair;

IL_{avg} is the average insertion loss of all 4 pairs of the disturbed channel in dB. When required, it shall be measured according to IEC 61935-1 and calculated per equation (10) below.

$$IL_{avg} = \frac{1}{4}\sum_{k=1}^{4} IL_k \text{ dB} \quad (10)$$

The average $PS\ AFEXT$ of all pairs is computed by averaging the values of each pair expressed in dB as in equation (11).

$$PS\ AFEXT_{avg} = \frac{1}{4}\sum_{k=1}^{4} PS\ AFEXT_k \text{ dB} \quad (11)$$

This average of the $PS\ AACR - F_{avg}$ is computed per equation (12).

$$PS\ AACR-F_{avg} = PS\ AFEXT_{avg} - IL_{avg} \text{ dB} \quad (12)$$

Table 18 – Equations for PS AACR-F limits for a channel

Frequency MHz	**Minimum PS AACR-F** dB	
$1 \le f \le 500$	$22{,}22 + IL_{250}/2{,}29 - 20\lg(f/100) - 10\lg(L/100)$	For each pair of the disturbed channel.
$1 \le f \le 500$	$26{,}22 + IL_{250}/2{,}29 - 20\lg(f/100) - 10\lg(L/100)$	For the average of the 4 pairs within the disturbed channel.

Where IL_{250} is channel insertion loss at 250 MHz in dB to one decimal place, L is physical channel length in m.

IL_{250} values less then 10,0 dB shall revert to a value of 10,0 dB; L reverts to 2,77 m.

For the purpose of field measurements $L = 2{,}77 \cdot \sqrt{f}$, where f is the frequency in MHz.

The average measured IL_{250} of all pairs of the disturbed channel is used in limit calculations applicable to all pairs.

When the $PS\ AFEXT$ exceeds $72 - 15\lg(f/100)$ the calculated $PS\ AACR\text{-}F$ result shall be for information only.

Calculated values greater than 67 dB revert to a minimum requirement of 67,0 dB.

Table 19 – Informative PS AACR-F limits for a channel at key frequencies and lengths

	Minimum PS AACR-F dB					
Frequency MHz	1,0	16,0	100,0	250,0	500,0	
IL_{250} = 20,3 dB; L = 55 m	67,0	49,6	**33,7**	25,7	19,7	For each pair of the disturbed channel.
IL_{250} = 33,8 dB; L = 100 m	67,0	52,9	**37,0**	29,0	23,0	
IL_{250} = 35,9 dB; L = 100 m	67,0	53,8	**37,9**	29,9	23,9	
IL_{250} = 20,3 dB; L = 55 m	67,0	53,6	37,7	29,7	23,7	For the average of the 4 pairs within the disturbed channel.
IL_{250} = 33,8 dB; L = 100 m	67,0	56,9	41,0	33.0	27,0	
IL_{250} = 35,9 dB; L = 100 m	67,0	57,8	41,9	33,9	27,7	
NOTE The 10GBASE-T constants are shown in bold.						

5.7.4 Alien crosstalk margin computation

The objective of alien crosstalk margin computation is to further characterize the alien crosstalk coupling between channels. The alien crosstalk margin computation that ensures the total combined *PS AFEXT* and *PS ANEXT* coupled into a channel is limited in order to maintain the minimum signal to noise ratio. The alien crosstalk margin is specified for each pair of the disturbed channel and for the average of the four pairs within the disturbed channel. See Annex B for the detailed approach to computation. If the alien crosstalk margin computation in accordance of Annex B is not met, then see clause 6 for mitigation techniques.

5.7.5 Examples of implementations at key insertion loss at 250 MHz

Table 19 provides examples of channel lengths that will support 10GBASE-T based on the minimum performance of Class E and Class F as specified in ISO/IEC 11801:2002 and the noise levels specified in 5.7.15.7.2 and 5.7.3.

Table 20 – Examples of implementations at key insertion loss

Channel length m	**Class**	**Length of fixed cable and cord** m + m	**Noise constant at 100 MHz** dB	
			PS ANEXT	*PS AACR-F*
***IL* at 250 MHz = 20,3 dB**				
55 [a]	E	42,8 + 10	47	33,7
55 [a]	F	45,8 + 10		
***IL* at 250 MHz = 33,8 dB**				
100 [a]	E	83,5 + 10	60	37
100 [a]	F	90 + 10		
***IL* at 250 MHz = 35,9 dB**				
100 [a]	E	90 + 10	62	37,9
100 [a]	F	90 + 10		
NOTE These values are given for information only.				
[a] Not exactly 55 m and 100 m respectively but equations not so length sensitive.				

5.8 Propagation delay

To support 10GBASE-T the propagation delay for each pair of a channel, measured, when required, according to IEC 61935-1, shall be less than the limits computed using the equations, to three decimal places, of Table 21. The limits shown in Table 22 are derived from the equations at key frequencies.

Table 21 – Equations for propagation delay limits for a channel

Frequency MHz	**Maximum propagation delay** µs
$1 \leq f \leq 500$	$0{,}534 + 0{,}036 / \sqrt{f} + 4 \times 0{,}002\,5$

Table 22 – Propagation delay limits for a channel at key frequencies

Frequency MHz	**Maximum propagation delay** µs
1,0	0,580
16,0	0,553
100,0	0,548
250,0	0,546
500,0	0,546
NOTE These values are given for information only.	

5.9 Delay skew

To support 10GBASE-T the skew between all pairs of a channel, measured, when required, according to IEC 61935-1, shall be less than the limits computed using the equation, to three decimal places, of Table 23.

Table 23 – Delay skew limits for a channel

Frequency MHz	**Maximum delay skew** µs
$1 < f < 500$	0,050 [a, b]

[a] Calculation is based upon 0,045 + 4 × 0,001 25.

[b] Skew between any two channel pairs due to environmental conditions shall not vary by more than 10 ns within the channel delay skew requirement (this is met by design).

6 Guidance for mitigation

6.1 Certification, measurement and documentation

The test procedures for balanced cabling installations are specified in IEC 61935-1 in accordance with ISO/IEC 11801:2002.

Additional care should be taken for the documentation of channels intended to be used for 10GBASE-T.

6.2 Mitigation techniques if in-channel parameters of the channel from clause 5 are not met

NOTE In-channel-parameters are all parameters in clause 5 except alien noise.

Depending on the components used and the layout of the cables and connecting hardware, some parameters will not be met. Suppliers should be consulted to improve the performance of these parameters.

Major failure sources:

- cables;
- connectors;

- cords.

Possibilities:

- use components with higher category;
- change the cross-connects to interconnects;
- replace the components at the consolidation points with components of higher performance.

6.3 Mitigation techniques in case external parameters of the channel (alien noise) from 5.7 are not met

6.3.1 General

Depending on the components used and the layout of the cable and connecting hardware, some parameters may not be met. A critical one is power sum alien crosstalk. For channels which are to be re-qualified the manufacturer should be asked on mitigation technique or the following actions should be taken:

a) replace patch cords with higher categorized patch cords;
b) remove cable bundle ties and, to the extent possible, randomise the cables at the near-end;
c) replace the patch panel with a higher category patch panel;
d) reduce the number of cabling components:
e) replace the cabling.

The following subclauses list possibilities to avoid or to decrease power sum alien crosstalk and may be subject to additions.

6.3.2 Screened cabling

Major coupling sources:

- connectors in the channel that are not individually screened (e.g. screened in groups – see 6.3.4).

Possibilities for improvement:

- the transfer impedance of the installed connectors to the cable should be checked (done by design). This is to confirm the alien noise reduction of shielded channels;
- improve the equipment cords (cords with better alien noise performance);
- use connectors that are individually screened, or separated by distance;
- for connectors screened in groups see 6.3.4.

6.3.3 Unscreened cabling

Major coupling sources:

- patchcords;
- distributors, outlets;
- cable runs.

Possibilities:

- use components with higher category, or components with better alien noise performance;
- keep cords unbundled and laid randomly;
- improve the equipment cords, mechanically randomizing them and using longer patch cords, or patch cords with better alien crosstalk performance. Longer cords may decrease the signal at the receiving end but because there is no coupling any more the noise will be attenuated, especially the high frequency *ANEXT*. Of course precautions are to be taken not to increase the insertion loss of the channel above the limit specified in clause 5;

- use an interconnect configuration to attach equipment rather than a cross-connect;
- unbundle and randomize the cabling within the telecommunications room; this is very helpful to minimise the *ANEXT* noise (by reducing the signal level at the starting point);
- if AACR-F noise is a problem the only remedy is to separate the channels over the entire length. Separating only at the beginning of the channel does very little, not like in ANEXT (see also grouping long and short channels – next bullet point);
- separate long runs from short runs. This is probably the best solution and may be the only remedy to decrease the short length, high frequency *AFEXT* noise (see also clause 5);
- unbundle the cabling (randomizing, separation);
- choose non-adjacent channels for the 10GBASE-T application, i.e. skip at patch panel;
- reduce channel length, if possible;
- separate physically all connectors (start at the patch panel end, as separation at the TO may not be needed, due to the applications nearby or may require replacement of the connecting hardware when 2 connectors are in one housing);
- if the connectors are grouped, see 6.3.4;
- install the cables not always with the same production direction;
- if metallic trays are used, cables should be physically separated to avoid alien crosstalk.

6.3.4 Grouped connectors

When the connectors are grouped together under a common shield or no mechanical separation is possible, (such as in TOs):

- use different protocols such as one 10GBASE-T and one telephone at TOs;
- separate 10GBASE-T channels at the patch panel by using non-adjacent connectors.

6.3.5 Example of a step by step mitigation procedure

The following procedure is suggested for the mitigation of unscreened Class E cabling.

1) Identify a set of channels of maximum lengths, which are in the same cable bundle.
2) When possible, select a cable bundle with the highest number of cables.
3) Measure the power sum crosstalk of at least 6 disturbed channels.
4) If any of the 6 channels does not meet the *ANEXT* requirement, mitigation is needed.
5) If the *ANEXT* negative margin is greater than 6 dB at any frequency between 1 MHz to 500 MHz, mitigation is not feasible. Limit the use of 10GBASE-T in this telecommunications room to those channels of sufficiently short length, and low insertion loss, that is where the negative margin is less than 6 dB, and replace the other channels with better cabling.
6) Replace the patch cords, equipment cords, and work area cords with longer patch cords, or patch cords with better alien crosstalk performance, keeping these unbundled and randomly organized.
7) Use an interconnect configuration to attach equipment to the horizontal cabling rather than a cross-connect.
8) Unbundle and randomize the horizontal cabling in the telecommunications room up to the point it exits the telecommunications room. This will reduce coupling in the first 5 m to 15 m, which is the major source of *ANEXT*.
9) Choose non-adjacent Class E channels for the 10GBASE-T application, i.e. skip patch panel positions. The “skipped” positions may be used for other applications.
10) Replace the interconnect or cross-connect with a better alien crosstalk performing inter-connect or cross-connect. The older cross-connect may be re-used for other applications.
11) Replace the consolidation point and telecommunications outlet connectors with better alien crosstalk performing connectors.

12) Repeat steps 1) to 5) above to assure that mitigation has been successful, selecting 6 different channels on which to measure *ANEXT*.

13) Once the channels have been qualified for *ANEXT*, each channel needs to be further qualified for internal transmission parameters up to 500 MHz. If any channel fails these internal transmission parameters, the mitigation steps above need to be repeated.

Consider doing several mitigation steps together (unbundling and randomizing, changing patchcords and equipment cords, replacing cross-connect with interconnect).

Annex A
(informative)

Permanent link performance guidelines

A.1 General

This annex contains some internal performance guidelines for balanced cabling permanent links to assess whether the permanently installed cabling has the potential to be used as part of a balanced cabling channel to support 10GBASE-T. The equations shown in Table A.1 to Table A.6 inclusive represent an extension to the Class E requirements of ISO/IEC 11801:2002. Class F of ISO/IEC 11801:2002 meets the equations in Tables A.1 to A.6 inclusive.

Measuring the internal link performance of an installed permanent link does not assure conformance to this Technical Report, and shall not be used instead of the channel qualification of Clause 5.

A.2 Return loss

Return loss should be measured according to IEC 61935-1 from both ends of the cabling, and should meet the limits computed from the equations in Table A.1.

Table A.1 – Return loss for permanent link

Frequency MHz	**Minimum return loss** dB
$1 \le f < 10$	21
$10 \le f < 40$	$26 - 5\lg(f)$
$40 \le f < 398,1$	$34 - 10\lg(f)$
$398,1 \le f \le 500$	8

A.3 Insertion loss

Insertion loss should be measured according to IEC 61935-1, and should meet the limits computed from the equation in Table A.2.

Table A.2 – Insertion loss for permanent link

Frequency MHz	**Maximum insertion loss** dB
$1 \le f \le 500$	$(L/100)\left(1,82 \times \sqrt{f} + 0,0169f + 0,25/\sqrt{f}\right) + 3 \times 0,02\sqrt{f}$

where L is the length of the fixed cable (in meter) plus length of the CP cord (where present) (in meter).

A.4 NEXT

A.4.1 Pair-to-pair NEXT

Pair-to-pair *NEXT* should be measured according to IEC 61935-1 from both ends of the cabling, and should meet the limits computed from the equations in Table A.3.