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TECHNICAL REPORT

Information technology – Generic cabling for customer premises – Part 9901: Guidance for balanced cabling in support of at least 40 Gbit/s data transmission

ISO/IEC TR 11801-9901:2014-10(en)

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colour inside

Information technology – Generic cabling for customer premises – Part 9901: Guidance for balanced cabling in support of at least 40 Gbit/s data transmission

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INFORMATION TECHNOLOGY – GENERIC CABLING FOR CUSTOMER PREMISES –

Part 9901: Guidance for balanced cabling in support of at least 40 Gbit/s data transmission

FOREWORD

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ISO/IEC TR 11801-9901, which is a technical report, has been prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology.

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

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.

IMPORTANT – The "colour inside" logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

INTRODUCTION

This Technical Report provides guidance for balanced cabling in support of at least 40 Gbit/s data transmission. The guidance proposes of two new channel specifications, namely Class I and Class II, with two connections able to support future 40GBASE-T up to at least 30 m.

In addition, this Technical Report contains the description of channels with two connections based on existing Category 6_A and Category 7_A components with and without characterization beyond the current upper frequency and length up to at least 30 m.

In order to evaluate the different channel approaches this Technical Report offers a preliminary assessment of Shannon capacity and reach using the channel transmission performance data described in this report. This assessment is not a definition of 40GBASE-T.

INFORMATION TECHNOLOGY – GENERIC CABLING FOR CUSTOMER PREMISES –

Part 9901: Guidance for balanced cabling in support of at least 40 Gbit/s data transmission

1 Scope

This part of ISO/IEC 11801 covers the following channel descriptions constructed from components with a nominal impedance of 100 Ω.

a) Class I: 30 m channel based on upcoming Category 8.1 components. This channel provides increased margin compared to ISO/IEC 11801, Class E_A channels, and an upper frequency limit of 1 600 MHz (2 000 MHz (ffs) (see Clause 4).

b) Class II: 30 m channel based on upcoming Category 8.2 components. This channel provides increased margin compared to ISO/IEC 11801, Class F_A channels, and an upper frequency limit of 1 600 MHz (2 000 MHz ffs) (see Clause 4).

c) Channels based on Category 6_A components of ISO/IEC 11801, length corrected to 30 m (Clause 5).

d) Channels based on Category 7_A components of ISO/IEC 11801, length corrected to 30 m (Clause 5).

e) Channels based on Category 6_A components of ISO/IEC 11801, length corrected to 30 m, characterized beyond the current upper frequency (see Annex B).

f) Channels based on Category 7_A components of ISO/IEC 11801, length corrected to 30 m, characterized beyond the current upper frequency (see Annex B).

This Technical Report offers an assessment (see Annex A) of expected capacity and reach for the channels defined in Clause 4, Clause 5 and Annex B.

All 30 m channels comprise a 2 m cord (50 % derated) attached at each end of a permanent link of 26 m length. These assumptions are for modelling only.

ISO/IEC 11801 gives the freedom to use different configurations as long as the channel values are fulfilled.

Specific component requirements are not addressed in this Technical Report. Any inferred component requirements are not intended to be normative.

2 Normative references

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

ISO/IEC 11801:2002, *Information technology – Generic cabling for customer premises*
Amendment 1:2008
Amendment 2:2010[1]

IEC TR 61156-1-3, *Multicore and symmetrical pair/quad cables for digital communications – Part 1-3: Electrical transmission parameters for modelling cable assemblies using symmetrical pair/quad cables*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document the terms and definitions of ISO/IEC 11801 and the following apply.

3.1.1
background noise
noise calculated from electronic background noise from transmit power and the maximum considered frequency

Note 1 to entry: Background noise is calculated in decibel (dB).

Note 2 to entry: Background noise is given in dBm/Hz.

Note 3 to entry: Transmit power (Tp) is given in dBm.

Note 4 to entry: The maximum considered frequency (fmax_system) is given in Hz.

3.1.2
cabling noise
single channel cabling noise is the power sum of return loss, power sum near end crosstalk and power sum far end crosstalk

3.1.3
connection
two mated connectors

EXAMPLE Jack and plug.

3.2 Abbreviations

For the purposes of this document the abbreviations of ISO/IEC 11801 and the following apply.

ACR	Attenuation CRosstalk
ANEXT	Alien (EXogenous) Near-End crosstalk loss
AACR	Attenuatin to Alien (exogenous) CRosstalk
BNp	Background Noise
CN	NEXT Cancellation
CF	FEXT Cancellation
CR	Return loss (Echo) Cancellation
ELTCTL	Equal Level TCTL
ffs	for further study
NEXT	Near-End crosstalk attenuation (loss)

[1] A consolidated version of this publication exists, comprising ISO/IEC 11801:2002, ISO/IEC 11801:2002/AMD 1:2008 and ISO/IEC 11801:2002/AMD 2:2010.

TCL	Transverse Conversion Loss
TCTL	Transverse Conversion Transfer Loss
fmax_system	maximum frequency considered for the calculation of capacity
PS	Power Sum
Tp	Transmit power

4 Channel requirements using components with enhanced performance and extended frequency

4.1 General

This clause specifies the transmission performance up to 1 600 MHz (2 000 MHz ffs) of 30 m channels assembled from two sets of enhanced components subject to future standardisation:

a) Class I based on upcoming Category 8.1 components

b) Class II based on upcoming Category 8.2 components

The parameters specified in this clause apply to screened channels.

For a balanced cabling installation to perform in accordance with this Technical Report:

1) the channel performance should meet the specifications of this clause;
2) the interfaces to the cabling shall conform to the requirements of ISO/IEC 11801:2002, with its amendments 1:2008 and 2:2010, Clause 10, with respect to mating interfaces;
3) local regulations concerning safety and EMC shall be met as applicable to the location of the installation.

4.2 Return loss

The return loss for each pair of a channel shall not exceed the limits computed, to one decimal place, using the formulae of Table 1. The limits shown in Table 2 are derived from the formulae at key frequencies.

The return loss requirement shall be met at both ends of the cabling.

Return loss values at frequencies where the insertion loss is below 3 dB (ffs) are for information only (see Table 2).

Table 1 – Formulae for return loss limits for a channel

Frequency MHz	**Minimum return loss Class I and Class II** dB
$1 \leq f \leq 10$	19,0
$10 < f \leq 100$	$24 - 5 \lg(f)$
$100 < f \leq 1\,000$	$26 - 6 \lg(f)$
$1\,000 < f \leq 1600$	8,0
$1\,600 < f \leq 2\,000$	8,0 ffs

Table 2 – Return loss limits for a channel at key frequencies

Frequency MHz	Minimum return loss Class I and Class II dB
1,0	19,0
16,0	18,0
100,0	14,0
250,0	11,6
500,0	9,8
600,0	9,3
1 000,0	8,0
1 600,0	8,0
2 000,0 ffs	8,0 ffs

4.3 Insertion loss

The insertion loss for each pair of a channel shall not exceed the limits computed, to one decimal place, using the formulae of Table 3. The limits shown in Table 4 are derived from the formulae at key frequencies. Table 4 is given for information only.

Table 3 – Formulae for insertion loss limits for a channel

	Frequency MHz	**Maximum insertion loss** dB
Class I	$1 < f \leq 250$	$0{,}32\left(1{,}8\sqrt{f}+0{,}005f+0{,}25/\sqrt{f}\right)+0{,}0324\sqrt{f}$ $+2\left(0{,}016835\sqrt{f}-10\lg\left[1-10^{\frac{32-20\lg(f/100)}{-10}}\right]-10\lg\left[1-10^{\frac{51-20\lg(f/100)}{-10}}\right]\right)$
	$250 < f \leq 500$	$0{,}32\left(1{,}8\sqrt{f}+0{,}005f+0{,}25/\sqrt{f}\right)+0{,}0324\sqrt{f}$ $+2\left(0{,}016835\sqrt{f}-10\lg\left[1-10^{\frac{32-20\lg(f/100)}{-10}}\right]-10\lg\left[1-10^{\frac{43{,}04-30\lg(f/250)}{-10}}\right]\right)$
	$500 < f \leq 1\,000$	$0{,}32\left(1{,}8\sqrt{f}+0{,}005f+0{,}25/\sqrt{f}\right)+0{,}0324\sqrt{f}$ $+2\left(0{,}016835\sqrt{f}-10\lg\left[1-10^{\frac{32-20\lg(f/100)}{-10}}\right]-10\lg\left[1-10^{\frac{34-40\lg(f/500)}{-10}}\right]\right)$
	$1\,000 < f \leq 1\,600$ $1\,600 < f \leq 2\,000$ ffs	$0{,}32\left(1{,}8\sqrt{f}+0{,}005f+0{,}25/\sqrt{f}\right)+0{,}0324\sqrt{f}$ $+2\left(0{,}016835\sqrt{f}+0{,}283-10\lg\left[1-10^{\frac{34-40\lg(f/500)}{-10}}\right]\right)$
NOTE The term $0{,}032\,4\sqrt{f}$ is ffs.		
Class II	$1 < f \leq 1\,600$ $1\,600 < f \leq 2\,000$ ffs	$0{,}32\left(1{,}8\sqrt{f}+0{,}005f+0{,}25/\sqrt{f}\right)+2\times 0{,}02\sqrt{f}$
For measurements the values below 4,0 dB revert to 4,0 dB (ffs).		

Table 4 – Insertion loss limits for a channel at key frequencies

Frequency MHz	Maximum insertion loss dB	
	Class I	**Class II**
1,0	0,7	0,7
16,0	2,6	2,5
100,0	6,6	6,3
250,0	10,6	10,1
500,0	15,3	14,6
600,0	16,9	16,1
1 000,0	22,5	21,1
1 600,0	29,2	27,2
2 000,0 ffs	33,4 ffs	30,8 ffs

4.4 Near-end crosstalk loss (NEXT)

4.4.1 Pair-to-pair NEXT

The pair-to-pair NEXT for each pair combination of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 5.The limits shown in Table 6 are derived from the formulae at key frequencies. The length dependency of cables and channels is neglected because it affects only low frequencies. Table 6 is given for information only.

Table 5 – Formulae for pair-to-pair NEXT limits for a channel

	Frequency MHz	**Minimum NEXT** dB
Class I	$1 \leq f \leq 500$	$-20\lg\left(10^{\frac{75,3-15\lg(f)}{-20}}+2\times10^{\frac{94-20\lg(f)}{-20}}\right)$ For measurements 65,0 ffs maximum.
	$500 < f \leq 1\ 600$ $1\ 600 < f \leq 2\ 000$ ffs	$-20\lg\left(10^{\frac{75,3-15\lg(f)}{-20}}+2\times10^{\frac{40-38\lg(f/500)}{-20}}\right)$ For measurements 65,0 ffs maximum.
Class II	$1 \leq f \leq 1\ 000$	$-20\lg\left(10^{\frac{105,4-15\lg(f)}{-20}}+2\times10^{\frac{116,3-20\lg(f)}{-20}}\right)$ For measurements 65,0 ffs maximum.
	$1\ 000 < f \leq 1\ 600$ $1\ 600 < f \leq 2\ 000$ ffs	$-20\lg\left(10^{\frac{105,4-15\lg(f)}{-20}}+2\times10^{\frac{56,3-60\lg(f/1\ 000)}{-20}}\right)$ For measurements 65,0 ffs maximum.

Table 6 – Pair-to-pair NEXT limits for a channel at key frequencies

Frequency MHz	**Minimum NEXT** dB	
	Class I	**Class II**
1,0	73,5	101,5
16,0	53,9	80,7
100,0	40,5	66,4
250,0	33,6	59,1
500,0	28,4	53,6
600,0	26,2	52,1
1 000,0	19,6	47,9
1 600,0	12,9	37,1
2 000,0 ffs	9,6 ffs	31,7 ffs

4.4.2 Power sum NEXT (PS NEXT)

The PS NEXT for each pair combination of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 7. The limits shown in Table 8 are derived from the formulae at key frequencies. The length dependency of cables and channels is neglected because it affects only low frequencies. Table 8 is given for information only.

Table 7 – Formulae for PS NEXT limits for a channel

	Frequency MHz	**Minimum PS NEXT** dB
Class I	$1 \leq f \leq 500$	$-20\lg\left(10^{\frac{72,3-15\lg(f)}{-20}}+2\times10^{\frac{91-20\lg(f)}{-20}}\right)$ For measurements 62,0 ffs maximum.
	$500 < f \leq 1\ 600$ $1\ 600 < f \leq 2\ 000$ ffs	$-20\lg\left(10^{\frac{72,3-15\lg(f)}{-20}}+2\times10^{\frac{37-38\lg(f/500)}{-20}}\right)$ For measurements 62,0 ffs maximum.
Class II	$1 \leq f \leq 1\ 000$	$-20\lg\left(10^{\frac{102,4-15\lg(f)}{-20}}+2\times10^{\frac{113,3-20\lg(f)}{-20}}\right)$ For measurements 62,0 ffs maximum.
	$1\ 000 < f \leq 1\ 600$ $1\ 600 < f \leq 2\ 000$ ffs	$-20\lg\left(10^{\frac{102,4-15\lg(f)}{-20}}+2\times10^{\frac{53,3-60\lg(f/1\ 000)}{-20}}\right)$ For measurements 62,0 ffs maximum.

Table 8 – PS NEXT limits for a channel at key frequencies

Frequency MHz	**Minimum PS NEXT** dB	
	Class I	Class II
1,0	70,5	98,5
16,0	50,9	77,7
100,0	37,5	63,4
250,0	30,6	56,1
500,0	25,4	50,6
600,0	23,2	49,1
1 000,0	16,6	44,9
1 600,0	9,9	34,1
2 000,0 ffs	6,6 ffs	28,7 ffs

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

4.5.1 Pair-to-pair ACR-N

This value is calculated from NEXT and insertion loss. For information, see ISO/IEC 11801:2002, with its amendments 1:2008 and 2:2010.

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

This value is calculated from PS NEXT and insertion loss. For information, see ISO/IEC 11801:2002, with its amendments 1:2008 and 2:2010.

4.6 Attenuation to crosstalk ratio far-end (ACR-F)

4.6.1 Pair-to-pair ACR-F

The ACR-F for each pair combination of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 9. The limits shown in Table 10 are derived from the formulae at key frequencies. Table 10 is given for information only.

Table 9 – Formulae for ACR-F limits for a channel

	Frequency MHz	**Minimum ACR-F** dB
Class I	$1 \le f \le 1\,600$ $1\,600 < f \le 2\,000$ ffs	$-20\lg\left(\sqrt{0{,}6}\times 10^{\frac{76{,}8-20\lg(f)}{-20}} + 2\times 10^{\frac{83{,}1-20\lg(f)}{-20}}\right)$ For measurements 65,0 ffs maximum.
Class II	$1 \le f \le 1\,000$	$-20\lg\left(\sqrt{0{,}6}\times 10^{\frac{98{,}4-20\lg(f)}{-20}} + 2\times 10^{\frac{103{,}9-20\lg(f)}{-20}}\right)$ For measurements 65,0 ffs maximum.
	$1\,000 < f \le 1\,600$ $1\,600 < f \le 2\,000$ ffs	$-20\lg\left(\sqrt{0{,}6}\times 10^{\frac{98{,}4-20\lg(f)}{-20}} + 2\times 10^{\frac{43{,}9-60\lg(f/1000)}{-20}}\right)$ For measurements 65,0 ffs maximum.
The term 0,6 is to calculate the cable part of the channel formula for 30 m while the cable definition refers to 50 m.		
ACR-F limits at frequencies that correspond to measured values of FEXT greater than 70 dB (ffs) shall be for information only.		

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

Frequency MHz	**Minimum pair-to-pair ACR-F** dB	
	Class I	Class II
1,0	72,0	93,1
16,0	47,9	69,0
100,0	32,0	53,1
250,0	24,0	45,2
500,0	18,0	39,1
600,0	16,4	37,6
1 000,0	12,0	33,1
1 600,0	7,9	23,5
2 000,0 ffs	6,0 ffs	18,4 ffs

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

The PS ACR-F for each pair combination of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 11. The limits shown in Table 12 are derived from the formulae at key frequencies. Table 12 is given for information only.

Table 11 – Formulae for PS ACR-F limits for a channel

	Frequency MHz	Minimum PS ACR-F dB
Class I	$1 \le f \le 1\,600$ $1\,600 < f \le 2\,000$ ffs	$-20\lg\left(\sqrt{0{,}6}\times 10^{\frac{73{,}8-20\lg(f)}{-20}} + 2\times 10^{\frac{80{,}1-20\lg(f)}{-20}}\right)$ For measurements 62 ffs maximum.
Class II	$1 \le f \le 1\,000$	$-20\lg\left(\sqrt{0{,}6}\times 10^{\frac{95{,}4-20\lg(f)}{-20}} + 2\times 10^{\frac{100{,}9-20\lg(f)}{-20}}\right)$ For measurements 62 ffs maximum.
	$1\,000 < f \le 1\,600$ $1\,600 < f \le 2\,000$ ffs	$-20\lg\left(\sqrt{0{,}6}\times 10^{\frac{95{,}4-20\lg(f)}{-20}} + 2\times 10^{\frac{40{,}9-60\lg(f/1\,000)}{-20}}\right)$ For measurements 62 ffs maximum.
The term 0,6 is to calculate the cable part of the channel formula for 30 m while the cable definition refers to 50 m.		
PSACR-F limit at frequencies that correspond to calculated values of PS FEXT greater than 67 dB (ffs) shall be for information only.		

Table 12 – PS ACR-F limits for a channel at key frequencies

Frequency MHz	Minimum PS ACR-F dB	
	Class I	Class II
1,0	69,0	90,1
16,0	44,9	66,0
100,0	29,0	50,1
250,0	21,0	42,2
500,0	15,0	36,1
600,0	13,4	34,6
1 000,0	9,0	30,1
1 600,0	4,9	20,5
2 000,0 ffs	3,0 ffs	15,4 ffs

4.7 Alien (Exogenous) crosstalk

4.7.1 PS ANEXT

The PS ANEXT for each pair combination of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 13. The limits shown in Table 14 are derived from the formulae at key frequencies. Table 14 is given for information only.

Table 13 – Formulae for PS ANEXT limits for a channel

	Frequency MHz	Minimum PS ANEXT dB
Class I Class II	$1 \le f < 100$	$105 - 10\lg(f)$ For measurements 67,0 ffs maximum.
	$100 \le f \le 1\,600$ $1\,600 < f \le 2\,000$ ffs	$115 - 15\lg(f)$ For measurements 67,0 ffs maximum.

Table 14 – PS ANEXT limits for a channel at key frequencies

Frequency MHz	Minimum PS ANEXT Class I and Class II dB
1,0	105,0
16,0	93,0
100,0	85,0
250,0	79,0
500,0	74,5
600,0	73,3
1 000,0	70,0
1 600,0	66,9
2 000,0 ffs	65,5 ffs

4.7.2 PS AACR-F

The PS AACR-F for each pair combination of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 15. The limits shown in Table 16 are derived from the formulae at key frequencies. Table 16 is given for information only.

Table 15 – Formulae for PS AACR-F limits for a channel

	Frequency MHz	Minimum PS AACR-F dB
Class I Class II	$1 \le f \le 1\,600$ $1\,600 < f \le 2\,000$ ffs	$101 - 20\lg(f)$ For measurements 67,0 ffs maximum.
PS AACR-F limit at frequencies that correspond to calculated values of PS AFEXT greater than 67,0 dB ffs or $102-15\lg(f)$ ffs shall be for information only.		

Table 16 – PS AACR-F limits for a channel at key frequencies

Frequency MHz	Minimum PS AACR-F Class I and Class II dB
1,0	101,0
16,0	76,9
100,0	61,0
250,0	53,0
500,0	47,0
600,0	45,4
1 000,0	41,0
1 600,0	36,9
2 000,0 ffs	35,0 ffs

4.8 DC loop resistance

The DC loop resistance in an installation shall not exceed 0,2 Ω/m (6 Ω maximum).

4.9 Propagation delay

The propagation delay for each pair of a channel shall not exceed the limits computed, to three decimal places, using the formulae of Table 17. The limits shown in Table 18 are derived from the formulae at key frequencies. Table 18 is given for information only.

Table 17 – Formulae for propagation delay limits for a 30 m channel

	Frequency MHz	Maximum propagation delay µs
Class I Class II	$1 \leq f \leq 1\,600$ $1\,600 < f \leq 2\,000$ ffs	$0,3 \times \left[0,534 + 0,036/\sqrt{(f)}\right] + 2 \times 0,0025$

Table 18 – Propagation delay limits for a channel at key frequencies

Frequency MHz	Maximum propagation delay dB
1,0	0,176
16,0	0,168
100,0	0,166
250,0	0,166
500,0	0,166
600,0	0,166
1 000,0	0,166
1 600,0	0,165
2 000,0 ffs	0,165 ffs

4.10 Delay skew

The skew between all pairs of a channel shall be less than the limits computed using the formulae, to three decimal places, of Table 19.

Table 19 – Delay skew limits for a 30 m channel

Class	Maximum delay skew [a,b] for 1 MHz < f < 1 600 MHz µs
Class I	0,016
Class II	0,010

[a] Calculation is based on 0,045*0,3 + 2 × 0,001 25 Class I

Calculation is based on 0,025*0,3 + 2 × 0,001 25 Class II

[b] Skew between any two channel pairs due to environmental conditions shall not vary by more than 3 ns within the channel delay skew requirement (this is met by design).

4.11 Unbalance attenuation near end (TCL), far end (ELTCTL) and coupling attenuation

4.11.1 General

In this subclause unbalance attenuation (TCL and ELTCTL) and coupling attenuation are specified. For further information on these parameters, see ISO/IEC 11801:2002, with its amendments 1:2008 and 2:2010, Annex D.

4.11.2 Unbalance attenuation, near end

The TCL for each pair of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 20. The limits shown in Table 21 are derived from the formulae at key frequencies. Table 21 is given for information only.

Table 20 – TCL for a channel

Frequency MHz	Minimum TCL for Class I and Class II dB	
	Channels using cables with unscreened pairs	**Channels using cables with screened pairs**
1 ≤ f ≤ 1 600	60 − 17lg(f) ffs	50 − 17lg(f) ffs
1 600 ≤ f ≤ 2 000 ffs	40,0 maximum	30,0 maximum, 3,0 minimum

Table 21 – TCL limits for a channel at key frequencies

Frequency MHz	Minimum TCL for Class I and II dB	
	Channels using cables with unscreened pairs	**Channels using cables with screened pairs**
1,0	40	30
16,0	39,5	39,5
100,0	26,0	16,0
250,0	19,2	9,2
500,0	14,1	4,1
600,0	12,8	3,0
1 000,0	9,0	3,0
1 600,0	5,5	3,0
2 000,0 ffs	3,9 ffs	3,0 ffs

4.11.3 Unbalance attenuation far end (ELTCTL)

The ELTCTL for each pair of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 22. The limits shown in Table 23 are derived from the formulae at key frequencies. Table 23 is given for information only.

Table 22 – ELTCTL for a channel

Frequency MHz	Minimum ELTCTL for Class I and Class II dB	
	Channels using cables with unscreened pairs	**Channels using cables with screened pairs**
$1 \le f \le 1\,600$	$44{,}6 - 20\lg(f)$ ffs	$34{,}6 - 20\lg(f)$ ffs
$1\,600 < f \le 2\,000$ ffs	3,0 minimum	3,0 minimum

Table 23 – ELTCTL limits for a channel at key frequencies

Frequency MHz	Minimum ELTCTL for Class I and Class II dB	
	Channels using cables with unscreened pairs	**Channels using cables with screened pairs**
1,0	44,6	34,6
16,0	20,5	10,5
100,0	4,6	3,0
250,0	3,0	3,0
500,0	3,0	3,0
600,0	3,0	3,0
1 000,0	3,0	3,0
1 600,0	3,0	3,0
2 000,0 ffs	3,0 ffs	3,0 ffs

4.11.4 Coupling attenuation

The coupling attenuation for each pair of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 24. The limits shown in Table 25 are derived from the formulae at key frequencies. Table 25 is given for information only.

Table 24 – Coupling attenuation for a channel

Frequency MHz	**Minimum coupling attenuation for Class I and Class II** dB
$30 \leq f < 100$	50,0
$100 \leq f \leq 1\,600$ $1\,600 < f \leq 2\,000$ ffs	$50 - 20\lg(f / 100)$

It is possible to asses coupling attenuation by laboratory measurements of representative samples of channels assembled using their component and connector practices.

Table 25 – Coupling attenuation limits for a channel at key frequencies

Frequency MHz	**Minimum coupling attenuation for Class I and Class II** dB
1,0	NA
16,0	NA
100,0	50,0
250,0	42,0
500,0	36,0
600,0	34,4
1 000,0	30,0
1 600,0	25,9
2 000,0 ffs	24,0 ffs

If coupling attenuation exceeds the values of Table 24 by 15 dB, then the requirements of 4.7 (alien noise) are met by design.

5 Channel requirements for Category 6_A and Category 7_A components

5.1 General

This clause specifies the performance of a 30 m channel assembled from Category 6_A components and a 30 m channel assembled from Category 7_A components using the channel formulae specified in ISO/IEC 11801:2002, with its amendments 1:2008 and 2:2010.

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.

5.2 Return loss

The return loss for each pair of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 26. The limits shown in Table 27 are derived from the formulae at key frequencies. Table 27 is given for information only.

Table 26 – Formulae for return loss limits for a channel

Component category	Frequency MHz	Minimum return loss dB
6_A	$1 \le f < 10$	19,0
	$10 \le f < 40$	$24-5\lg(f)$
	$40 \le f < 398,1$	$32-10\lg(f)$
	$398,1 \le f \le 500$	6,0
7_A	$1 \le f < 10$	19,0
	$10 \le f < 40$	$24-5\lg(f)$
	$40 \le f < 251,2$	$32-10\lg(f)$
	$251,2 \le f < 631$	8,0
	$631 \le f \le 1\,000$	$36-10\lg(f)$
NOTE The values of this Table are the values for 100 m in ISO/IEC 11801:2002, with its amendments 1:2008 and 2:2010 values.		

Table 27 – Return loss limits for a channel at key frequencies

Frequency MHz	Minimum Return loss dB	
	6_A	**7_A**
1,0	19,0	19,0
16,0	18,0	18,0
100,0	12,0	12,0
250,0	8,0	8,0
500,0	6,0	8,0
600,0	N/A	8,0
1 000,0	N/A	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

The insertion loss of each pair of a channel shall not exceed the limits computed, to one decimal place, using the formulae of Table 28. The limits shown in Table 29 are derived from the formulae at key frequencies. Table 29 is given for information only.

Table 28 – Formulae for insertion loss limits for a channel

Component category	Frequency MHz	Maximum insertion loss dB
6_A	$1 \le f \le 500$	$0,32\left(1,82\sqrt{f}+0,009\,1f+0,25/\sqrt{f}\right)+2\times 0,02\sqrt{f}$
7_A	$1 \le f \le 1\,000$	$0,32\left(1,8\sqrt{f}+0,005f+0,25/\sqrt{f}\right)+2\times 0,02\sqrt{f}$
NOTE Values below 4,0 dB revert to 4,0 dB.		

Table 29 – Insertion loss limits for a channel at key frequencies

Frequency MHz	Maximum insertion loss dB	
	6_A	**7_A**
1,0	4,0	4,0
16,0	4,0	4,0
100,0	6,5	6,3
250,0	10,6	10,1
500,0	15,4	14,6
600,0	NA	16,1
1 000,0	NA	21,1

5.4 Near-end crosstalk loss (NEXT)

5.4.1 Pair-to-pair NEXT

The pair-to-pair NEXT between each pair combination of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 30. The limits shown in Table 31 are derived from the formulae at key frequencies. The length dependency of cables is neglected because it affects only low frequencies. Table 31 is given for information only.

Table 30 – Formulae for NEXT limits for a channel

Component category	Frequency MHz	Minimum NEXT dB
6_A	$1 \leq f \leq 500$	$-20\lg\left(10^{\frac{74{,}3-15\lg(f)}{-20}}+2\times10^{\frac{94-20\lg(f)}{-20}}\right)$ 65,0 maximum
7_A	$1 \leq f \leq 1\,000$	$-20\lg\left(10^{\frac{105{,}4-15\lg(f)}{-20}}+2\times10^{\frac{116{,}3-20\lg(f)}{-20}}\right)$ 65,0 maximum

Table 31 – NEXT limits for a channel at key frequencies

Frequency MHz	Minimum NEXT dB	
	6_A	**7_A**
1,0	65,0	65,0
16,0	61,8	65,0
100,0	45,8	65,0
250,0	37,9	59,1
500,0	31,9	53,6
600,0	N/A	52,1
1 000,0	N/A	47,9

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)

The *PS NEXT* for each pair of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 32. The limits shown in Table 33 are derived from the formulae at key frequencies. Table 33 is given for information only.

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

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

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

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 32 – Formulae for PS NEXT limits for a channel

Component Category	**Frequency** MHz	**Minimum PSNEXT** dB
6_A	$1 \leq f \leq 500$	$-20\lg\left(10^{\frac{72,3-15\lg(f)}{-20}} + 2\times 10^{\frac{90-20\lg(f)}{-20}}\right)$ 62,0 maximum
7_A	$1 \leq f \leq 1\ 000$	$-20\lg\left(10^{\frac{102,4-15\lg(f)}{-20}} + 2\times 10^{\frac{113,3-20\lg(f)}{-20}}\right)$ 62,0 maximum

Table 33 – PS NEXT limits for a channel at key frequencies

Frequency MHz	**Minimum PSNEXT** dB	
	6_A	**7_A**
1,0	62,0	62,0
16,0	52,2	62,0
100,0	39,1	62,0
250,0	32,7	56,1
500,0	27,6	50,6
600,0	N/A	49,1
1 000,0	N/A	44,9

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

This value is calculated by NEXT and insertion loss. For information, see ISO/IEC 11801:2002, with its amendments 1:2008 and 2:2010.

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

This value is calculated by PS NEXT and insertion loss. For information, see ISO/IEC 11801:2002, with its amendments 1:2008 and 2:2010.

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

5.6.1 Pair-to-pair ACR-F

The *ACR-F* for each pair combination of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 34. The limits shown in Table 35 are derived from the formulae at key frequencies. The length dependency of cables is included as presented in IEC TR 61156-1-3. Table 35 is given for information only.

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

$$ACR\text{-}F_{ik} = FEXT_{ik} - IL_k \quad \text{dB} \tag{2}$$

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.

IL_k is the insertion loss of pair k.

Table 34 – Formulae for ACR-F limits for a channel

Component Category	**Frequency** MHz	**Minimum ACR-F** dB
6_A	$1 \le f \le 500$	$-20\lg\left(\sqrt{0,30}\times 10^{\frac{67,8-20\lg(f)}{-20}} + 2\times 10^{\frac{83,1-20\lg(f)}{-20}}\right)$
7_A	$1 \le f \le 1\ 000$	$-20\lg\left(\sqrt{0,30}\times 10^{\frac{95,3-20\lg(f)}{-20}} + 2\times 10^{\frac{103,9-20\lg(f)}{-20}}\right)$
ACR-F values at frequencies that correspond to measured FEXT values of greater than 70,0 dB are for information only. The ACR-F limit at frequencies that correspond to calculated values of greater than 65,0 dB shall revert to a minimum requirement of 65,0 dB.		

Table 35 – ACR-F limits for a channel at key frequencies

Frequency MHz	**Minimum ACR-F** dB	
	6_A	**7_A**
1,0	65,0	65,0
16,0	45,2	65,0
100,0	29,3	53,1
250,0	21,3	45,1
500,0	15,3	39,1
600,0	N/A	37,5
1 000,0	N/A	33,1

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

The PS ACR-F for each pair of a channel shall meet the limits computed, to one decimal place, using the formulae of Table 36. The limits shown in Table 37 are derived from the formulae at key frequencies. The length dependency of cables is included as presented in IEC TR 61156-1-3. Table 37 is given for information only.

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

$$PSACR\text{-}F_k = -10\lg\left[\sum_{i=1, i\neq k}^{n} 10^{\frac{-FEXT_{ik}}{10}} - IL_k\right] \text{ dB} \qquad (3)$$

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 36 – Formulae for PS ACR-F limits for a channel

Component category	**Frequency** MHz	**Minimum PS ACR-F** dB
6_A	$1 \le f \le 500$	$-20\lg\left(\sqrt{0,30}\times 10^{\frac{64,8-20\lg(f)}{-20}} + 2\times 10^{\frac{80,1-20\lg(f)}{-20}}\right)$
7_A	$1 \le f \le 1\,000$	$-20\lg\left(\sqrt{0,30}\times 10^{\frac{92,3-20\lg(f)}{-20}} + 2\times 10^{\frac{100,9-20\lg(f)}{-20}}\right)$
PS ACR-F values at frequencies that correspond to measured FEXT values of greater than 70,0 dB are for information only. The PS ACR-F limit at frequencies that correspond to calculated values of greater than 62,0 dB shall revert to a minimum requirement of 62,0 dB.		

Table 37 – PS ACR-F limits for a channel at key frequencies

Frequency MHz	**Minimum PSACR-F** dB	
	6_A	**7_A**
1,0	62,0	62,0
16,0	44,2	62,0
100,0	26,3	50,1
250,0	18,3	42,1
500,0	12,3	36,1
600,0	N/A	34,5
1 000,0	N/A	30,1

5.7 Alien (Exogenous) crosstalk

As there is no length dependency defined for channels the 100 m values are valid also for shorter lengths. See ISO/IEC 11801 for relevant values.

5.8 DC loop resistance

The DC loop resistance in an installation shall not exceed 0,25 Ω/m (7,5 Ω maximum).

5.9 Propagation delay

The propagation delay for each pair of a channel shall be less than the limits computed using the formulae, to three decimal places, of Table 38. The limits shown in Table 39 are derived from the formulae at key frequencies. Table 39 is given for information only.

Table 38 – Formulae for propagation delay limits for a channel

Component category	**Frequency** MHz	**Maximum propagation delay for 30 m** µs
E_A	$1 \le f \le 500$	$0{,}3 * (0{,}534 + 0{,}036/\sqrt{f}) + 2 \times 0{,}0025$
F_A	$1 \le f \le 1\ 000$	$0{,}3 * (0{,}534 + 0{,}036/\sqrt{f}) + 2 \times 0{,}0025$

Table 39 – Propagation delay limits for a channel at key frequencies

Frequency MHz	**Maximum propagation delay for 30 m** µs	
	Component category	
	E_A	F_A
1,0	0,176	0,176
16,0	0,168	0,168
100,0	0,166	0,166
250,0	0,166	0,166
500,0	0,166	0,166
600,0	NA	0,166
1 000,0	NA	0,166

5.10 Delay skew

The skew between all pairs of a channel shall be less than the limits computed using the formulae, to three decimal places, of Table 40.

Table 40 – Delay skew limits for a channel

Component category	**Frequency** MHz	**Maximum delay skew [a, b] for 30 m** µs
6_A	$1 \le f \le 500$	0,016
7_A	$1 \le f \le 1\ 000$	0,010

[a] Calculation is based on 0,045 × 0,3 + 2 × 0,001 25, for Class E_A.

Calculation is based on 0,025 × 0,3 + 2 × 0,001 25, for Class F_A.

[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).

5.11 Transverse conversion loss (TCL)

As there is no length dependency defined for unscreened channels the 100 m value is valid also for short lengths. See ISO/IEC 11801 for values.

5.12 Equal level transverse conversion loss (ELTCTL)

As there is no length dependency defined for unscreened channels the 100 m value is valid also for short lengths. See ISO/IEC 11801 for values.

5.13 Coupling attenuation

As there is no length dependency defined for screened channels the 100 m values and conditions are valid also for short lengths. See ISO/IEC 11801 for values and additional conditions.

Annex A
(informative)

Assessment of cabling capacity for 40 Gbit/s

A.1 Overview

This annex describes Shannon capacity and margin using the cabling transmission characteristics described in this technical report. The annex also provides results for Shannon capacity and/or margin as criteria for assessing the suitability of such channels for 40GBASE-T. The assessment of support is not intended as a definition of 40GBASE-T, but as a report to assist the development of structured cabling systems.

Three cases are presented:

a) Case 1: Fixed cancellation values; the cancellation assumes values used in 10GBASE-T, they are guideline assumptions:
   – NEXT cancellation 40 dB
   – FEXT cancellation 25 dB
   – RI (Echo) cancellation 55 dB
   – Background noise –150 dBm/Hz
   – Transmit power 3 dBm
   – Power sum alien crosstalk cannot be cancelled and it is therefore assumed that it can be neglected.
b) Case 2: Variable cancellation values; the cancellation assumes:
   – NEXT cancellation to be defined dB[a]
   – FEXT cancellation to be defined dB[a]
   – RI (Echo) cancellation to be defined dB[a]
   – Background noise –150 dBm/Hz
   – Transmit power 3 dBm
   – Power sum alien crosstalk cannot be cancelled and it is therefore assumed that it can be neglected.
c) Case 3: As case 2 but including power sum alien crosstalk

[a] The cabling noise is cancelled below electronic background noise.

The set up for the 3 cases are:

1) Top: Maximum frequency, cancellation levels, background noise (BN(1)) and transmit power used for the calculation of the following graphs.
2) Upper left graph: Capacity in Gbit/s over length in m.
3) Upper right graph: Margin in dB over length in m. The margin is the sum of code and implementation margin (see A.5.2).
4) Centre: Capacity and margin values at a length of 30 m, or at the length (*L*) indicated.
5) Lower left graph: Signal and power sum of all noise sources over frequency in MHz for a length of 30 m (see A.5.10).The signal, PSACR-F and PSAACR-F are length dependent.
6) Lower right graph: As above, but showing the individual power sum noise sources used in the calculation.

A.2 Channels Class I and Class II (Clause 4)

A.2.1 General

In Table A.1 and Table A.2 the assumed compensation levels are given for Class I and Class II for different system frequencies. In the following clauses only the 1 600 MHz case is shown in figures. The 1 200 MHz and the 2 000 MHz cases were calculated and inserted in the tables. For 2 000 MHz the (ffs) formulas from Clause 4 were used.

The Shannon and margin figures deviate from a straight line because

a) at short length PSFEXT increases and cancellation is kept constant,

b) at longer lengths attenuation gets high and crosses noise.

The alien crosstalk limits can be established but were set to be negligible (see Case 3).

A.2.2 Results

Table A.1 – Cancellation levels at 30 m channel length, Case 1: Fixed cancellation values

Parameter	Class I			Class II		
Maximum frequency in GHz	1,2	1,6	2,0	1,2	1,6	2,0
Background noise level in dB	62	61	60	62	61	60
CN in dB	40	40	40	40	40	40
CF in dB	25	25	25	25	25	25
CR in dB	55	55	55	55	55	55
Comment	*FEXT limited* *NEXT limits at higher frequencies* $f > 0,6$ *GHz*			*NEXT and FEXT cancellation could be lower*		
Margin at 30 m in dB	13	14	16	20	23	23
Shannon Capacity at 30 m in Gbit/s	61	62	82	72	88	102

Table A.2 – Cancellation levels at 30 m channel length Case 2: cabling noise cancelled below background noise

Parameter	Class I			Class II		
Maximum frequency in GHz	1,2	1,6	2,0	1,2	1,6	2,0
Background noise level in dB	62	61	60	62	61	60
CN dB	47	52	55	20	28	30
CF dB	33	35	30	12	14	15
CR dB	55	55	54	55	55	53
Margin at 30 m in dB	18	21	21	18	21	22
Shannon Capacity at 30 m in Gbit/s	68	84	95	69	86	98

The margins for Class I and Class II are similar, but the cancellations needed to achieve this are much lower for Class II.

For different background noise or transmit power levels the values scale linearly.

A.2.3 Case 1

A.2.3.1 General

The cancellation levels are fixed as indicated in the introduction. It can be concluded that the cancellation levels are not optimal. For a summary, see Table A.1.

A.2.3.2 Channel Class I

Figure A.1 shows Class I Shannon capacity and margin with the assumptions mentioned in the figure.

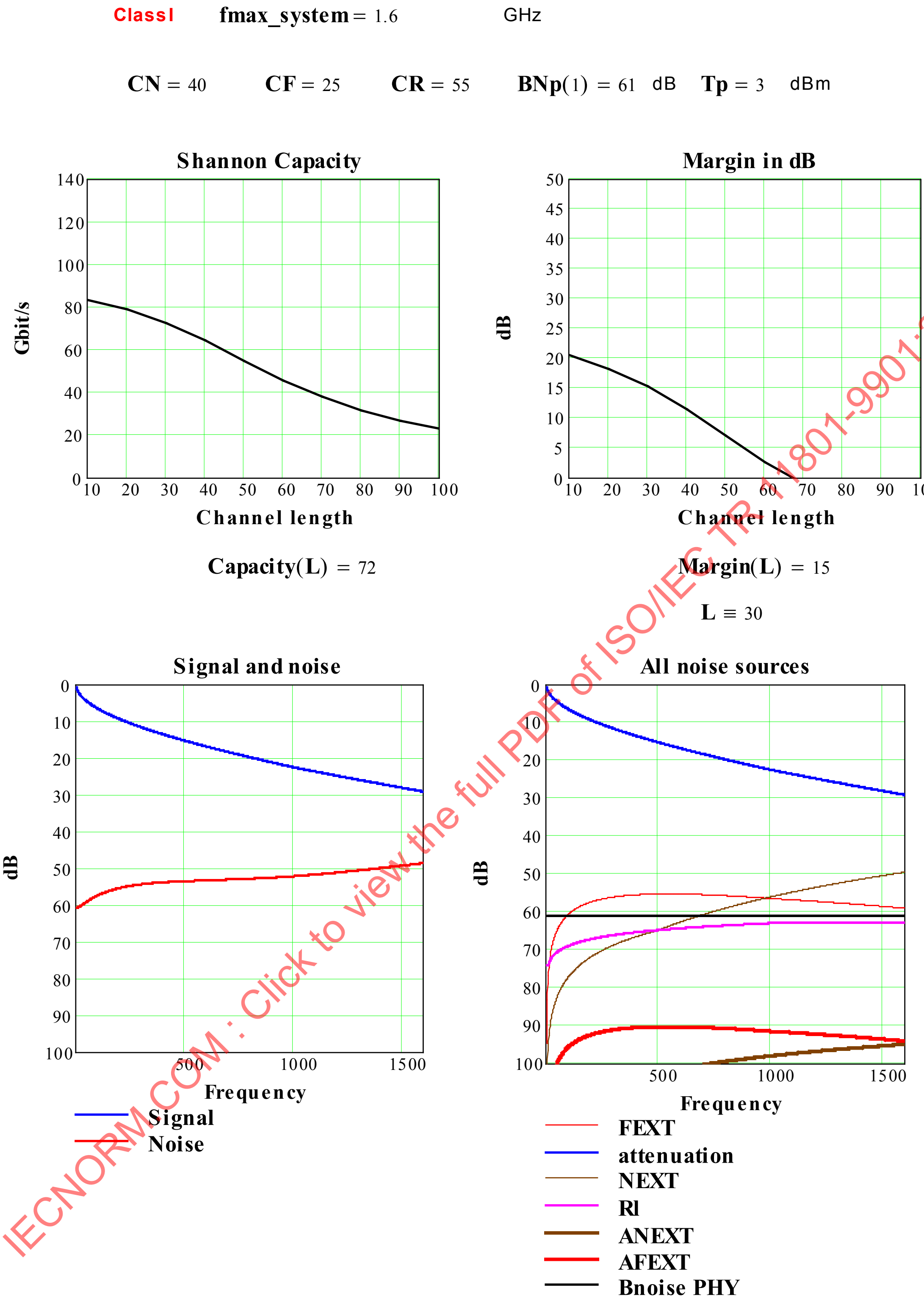


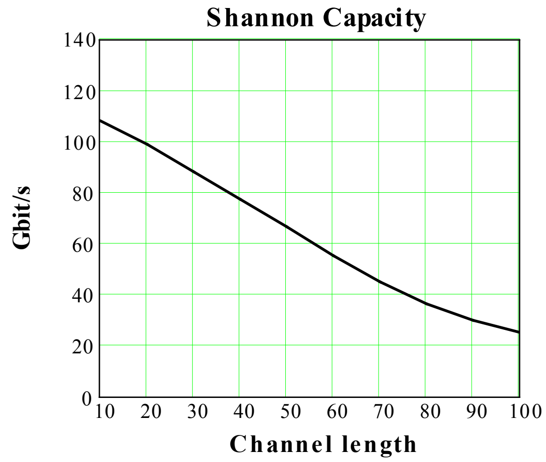
Figure A.1 – Channel Shannon capacity and margin for Class I

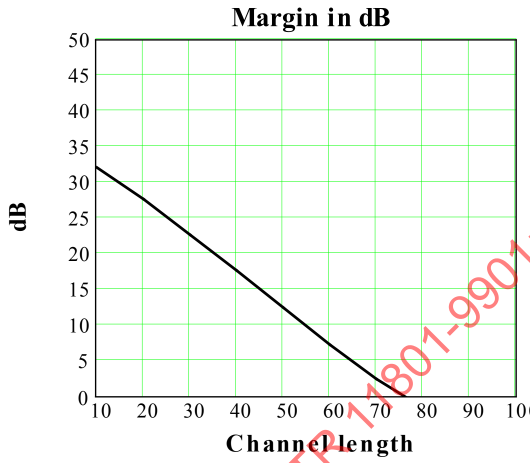
A.2.3.3 Channel Class II

Figure A.2 shows Class II Shannon capacity and margin with the assumptions mentioned in the figure.

Class II **fmax_system** = 1.6 GHz

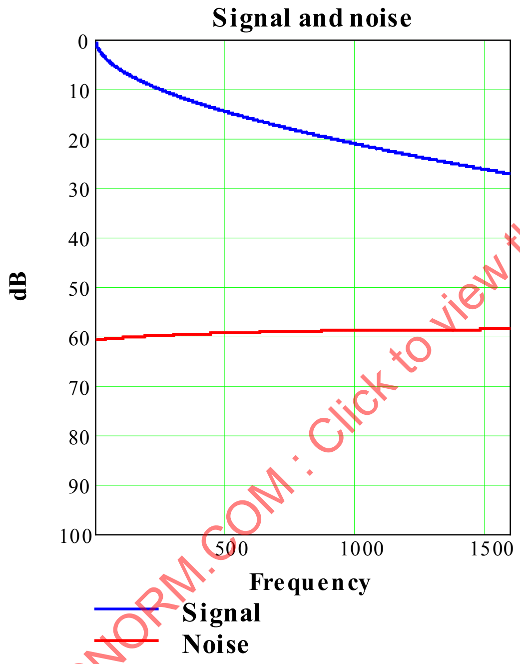
CN = 40 **CF** = 25 **CR** = 55 **BNp**(1) = 61 dB **Tp** = 3 dBm





Capacity(**L**) = 88 **Margin**(**L**) = 23

L ≡ 30



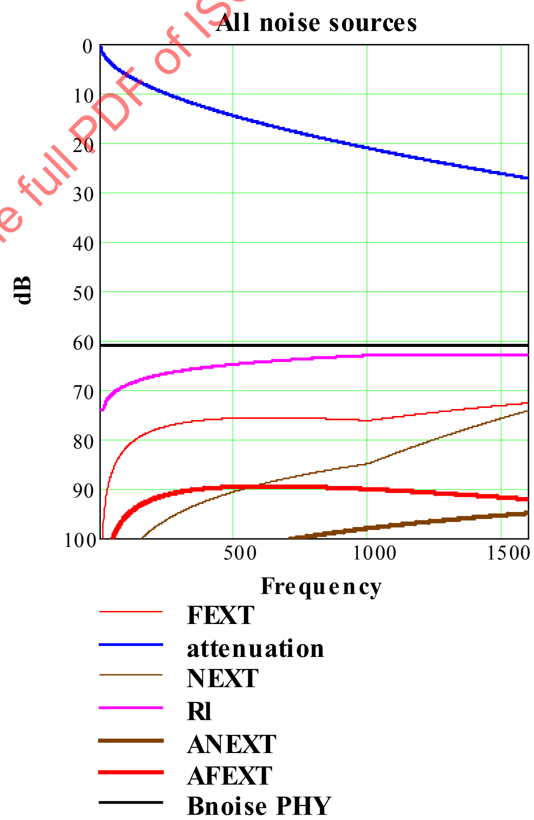


Figure A.2 – Channel Shannon capacity and margin for Class II

A.2.4 Case 2

A.2.4.1 General

The cancellation levels for the two classes are plotted for values to keep the cabling noise below the background noise level. Alien noise is assumed to be below this level. For a summary see Table A.2.

A.2.4.2 Channel Class I

Figure A.3 shows Class I Shannon capacity and margin with the assumptions mentioned in the figure.

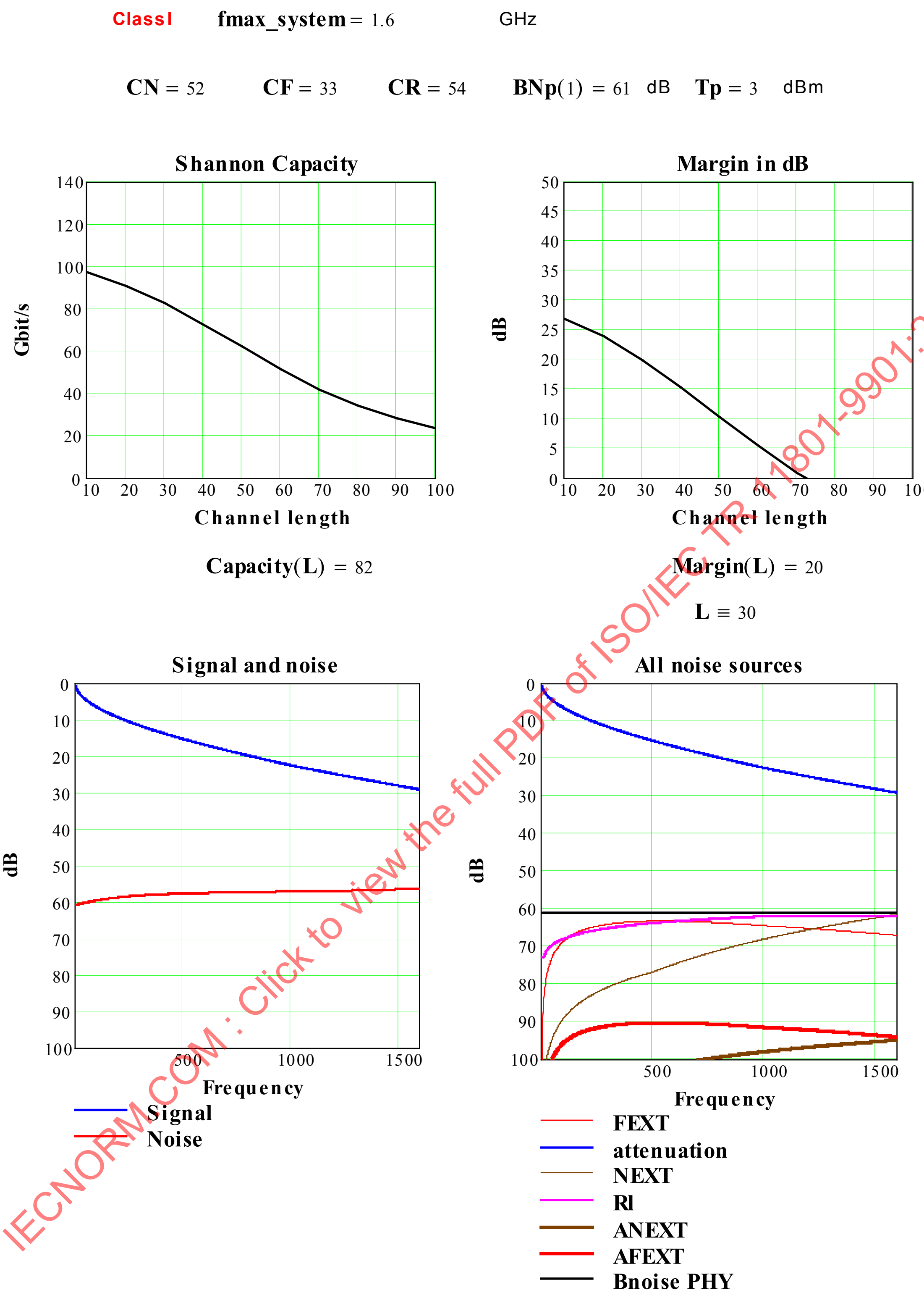


Figure A.3 – Channel Shannon capacity and margin for Class I

A.2.4.3 Channel Class II

Figure A.4 shows Class II Shannon capacity and margin with the assumptions mentioned in the figure.

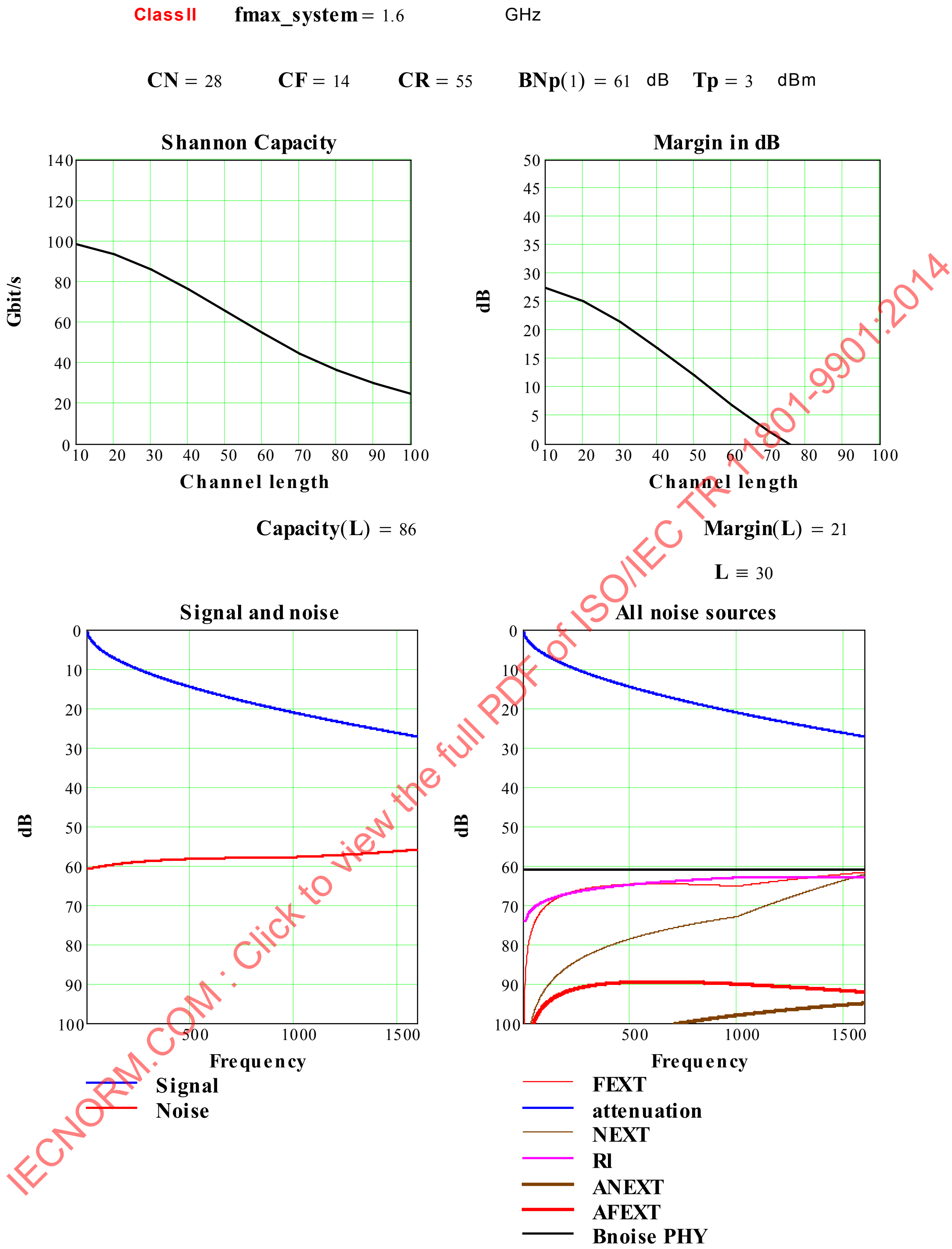


Figure A.4 – Channel Shannon capacity and margin for Class II

A.2.5 Case 3: alien crosstalk included

A.2.5.1 General

Alien noise is not sufficiently specified for the 30 m channels.

a) For a 100 m channel there exists a 100 m 6 over 1 cable measurement, set ups and connection definitions.

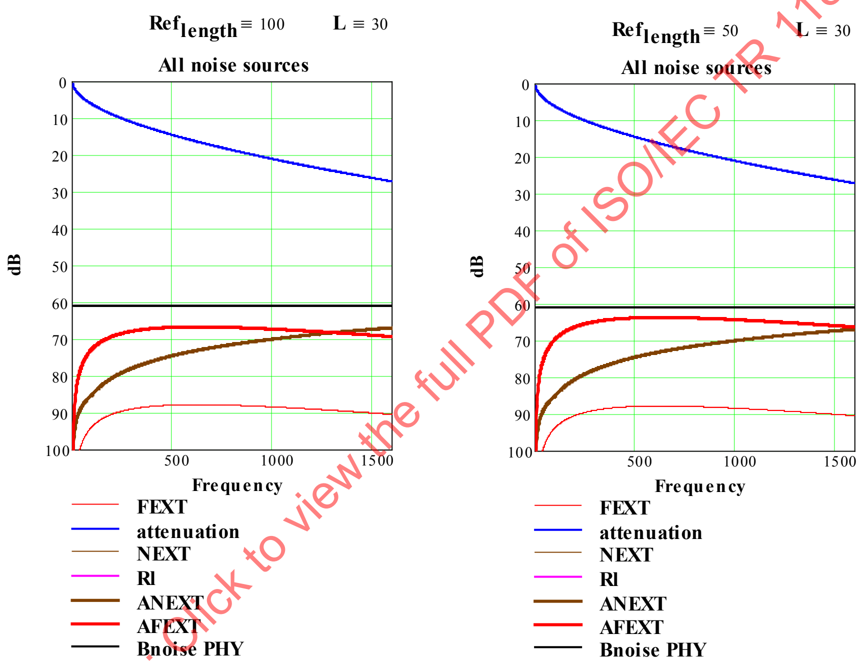
b) In ISO/IEC TR 11801-9901 it says that the 30 m channel shall comply with a formula that is also the 100 m formula.

c) IEC refers in the working draft 8.1 and 8.2 for the cable to the 100 m specification while for ACR-F it refers to 50 m.

d) It will be assumed in this clause that the reference for PS AACR-F will be like ACR-F 50 m using the formula presented in 4.7.

e) PS ANEXT is no issue because it happens in the first meters and length dependency is considered like NEXT only at low frequencies.

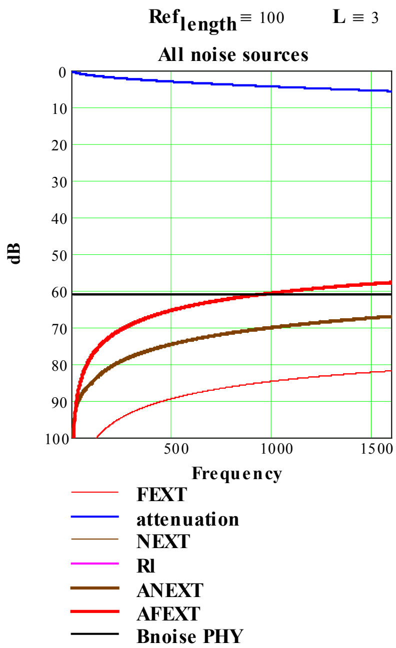
In the following Figure A.5 the influence of the PS AACR-F reference length on the 30 m channel is shown. In Figure A.6 the influence is shown on a 3 m channel.



Levels of noise in case of a short 3 m channel:

100 m reference for PS AACR-F 50 m reference for PS AACR-F

Figure A.5 – Influence of the PS AACR-F reference length on noise level on a 30 m channel



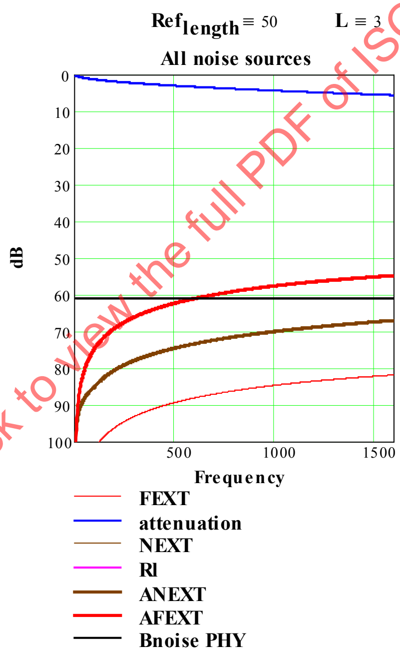


Figure A.6 – Influence of the PS AACR-F reference length on noise level on a 3 m channel

The PS AACR-F definitions for Class I and Class II (they are equal) are very stringent and they are in any case for the 30 m channel just below the background noise of −150 dBm/Hz and add only little noise to the overall noise. Also the short length issue is not as pronounced.

Therefore, only one comparison of Class II will be made to A.2.4.3 (case 2).

NOTE AACR-F limit of Class I is 24 dB higher than Class E_A or for Class II 15 dB higher than Class F_A.

A.2.5.2 Channel Class II with alien crosstalk included

Figure A.7 shows Class II Shannon capacity and margin with the assumptions mentioned in the figure with alien crosstalk included.

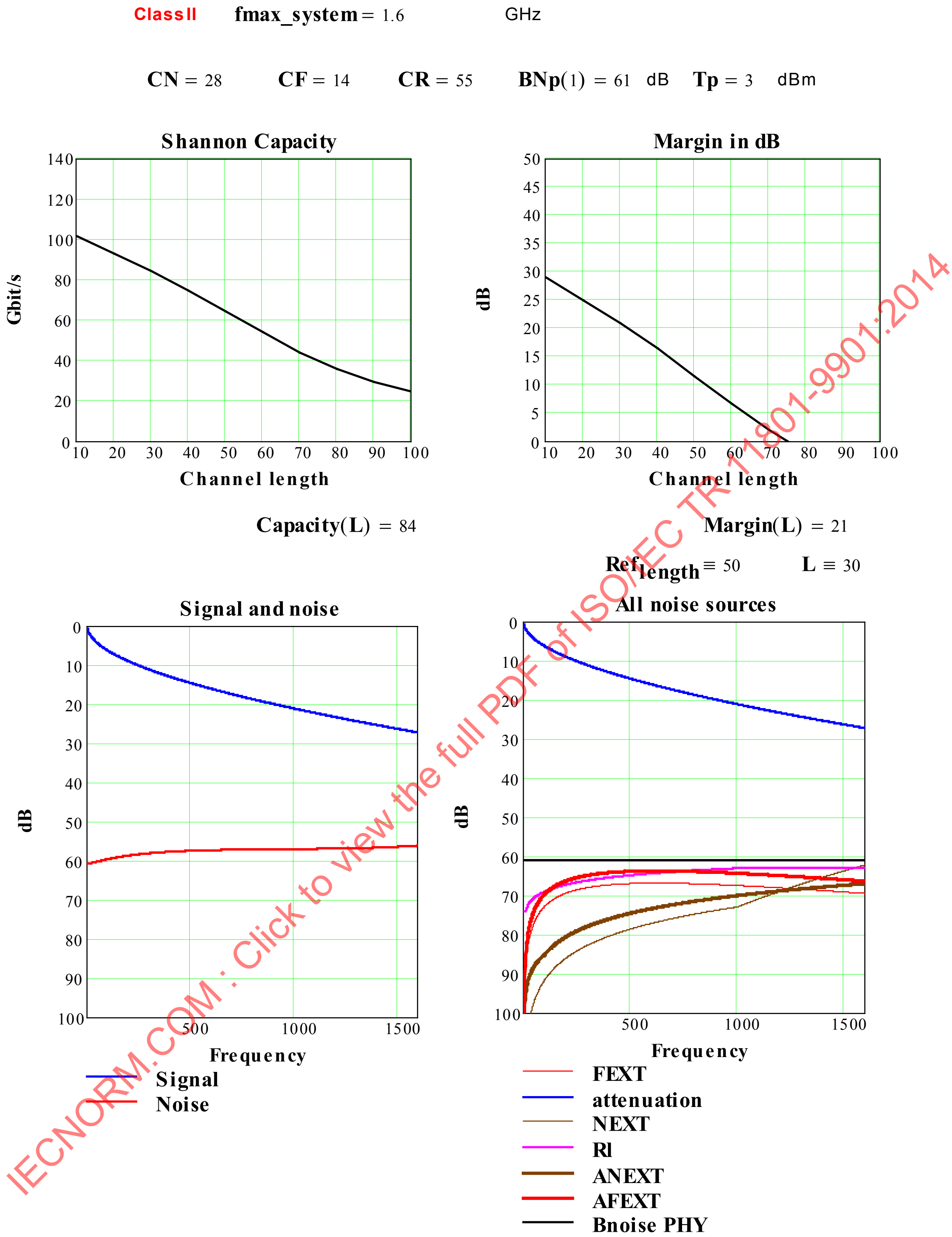


Figure A.7 – Influence of PS AACR-F on Shannon capacity and margin

There is no margin difference at 30 m (A.2.4.3). Class I results are similar compared to A.2.4.2.

For a 10 m channel there is a decrease in margin of 2 dB (not presented).

A.3 Channel requirement for Category 6_A and Category 7_A components (Clause 5)

A.3.1 Category 6_A Case 2

Figure A.8 shows Category 6_A Shannon capacity and margin with the assumptions mentioned in the figure.

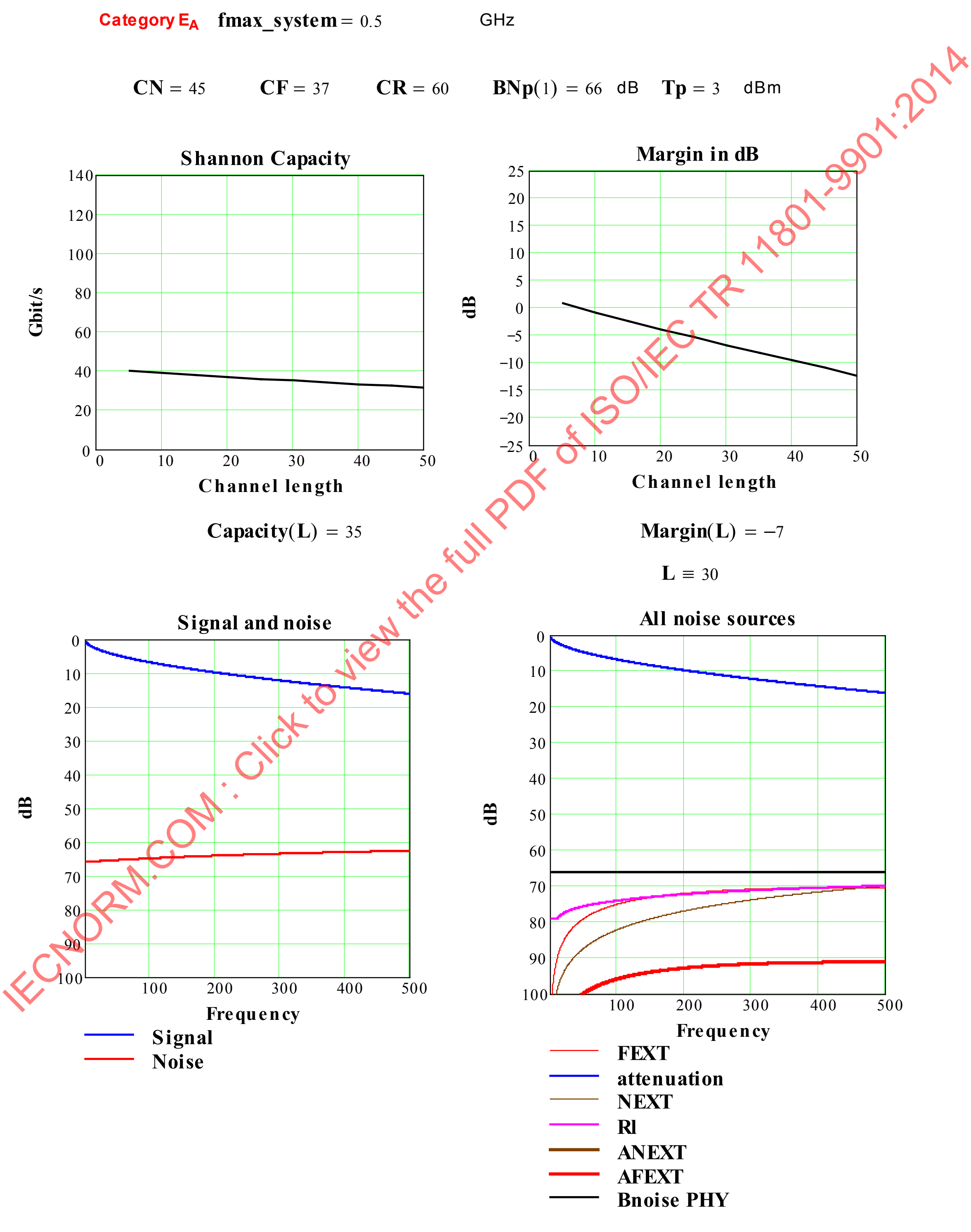


Figure A.8 – Channel Shannon capacity and margin for Category 6_A

Only case 2 with variable cancellation and neglected alien noise presented. It can be seen that 500 MHz as upper frequency is not sufficient for a 40 Gbit/s transmission. The minimum of 6 dB margin cannot be reached even for a very short length.

A.3.2 Category 7_A Case 2

Figure A.9 shows Shannon capacity and margin with the assumptions mentioned in the figure for Category 7_A.

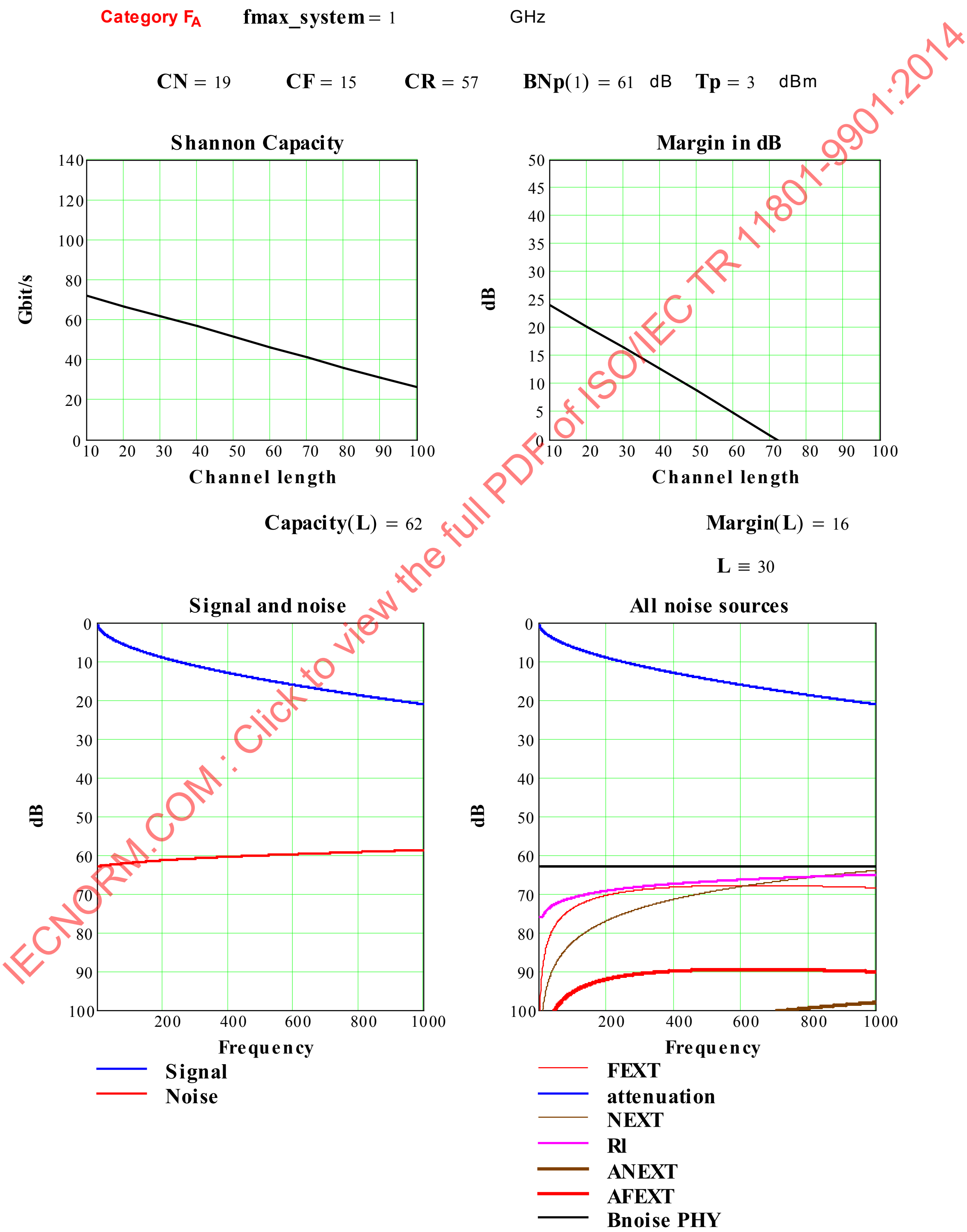


Figure A.9 – Channel Shannon capacity and margin for Category 7_A

It would be viable to consider this channel for 30 m 40 Gbit/s transmission.

A.4 Characterisation of channels using standardised components with extended frequency (Annex B)

A.4.1 General

As the cabling limits needed for calculation of capacity are very similar to Class I and Class II the results resemble the ones from Clause A.2. Therefore only some summary examples are presented.

A.4.2 CHε using the same cancellation as in A.2.4.2

The results are similar if alien noise can be neglected.

$\mathbf{fmax\_system} = 1.6$ GHz

$\mathbf{CN} = 52$ $\mathbf{CF} = 33$ $\mathbf{CR} = 54$ $\mathbf{BNp}(1) = 61$ dB $\mathbf{Tp} = 3$ dBm

$\mathbf{Capacity(L)} = 81$ in Gbit/s

$\mathbf{Margin(L)} = 19$ in dB

$\mathbf{L} \equiv 30$ in m

When including alien noise specification the margin drops drastically to not acceptable values. As a conclusion, these channels are very limited if not built with shielded materials or reducing alien noise to Class I levels by other means. See A.2.5.2 for details.

$\mathbf{fmax\_system} = 1.6$ GHz

$\mathbf{CN} = 52$ $\mathbf{CF} = 33$ $\mathbf{CR} = 54$ $\mathbf{BNp}(1) = 61$ dB $\mathbf{Tp} = 3$ dBm

$\mathbf{Capacity(L)} = 44$ in Gbit/s

$\mathbf{Margin(L)} = 2$ in dB

$\mathbf{L} \equiv 30$ in m

A.4.3 CHγ using the same cancellation as in A.2.4.3

The results are similar if alien noise can be ignored.

$\mathbf{fmax\_system} = 1.6$ GHz

$\mathbf{CN} = 28$ $\mathbf{CF} = 14$ $\mathbf{CR} = 55$ $\mathbf{BNp}(1) = 61$ dB $\mathbf{Tp} = 3$ dBm

$\mathbf{Capacity(L)} = 85$ in Gbit/s

$\mathbf{Margin(L)} = 21$ in dB

$\mathbf{L} \equiv 30$ in m

When including alien noise specification the margin drops to still usable values. The cancellation values could be reduced. See A.2.5.2 for details.

$\mathbf{fmax\_system} = 1.6$ GHz

$\mathbf{CN} = 28$ $\mathbf{CF} = 14$ $\mathbf{CR} = 55$ $\mathbf{BNp}(1) = 61$ dB $\mathbf{Tp} = 3$ dBm

$\mathbf{Capacity(L)} = 73$ in Gbit/s

$\mathbf{Margin(L)} = 15$ in dB

$\mathbf{L} \equiv 30$ in m

A.5 Excerpt of definitions and formulae used in this annex

A.5.1 Shannon capacity

$$Shannon_{\text{capacity}}(l) = 10^{-3} \int_0^{f\_\max(l)} \log_2 \left[\left(1 + \frac{Signal(f,l)}{Noise(f,l)} \right) \right] \mathrm{d}f \quad \text{GHz}$$

For the capacity calculation, Hartley's approach is used to apply Shannon's theorem.

A.5.2 Margin

The following formula provides the margin for 10 Gbit/s per pair in dB.

$$C_{\text{ReqdMargin}} = 10\,\text{Gbit/s} + \frac{BW}{3{,}01} + (Code_{\text{Margin}} + Impl_{\text{Margin}})$$

A.5.3 Transmit power

The transmit power (Tp in dBm) is the output power of the transmitter. The power spectra is assumed flat over frequency. All signal to noise values are referenced to this level (e.g. NEXT). It is assumed at the cabling input.

A.5.4 Cancellation

The cancellation levels are assumed flat over frequency up to the bandwidth considered.

- CR = Return loss (Echo) compensation in dB
- CN = NEXT loss compensation in dB,
- CF = FEXT loss compensation in dB,

Alien noise cannot be compensated because the source is not known.

A.5.5 Background noise

Noise calculated from electronc background noise from transmit power and the maximum considered frequency.

A.5.6 Bandwidth

Is the maximum frequency considered in the calculation with an ideal filter.

A.5.7 Electronic noise

Electronic noise is the noise from electronic circuitry. It excludes cabling noise.

A.5.8 Cabling noise

Single channel cabling noise is the power sum of return loss, power sum near end crosstalk and power sum far end crosstalk.

A.5.9 Signal

The signal at the cable output is the transmit power decreased by the cabling insertion loss.

A.5.10 Noise

Noise at the output of the cabling is the power sum of all noise sources (in power values not dB) referenced to the transmit power.

$$noise = \sum(all\_noisesources\_in\_power\_as\_value)$$

The individual noise sources are given below.

PSNEXT

PSFEXT

RL (only one pair)

Background noise

PS AFEXT

PS ANEXT

(even if only 2 pairs are evaluated all pair noise is included in the calculation as the power sum limits are used).