

TR-285

Broadband Copper Cable Models

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Executive Summary

This Technical Report is focused on the subject of cable models for physical layer testing of the G.fast Access Network. It provides complete cable models focusing on the frequency range extending above 30 MHz. These models are *complete*. A cable model for the Access Network is complete when it presents a precise and unambiguous specification of the network characteristics of the cable across the total extent from the Distribution Point Unit (DPU) to the Network Interface Device (NID) located at the end subscriber. The cable over this total extent is termed the *Loop End Access Network – The Final Drop*.

The intent of this Technical Report is to provide those complete models which can be referenced in Broadband Forum Working Texts/Technical Reports for interoperability and performance testing of the transmission technologies such as ITU-T G.9701 / 9700 (G.fast). A complete cable model of the Access network for G. fast provides the transfer functions of both direct path and crosstalk paths of the Loop End Access Network – The Final Drop. A complete cable model addresses both the attenuation and phase of these transfer functions.

Annexes will provide the various cable models.

Summary of changes in TR-285 Issue 2

- Updated the transfer function for the CAD55 patch cable in section A.1.1
- Updated the transfer function for the Multi Pair CAD55 cable in section A.2.1
- Added new reference cable models for Quad Cable deployed by European Operators.
 - Cable Model for PE4D-ALT 4x10x0.6 mm Quad Cable in Annex C.1.
 - Cable Model for P-Pb 4x10x0.6 mm Quad Cable in Annex C.2.
 - Crosstalk Cable Models for Swiss In-House Cables in Annex C.3.
- Added new cable and reference models for Coax Cable deployed by North American Operators in Annex D
- Added a single line TP100 model up to 212 MHz in Annex E.
- Added cable models for Twisted Pair TP100 and QUAD TP100 in Annex E.
- Added a 24AWG Twisted Pair cable Model as Annex F.

Purpose and Scope

Purpose

The purpose of this Technical Report is to support the development of testing capabilities at frequencies above 30 MHz by providing detailed models of copper cables. This work complements emerging specifications for G.fast access technology and FTTdp transmission deployments.

Scope

This Technical Report focuses on the subject of modeling copper cables at frequencies above 30 MHz. This Technical Report provides models that can be used in Broadband Forum specifications for testing of G.fast implementations.

These models include the single line parameters, the transfer function of the direct path, the transfer function of the FEXT coupling, and the input impedance of the line.

This Technical Report addresses the cable that extends from the Distribution Point (DP) to the Network Interface Device (NID) at the Customer Premises.

References and Terminology

Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found in RFC 2119 [1].

- SHALL** This word, or the term “REQUIRED”, means that the definition is an absolute requirement of the specification.
- SHALL NOT** This phrase means that the definition is an absolute prohibition of the specification.
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- MAY** This word, or the term “OPTIONAL”, means that this item is one of an allowed set of alternatives. An implementation that does not include this option **MUST** be prepared to inter-operate with another implementation that does include the option.

References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.

A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

	Document	Title	Source	Year
[1]	RFC 2119	Key words for use in RFCs to indicate Requirement Levels [2]	BBF	1997
[2]	ATIS-0600024	Multiple-Input Multiple Output Crosstalk Channel Model	ATIS	2009
[3]	ITU-T G.9701	Telecommunications Standardization Draft Recommendation Study Group 15 TD 159 Rev, 2 (PLEN/15) Fast Access to Subscriber Terminals (FAST) – Physical layer specifications.	ITU-T	2014
[4]	ITU-T G.993.2	Very high-speed digital subscriber line transceivers 2 (VDSL2)	ITU-T	2006
[5]	ETSI TS 101 271, V1.2.1	Access Terminals Transmission and Multiplexing (ATTM); Access transmission system on metallic pairs. Very High-Speed digital subscriber line systems. (VDSL2)	ETSI	Jan. 2013
[6]	Jon Freeman	Fundamentals of Microwave Transmission Lines	Wiley-Interscience	1996
[7]	David Large, James Farmer	Broadband Cable Access Networks – Chapter 2	Morgan Kaufmann	2009

Definitions

The following terminology is used throughout this Technical Report.

$H_{ij\text{FX-LTI}}(f,d)$ Linear Time Invariant CAD55 Crosstalk Transfer Function from loop i to j

$H_{ij\text{FX T-V}}(f,d)$ Linear Time Varying CAD55 Crosstalk Function from loop i to j

Abbreviations

This Technical Report uses the following abbreviations:

ATIS	Alliance for Telecommunications Industry Standards
CPE	Customer Premises Equipment
Diplexer	A two port to one port multiplexer
DMT	Discrete Multi-Tone
DP	Distribution Point
DPU	Distribution Point Unit
ELFEXT	Equal Level Far End Crosstalk
ETSI	European Telecommunications Standards Institute
FEXT	Far End Crosstalk
FTTB	Fiber to The Building
FTU-O	FTU at the Optical Network Unit (i.e., operator end of the loop)
FTU-R	FTU at the Remote site (i.e., subscriber end of the loop)
IL	Insertion Loss
ITU-T	International Telecommunications Union Telecommunications Standardization Sector
MAE	Mean Absolute Error
MDU	Multi Dwelling Unit
MIMO	Multiple-Input Multiple-Output
NID	Network Interface Device
NT_c	Network Termination Customer Premises
q-MIMO	Quad Multiple-Input Multiple-Output
RG-x	Radio Guide – Standard Coaxial Cable designations
TR	Technical Report

Technical Report Impact

Energy Efficiency

TR-285 has no impact on energy efficiency.

IPv6

TR-285 has no impact on IPv6.

Security

TR-285 has no impact on security.

Privacy

Any issues regarding privacy are not affected by TR-285.

Physical Layer Topology

Overview of the Loop End Access Network

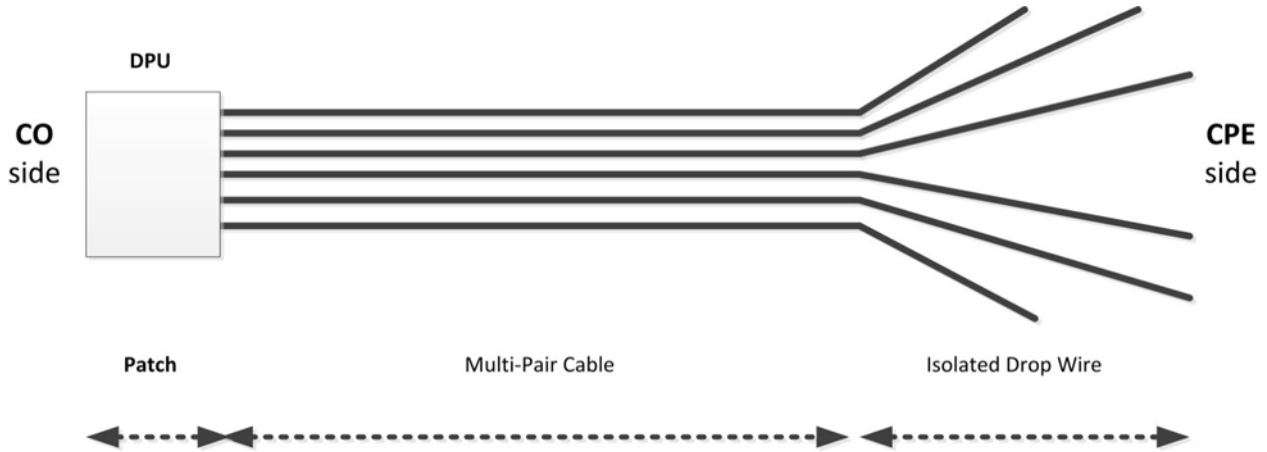


Figure 1 - Overview of the Loop End Access Network – The Final Drop

The Loop End Access Network – The Final Drop as shown in Figure 1 is consistent with the G.fast environment.

The Loop End Access Network - The Final Drop illustrated in Figure 1 is a cascade of 3 individual segments or sections. These are the 1) Patch 2) Multi-Pair Cable and 3) Isolated Drop Wire. The “Patch” is the wiring of the loop which physically resides in the DP. In the context of G.fast this is where the DPU, is located. It is short fractions of a meter and can be usually considered as jumper cable with a “reasonable” twist. The “Multi-Pair Cable” is a path which is part of the general distribution network and is physically close to other paths of other loops – each of which is connected to a different Customer Premise. It may be realized by the usual candidates for twisted pair cable used in distribution networks. The “Isolated Drop Wire” represents the individual subscriber drop wires. It may be realized by different wire types in different installations. The cascade of all three segments determines the overall end-to-end loop attenuation, phase/group delay and impedance. However, as well indicated by the topology illustrated in Figure 1 the FEXT coupling only occurs on the overlap or exposure length of the Patch and Multi-Pair Cable.

An efficient taxonomy of the various complete cable models corresponding to the topology of Figure 1 is to base it upon the different wire types used to realize the cascade of segments. The various complete cable models corresponding to this organizing approach are provided in the Annexes.

In carrying out the modeling, consideration was given to the complexity of the instrumentation / facilities, since the models will ultimately be used for performance testing.

Annex A: CAD55 Cable Model

This cable model uses CAD55 wire for each of the three segments, the Patch, the Multi-Pair Cable and the Isolated Drop Wire. It is based upon work carried out in ITU-T. The model presented only applies to the spectral region from 30 MHz to 106 MHz and this is a natural extension of the known behavior of this model below 30 MHz. There are several reasons for it focusing on the spectral region from 30 MHz to 106 MHz. While it may ultimately reach 212 MHz the G.fast application is initially expected to extend, in the near and medium term only to 106 MHz. Significant experimental work has been carried out and is available to guide the modeling in the spectral region up to 106 MHz.

Consequently, the CAD55 model is based upon a firm foundation of actual measurements.

Corresponding measurements beyond 106 MHz are very sparse.

A.1 Patch

A.1.1 Transfer Function

The transfer function for the Patch will be based upon the distributed transmission line parameters, $Z_s(j\omega)$ and $Y_p(j\omega)$. Additional values needed to derive these parameters for CAD55 are given in Table 1 obtained from [3]. Here, $\omega = 2\pi f$. The equations for $Z_s(j\omega)$ and $Y_p(j\omega)$ are given for convenience in Table 2.

Table 1 - Wire type used for modeling

Cable Type	Parameters
(CAD55)	$Z_{0\infty} = 105.0694$ $\eta_{VF} = 0.6976$ $R_{s0} = 0.1871$ $q_L = 1.5315$ $q_H = 0.7415$ $q_x = 1$ $q_y = 0$ $q_c = 1.0016$ $\phi = -0.2356$ $f_d = 1.000000$

Table 2 - Parameterized model for CAD55

$$[Z_s, Y_p] = Model (Z_{0\infty}, \eta_{VF}, R_{s0}, q_L, q_H, q_c, q_x, q_y, \phi, f_d)$$

$Z_s(j\omega) = j\omega \cdot L_{s\infty} + R_{s0} \times \left(1 - q_s \cdot q_x + \text{sqrt} \left(q_s^2 \cdot q_x^2 + 2 \cdot \frac{j\omega}{\omega_s} \cdot \left(\frac{q_s^2 + j\omega / \omega_s \cdot q_y}{q_s^2 / q_x + j\omega / \omega_s \cdot q_y} \right) \right) \right)$ $Y_p(j\omega) = j\omega \cdot C_{p0} \times (1 - q_c) \times \left(1 + \frac{j\omega}{\omega_d} \right)^{-2 \cdot \phi / \pi} + j\omega \cdot C_{p0} \times q_c$	
$L_{s\infty} = \frac{1}{\eta_{VF} \cdot c_0} \times Z_{0\infty}$ $C_{p0} = \frac{1}{\eta_{VF} \cdot c_0} \times \frac{1}{Z_{0\infty}}$ $q_s = \frac{1}{q_H^2 \cdot q_L}$ $\omega_s = q_H^2 \cdot \omega_{s0} = q_H^2 \cdot \left(\frac{4\pi \cdot R_{s0}}{\mu_0} \right)$ $\omega_d = 2\pi \cdot f_d$	$c_0 = 3 \cdot 10^8 \text{ [m/s]}$ $\mu_0 = 4\pi \cdot 10^{-7} \text{ [H/m]}.$

For purposes of modeling and precise implementation of models the length of the Patch Section is a constant value of 0.6 m.

From these distributed transmission line parameters, $Z_s(j\omega)$ and $Y_p(j\omega)$, the model of the transfer function of the Patch Section direct path is obtained in the following way:

Use the nomenclature:

- Patch Section length = “ d_p ”
- Source impedance = “ Z_{soP} ”
- Load impedance of “ Z_{LP} ”

Compute

$$\gamma = \alpha + j\beta = [Z_s(j\omega) Y_p(j\omega)]^{0.5}$$

$$Z_0 = [Z_s(j\omega) / Y_p(j\omega)]^{0.5}$$

The Patch Section transfer function, “ H_p ,” is then given by the following equation:

$$H_p = 2 * [Z_{inP} / (Z_{inP} + Z_{soP})] T_p$$

NOTE – The Isolated Drop Wire transfer function definition is associated with a two-port network, normalized to the reference load impedance Z_{LW} (see clause 11.4.1.1.1 of [ITU-T G.993.2]). The formula assumes that Z_{LW} and Z_{soW} are equal.

Here:

$$T_P = [\cosh(\gamma d_P) + (Z_0 / Z_{LP}) \sinh(\gamma d_P)]^{-1}$$

Z_{inP} = The Input Impedance of the Patch Section– which follows in Section A.1.2.

The magnitude of “ T_P ” given by $|T_P|$ gives the “attenuation” of the direct path. The phase of “ T_P ” gives the “phase” of the direct path. The derivative of the phase with respect to frequency can be used to obtain the delay.

“ Z_{soP} ” and “ Z_{LP} ” are specified at 100 Ohms resistive. These values are standard industry practice and correspond to the characteristic impedance of the actual patch cables (as well as terminations used within modems).

A.1.2 Impedance

The input impedance will be based upon the distributed transmission line parameters, $Z_s(j\omega)$ and $Y_p(j\omega)$ which can be obtained for CAD55 by using Table 1. Here, $\omega = 2\pi f$. The equations for these parameters as provided are given for convenience in Table 2.

Also, as with the transfer function the length of the Patch Section will be taken as a constant value of 0.6 m.

From these distributed transmission line parameters, the model of the input impedance of the Patch Section is obtained in the following way:

Again, use the nomenclature:

Patch Section length = “ d_P ”
 Source impedance = “ Z_{soP} ”
 Load impedance of “ Z_{LP} ”

Compute

$$\gamma = \alpha + j\beta = [Z_s(j\omega) Y_p(j\omega)]^{0.5}$$

$$Z_0 = [Z_s(j\omega) / Y_p(j\omega)]^{0.5}$$

The input impedance of the Patch Section, “ Z_{in} ,” is then given by the following equation:

$$Z_{inP} = Z_0 [(Z_{LP} + Z_0 \tanh(\gamma d_P))] / [(Z_0 + Z_{LP} \tanh(\gamma d_P))]$$

“ Z_{LP} ” is specified at 100 Ohms resistive.

A.1.3 FEXT

There is FEXT over this segment. However, the segment is short, 0.6 m. Furthermore, the same wire type, CAD55 is taken for this segment and the Multi-Pair Cable Segment. So, the FEXT over this segment will be dealt with by increasing the exposure length of the Multi-Pair Cable segment by 0.6 m.

A.2 Multi-Pair Cable

A.2.1 Transfer Function

The transfer function for the Multi-Pair Cable will be based upon the distributed transmission line parameters, $Z_s(j\omega)$ and $Y_p(j\omega)$. Additional values needed to derive these parameters for CAD55 are given in Table 1. Here, $\omega = 2\pi f$. The equations for these parameters as provided are given for convenience in Table 2.

By way of example the length of the Multi-Pair Cable Section can be considering as varying from 10's of meters to more than 100 meters. However, this also should be considered as possibly zero length.

From these distributed transmission line parameters, $Z_s(j\omega)$ and $Y_p(j\omega)$, the model of transfer function of the Multi-Pair Cable direct path can be obtained in the following way:

Use the nomenclature:

Multi-Pair Cable Section length = " d_D "
 Source impedance = " Z_{soD} "
 Load impedance of " Z_{LD} "

Compute

$$\gamma = \alpha + j\beta = [Z_s(j\omega) Y_p(j\omega)]^{0.5}$$

$$Z_0 = [Z_s(j\omega) / Y_p(j\omega)]^{0.5}$$

The Multi-Pair Cable transfer function, " H_D ," is then given by the following equation

$$H_D = 2 * [Z_{inD} / (Z_{inD} + Z_{soD})] T_D$$

NOTE – The Isolated Drop Wire transfer function definition is associated with a two-port network, normalized to the reference load impedance Z_{LW} (see clause 11.4.1.1.1 of [ITU-T G.993.2]). The formula assumes that Z_{LW} and Z_{soW} are equal.

Here:

$$T_D = [\cosh(\gamma d_D) + (Z_0 / Z_{LD}) \sinh(\gamma d_D)]^{-1}$$

Z_{inD} = The Input Impedance of the Multi-Pair Cable– which follows in Section A.2.2

The magnitude of “ T_D ” given by $|T_D|$ gives the “attenuation” of the direct path. The phase of “ T_D ” gives the “phase” of the direct path. The derivative of the phase with respect to frequency can be used to obtain the delay.

A.2.2 Impedance

This will be based upon the distributed transmission line parameters, $Z_s(j\omega)$ and $Y_p(j\omega)$. Additional values needed to derive these parameters for CAD55 are given in Table 1. Here, $\omega = 2\pi f$. The equations for these parameters are given for convenience in Table 2.

By the way of example, the length of the Multi-Pair Cable can be considering as varying from 10’s of meters to more than 100 meters.

From these distributed transmission line parameters, the model of the input impedance of the Multi-Pair Cable is obtained in the following way:

Again, use the nomenclature:

Multi-Pair Cable Section length = “ d_D ”
 Source impedance = “ Z_{soD} ”
 Load impedance of “ Z_{LD} ”

Compute

$$\gamma = \alpha + j\beta = [Z_s(j\omega) Y_p(j\omega)]^{0.5}$$

$$Z_0 = [Z_s(j\omega) / Y_p(j\omega)]^{0.5}$$

The input impedance of the Multi-Pair Cable, “ Z_{in} ”, is then given by the following equation:

$$Z_{inD} = Z_0 [(Z_{LD} + Z_0 \tanh(\gamma d_D))] / [(Z_0 + Z_{LD} \tanh(\gamma d_D))]$$

“ Z_{LD} ” is specified at 100 Ohms resistive.

This value corresponds to the asymptotic impedance of the distribution wiring and is also standard industry practice as it corresponds to modem terminations.

A.2.3 FEXT

In dealing with FEXT, account must be taken of two salient characteristics noted in the experimental observations of the G.fast environment, the Dual Slope Effect and the Time Variation Effect. Furthermore, the Time Variation Effect may not always be present.

A.2.3.1 Dual Slope Effect

This FEXT transfer function between two paths “i” and “j” and where the signal generating the FEXT comes from path “i.” It will be taken as:

$$H_{ijFX-LTI}(f,d) = [K_{FEXT}] [\sqrt{L}] [A(f)] [10^{\theta_{ij}/20}] | H(f,d) | [e^{-j\Psi_{ij}}] \quad (1)$$

Relative to equation (1)

$$K_{\text{FEXT}} = 1.594 \times 10^{-10} \text{ when lengths are in meters}$$

“d” is the total length of all of the 3 segments that the FEXT generating signal traverses.

“L” is the exposure length, the minimum of the 2 path lengths. As FEXT is only generated by coupling over the Multi-Pair Cable it is only this overlap corresponding to the 2 paths that enters the equation.

“ θ_{ij} ” is called the “Amplitude Offset Factor” and is given in dB.

“ Ψ_{ij} ” is the phase of the transfer function. For purposes of simplification in the model, it may be considered equal to 0, which will have minimal impact on the generality of this model.

The term, $|H(f,d)|$, provides the attenuation across the three segments that the FEXT signal traverses.

The corresponding Amplitude Offset Factor is given by the 24 X 24 matrix provided in Table 3 and Table 4. In whatever manner this model is realized the FEXT transfer function SHALL accurately correspond to this same 24 X 24 submatrix.

The term “A(f)” in equation (1) addresses the requirement to model the Dual Slope Effect.

A (f) is given by the following equation which is more precisely and conveniently defined using “dB” representation:

$$[A(f)]_{\text{dB}} = 20 \text{ Log}[f]; f \leq 75 \text{ MHz} - \text{ “lower slope straight line in [Log (f)]”}$$

$$[A(f)]_{\text{dB}} = -157.4 + 40 \text{ Log} [f]; f > 75 \text{ MHz} - \text{ “higher slope straight line in [Log (f)]”}$$

The equation for the region of $f \leq 75$ MHz was specifically chosen so as to be consistent with investigations carried out to date.

Figure 2 provides an illustration of the model of the Dual Slope Effect presented by the above equations.

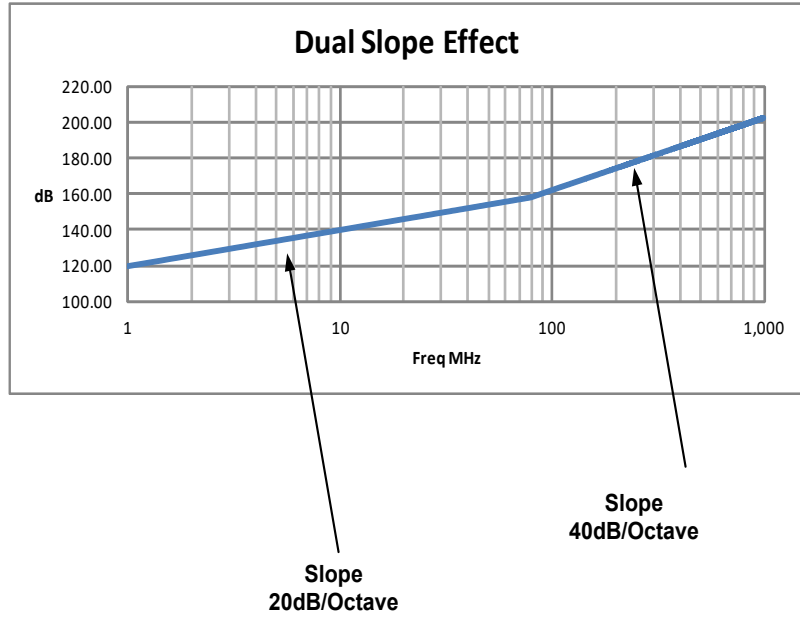


Figure 2 - Illustration of the Dual Slope Effect

Table 3 - Amplitude Offset matrix; Pairs 1-24 x 1-12

	PAIR											
PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	NA	-17.31265	-14.9461	-15.84765	-13.3471	2.723	-13.0652	-15.0038	-28.19565	-6.1845	-11.3075	-11.3746
2	-17.31265	NA	-8.0286	-24.6118	-15.2244	-8.62275	-22.1296	-13.1816	-14.7243	-13.44415	-18.5443	-15.4273
3	-14.9461	-8.0286	NA	-13.0938	-11.2835	-6.212	-5.63245	-18.9845	-13.0974	-22.09845	-25.6328	-9.56635
4	-15.84765	-24.6118	-13.0938	NA	-16.274	-38.32415	-3.31125	-9.63	-29.84665	-22.37315	-5.3606	-11.65035
5	-13.3471	-15.2244	-11.2835	-16.274	NA	-14.02725	-7.5534	-17.4449	-17.60485	-13.25325	-8.43375	-23.29085
6	2.723	-8.62275	-6.212	-38.32415	-14.02725	NA	-26.7482	-19.91025	-11.22645	-15.84095	-12.3096	-11.15845
7	-13.0652	-22.1296	-5.63245	-3.31125	-7.5534	-26.7482	NA	-18.53805	-9.93615	-20.955	-15.09025	-9.85215
8	-15.0038	-13.1816	-18.9845	-9.63	-17.4449	-19.91025	-18.53805	NA	-16.13495	-21.84445	-5.9776	-26.14815
9	-28.19565	-14.7243	-13.0974	-29.84665	-17.60485	-11.22645	-9.93615	-16.13495	NA	-11.1622	-19.4281	-13.4344
10	-6.1845	-13.44415	-22.09845	-22.37315	-13.25325	-15.84095	-20.955	-21.84445	-11.1622	NA	-28.26175	-11.4845
11	-11.3075	-18.5443	-25.6328	-5.3606	-8.43375	-12.3096	-15.09025	-5.9776	-19.4281	-28.26175	NA	-20.8765
12	-11.3746	-15.4273	-9.56635	-11.65035	-23.29085	-11.15845	-9.85215	-26.14815	-13.4344	-11.4845	-20.8765	NA
13	-28.53535	-29.96765	-14.3917	-34.3724	-7.84855	-4.04895	-19.7909	-11.4549	-11.2789	-21.8149	-25.81155	-15.59565
14	-10.7234	-9.56285	-13.9757	-21.65435	-23.16935	-22.31825	-15.84415	-21.14595	-2.66265	-37.14705	-3.5382	-11.00085
15	-21.6676	-5.42805	-16.9957	-20.3793	-21.04625	-9.5852	-10.6836	-8.6874	-3.8091	-12.9687	-16.124	-8.96255
16	-4.6259	-16.19075	-15.53095	-21.66025	-15.9353	-25.75635	-18.42095	-13.56225	-5.0706	-13.6933	-5.97635	-13.2371
17	-21.16065	-6.1035	-29.3948	-14.9075	-27.6398	-17.4027	-13.84365	-0.09865	3.76715	-10.8099	-19.03525	-19.9293
18	-17.33905	-24.67215	-6.1154	-4.4703	-14.91315	-24.37995	-19.04875	-20.9582	-17.9909	-0.23475	-8.0264	-6.46965
19	-7.93135	-25.12665	-24.49455	-26.13685	-3.0255	-20.76555	-11.43335	-12.8043	-5.42685	-9.4188	-7.96445	-7.8781
20	-26.52515	-27.85225	-11.60245	-10.706	-8.3687	-20.82455	-15.7878	-28.116	-11.7269	-5.3491	-26.1619	-27.75305
21	-2.27785	-9.47075	-9.5735	-25.99645	-8.2402	-21.31865	-8.5485	-4.30235	-25.16555	-29.1577	-21.7178	-24.8707
22	-4.913	-21.16665	-4.9409	1.6418	-11.35055	-17.43955	-22.915	-35.2763	-18.55295	-8.52	-16.0737	-19.20825
23	-14.449	-21.0245	-16.47175	-24.882	-15.51865	-8.8542	-13.3066	-4.0971	-13.607	-20.15235	-12.51735	-14.39285
24	-19.74	-6.60365	-9.2926	-22.57925	-6.35715	-18.20445	-13.8568	-14.11105	-22.31145	-13.72325	-23.53785	-14.0074

Table 4 - Amplitude Offset matrix; Pairs 1-24 x 13-24

	PAIR											
PAIR	13	14	15	16	17	18	19	20	21	22	23	24
1	-28.53535	-10.7234	-21.6676	-4.6259	-21.16065	-17.33905	-7.93135	-26.52515	-2.27785	-4.913	-14.449	-19.74
2	-29.96765	-9.56285	-5.42805	-16.19075	-6.1035	-24.67215	-25.12665	-27.85225	-9.47075	-21.16665	-21.0245	-6.60365
3	-14.3917	-13.9757	-16.9957	-15.53095	-29.3948	-6.1154	-24.49455	-11.60245	-9.5735	-4.9409	-16.47175	-9.2926
4	-34.3724	-21.65435	-20.3793	-21.66025	-14.9075	-4.4703	-26.13685	-10.706	-25.99645	1.6418	-24.882	-22.57925
5	-7.84855	-23.16935	-21.04625	-15.9353	-27.6398	-14.91315	-3.0255	-8.3687	-8.2402	-11.35055	-15.51865	-6.35715
6	-4.04895	-22.31825	-9.5852	-25.75635	-17.4027	-24.37995	-20.76555	-20.82455	-21.31865	-17.43955	-8.8542	-18.20445
7	-19.7909	-15.84415	-10.6836	-18.42095	-13.84365	-19.04875	-11.43335	-15.7878	-8.5485	-22.915	-13.3066	-13.8568
8	-11.4549	-21.14595	-8.6874	-13.56225	-0.09865	-20.9582	-12.8043	-28.116	-4.30235	-35.2763	-4.0971	-14.11105
9	-11.2789	-2.66265	-3.8091	-5.0706	3.76715	-17.9909	-5.42685	-11.7269	-25.16555	-18.55295	-13.607	-22.31145
10	-21.8149	-37.14705	-12.9687	-13.6933	-10.8099	-0.23475	-9.4188	-5.3491	-29.1577	-8.52	-20.15235	-13.72325
11	-25.81155	-3.5382	-16.124	-5.97635	-19.03525	-8.0264	-7.96445	-26.1619	-21.7178	-16.0737	-12.51735	-23.53785
12	-15.59565	-11.00085	-8.96255	-13.2371	-19.9293	-6.46965	-7.8781	-27.75305	-24.8707	-19.20825	-14.39285	-14.0074
13	NA	-29.06075	-10.88475	-21.0529	-17.9212	-24.418	-22.5741	-22.67335	-16.28415	-4.45135	-8.8703	-8.63295
14	-29.06075	NA	-14.2385	-25.5091	-13.06115	-20.0781	-14.64465	-15.1628	-15.0915	-28.36955	-6.5151	-16.5484
15	-10.88475	-14.2385	NA	-16.4476	-24.8574	-2.21745	-15.52375	-15.0098	-4.31375	-19.3664	-19.01425	-10.9133
16	-21.0529	-25.5091	-16.4476	NA	-15.92145	-27.01695	-19.52455	-14.55545	-3.9918	-13.43735	-26.364	-25.5192
17	-17.9212	-13.06115	-24.8574	-15.92145	NA	-11.80115	-13.9044	-11.92845	-4.53455	-10.0134	-23.0323	-19.0674
18	-24.418	-20.0781	-2.21745	-27.01695	-11.80115	NA	-21.0828	-10.28275	-11.86635	-16.0446	-10.09645	-10.8408
19	-22.5741	-14.64465	-15.52375	-19.52455	-13.9044	-21.0828	NA	-17.8733	-16.68065	-32.1195	-24.2222	-18.77675
20	-22.67335	-15.1628	-15.0098	-14.55545	-11.92845	-10.28275	-17.8733	NA	-14.0837	-35.85185	-14.626	-18.4924
21	-16.28415	-15.0915	-4.31375	-3.9918	-4.53455	-11.86635	-16.68065	-14.0837	NA	-13.9565	-7.56505	-4.5634
22	-4.45135	-28.36955	-19.3664	-13.43735	-10.0134	-16.0446	-32.1195	-35.85185	-13.9565	NA	-13.9274	-16.6203
23	-8.8703	-6.5151	-19.01425	-26.364	-23.0323	-10.09645	-24.2222	-14.626	-7.56505	-13.9274	NA	-27.9116
24	-8.63295	-16.5484	-10.9133	-25.5192	-19.0674	-10.8408	-18.77675	-18.4924	-4.5634	-16.6203	-27.9116	NA

Note: Table 3 and Table 4 (CAD55 Amplitude Offset Matrix.xlsx) is contained in TR-285.05.zip

A.2.3.2 Time Variation Effect

The “Time Variation Effect” will present increased complexity in the operation of Vectoring in G.fast in the cancellation of FEXT. While it is important to capture the effect of this “time variation” on the complexity of the operation of Vectoring it is also important to keep the model itself to limited complexity so that it can be implemented. Accordingly, in the model being presented the focus will be on the impact of this “time variation” on the FEXT coupling associated with just two loops “1” and “2.”

For the present model with the inclusion of both the Dual Slope Effect and the Time Variation Effect when reference is made to the “i-j” FEXT crosstalk coupling combination this means reference to coupling which originates on Loop i and has a target as Loop j.

For this model the FEXT transfer function for the coupling from Loop i to Loop j is given by $H_{ij\text{FX T-V}}(f,d)$ which is defined below as:

$$H_{ij\text{FX T-V}}(f,d) = [1 + 3[W(t)] [H_p(f)]] H_{ij\text{FX-LTI}}(f,d) \quad (2)$$

The extreme rightmost term, $H_{ij\text{FX-LTI}}(f,d)$, is given by equation (1). Accordingly, $H_{ij\text{FX T-V}}(f,d)$ is built upon the foundation of $H_{ij\text{FX-LTI}}(f,d)$.

Completion of the definition of $H_{ij\text{FX T-V}}(f,d)$ requires then only dealing with the leftmost, 2, bracketed terms on the right-hand side of equation (2).

Consider the following two “i-j” FEXT crosstalk coupling combinations:

$$i-j = 1-2, 2-1,$$

For these two combinations

$W(t)$ and $H_p(f)$ are defined as follows:
 $W(t) = \sum P(t - mT_p)$

Here $P(t)$ is a “window pulse” which is T_u seconds long:

$$P(t) = U_{-1}(t) - U_{-1}(t-T_u)$$

Where $U_{-1}(t)$ is the unit step function. T_u is the “on time of the window” and T_p is the period of the window. These are defined as:

$$\begin{aligned} T_u &= 300 \text{ seconds} \\ T_p &= 1,200 \text{ seconds} \end{aligned}$$

The “300” seconds corresponding to T_u corresponds to the average duration of a voice call - going “off hook.” The 1,200 seconds corresponding to T_p corresponds to the average time between voice calls.

The summation above occurs over all “m.” This is unlimited. In other words, $W(t)$ is a pulse train.

$H_p(f)$ is defined as follows:

$$H_p(f) = \frac{1}{[1+(f_{cv}/f)^6]^{0.5}}$$

Where $f_{cv} = 50$ MHz.

This is the magnitude response function of a 3rd order Butterworth Filter.

In other words, for the case of these two FEXT coupling combinations, 1-2 and 2-1 during the “on time” of the pulse, $H_{ij\text{FXT-V}}(f,d)$ experiences a rise of approximately 12 dB above $H_{ij\text{FXT-LTI}}(f,d)$ when $f > f_{cv}$.

For all other “i-j” FEXT crosstalk coupling combinations:

$$\begin{aligned} W(t) &= 0 \\ H_p(f) &= 0 \end{aligned}$$

In other words, for the case of these FEXT crosstalk coupling combinations there is no rise in the FEXT level and $H_{ij\text{FXT-V}}(f,d) = H_{ij\text{FXT-LTI}}(f,d)$.

A.3 Isolated Drop Wire

By way of example the length of the Isolated Drop Wire can be considering as being 10's of meters. However, this also should be considered as possibly zero length, as many businesses and Multi Dwelling Unit (MDU) basements have no drop wire.

A.3.1 Transfer Function

The transfer function for the Isolated Drop Wire will be based upon the distributed transmission line parameters, $Z_s(j\omega)$ and $Y_p(j\omega)$ for CAD55. Additional values needed to derive these parameters for CAD55 are given in Table 1

In providing the transfer function for the Isolated Drop Wire the following nomenclature is used:

Isolated Drop Wire Section length = "d_w"
 Source impedance = " Z_{sow} "
 Load impedance of " Z_{LW} "

Compute

$$\gamma = \alpha + j\beta = [Z_s(j\omega) Y_p(j\omega)]^{0.5}$$

$$Z_0 = [Z_s(j\omega) / Y_p(j\omega)]^{0.5}$$

In order to compute this $Z_s(j\omega)$ and $Y_p(j\omega)$ are required for CAD55 cable. The equations for these entities are:

$$Z_s(j\omega) = R(\omega) + j\omega L$$

$$Y_p(j\omega) = G(\omega) + j\omega C$$

For purposes here it will be more convenient to express these in terms of frequency, f, where $\omega = 2\pi f$. Doing so these become:

$$Z_s(f) = R(f) + j 2\pi f L(f)$$

$$Y_p(f) = G(f) + j 2\pi f C(f)$$

With the following definitions:

R(f): The distributed transmission line series resistance of the CAD55 Isolated Drop Wire.
 L(f): The distributed transmission line series inductance of the CAD55 Isolated Drop Wire.
 C(f): The distributed transmission line shunt capacitance of the CAD55 Isolated Drop Wire.
 G(f): The distributed transmission line Conductance of the Isolated Drop Wire.

Equations for $Z_s(j\omega)$ and $Y_p(j\omega)$ are provided in Table 2.

The Isolated Drop Wire transfer function, “ H_W ,” is then obtained by the following equation

$$H_W = 2*[Z_{inW} / (Z_{inW} + Z_{soW})] T_w$$

NOTE – The Isolated Drop Wire transfer function definition is associated with a two-port network, normalized to the reference load impedance Z_{LW} (see clause 11.4.1.1.1 of [ITU-T G.993.2]). The formula assumes that Z_{LW} and Z_{soW} are equal.

Here:

$$T_w = [\cosh(\gamma d_w) + (Z_0 / Z_{LW}) \sinh(\gamma d_w)]^{-1}$$

Z_{inW} = The Input Impedance of the Isolated Drop Wire– which follows in Section A.3.2

The magnitude of “ T_w ” given by $|T_w|$ gives the “attenuation” of the direct path. The phase of “ T_w ” gives the “phase” of the direct path. The derivative of the phase with respect to frequency can be used to obtain delay.

“ Z_{soW} ” and “ Z_{LW} ” are specified at 100 Ohms resistive. In this case this value corresponds to the asymptotic impedance of the distribution wire and is also standard industry practice as it corresponds to modem terminations.

A.3.2 Impedance

The following nomenclature is again used:

Isolated Drop Wire Section length = “ d_w ”
 Source impedance = “ Z_{soW} ”
 Load impedance of “ Z_{LW} ”

Compute

$$\gamma = \alpha + j\beta = [Z_s(j\omega) Y_p(j\omega)]^{0.5}$$

$$Z_0 = [Z_s(j\omega) / Y_p(j\omega)]^{0.5}$$

In carrying out this computation as before use the equations:

$$Z_s(j\omega) = R(\omega) + j\omega L$$

$$Y_p(j\omega) = G(\omega) + j\omega C$$

As before, for purposes here it will be more convenient to express these in terms of frequency, f , where $\omega = 2\pi f$. Doing so these become:

$$Z_s(f) = R(f) + j2\pi f L(f)$$

$$Y_p(f) = G(f) + j2\pi f C(f)$$

With the following definitions:

- R(f): The distributed transmission line series resistance of the CAD55 Drop Wire Section.
- L(f): The distributed transmission line series inductance of the CAD55 Drop Wire Section.
- C(f): The distributed transmission line shunt capacitance of the CAD55 Drop Wire Section.
- G(f): The distributed transmission line Conductance of the CAD55 Drop Wire Section.

Equations for $Z_s(j\omega)$ and $Y_p(j\omega)$ are provided in Table 2.

The input impedance of the Isolated Drop Wire, “ Z_{inW} ,” is then given by the following equation:

$$Z_{inW} = Z_0 \left[\left(Z_{LW} + Z_0 \tanh(\gamma d_w) \right) \right] / \left[\left(Z_0 + Z_{LW} \tanh(\gamma d_w) \right) \right]$$

“ Z_{LW} ” is specified at 100 Ohms resistive.

This value corresponds to the asymptotic impedance of the drop wiring and is also standard industry practice as it corresponds to modem terminations.

A.3.3 FEXT

There is no FEXT over this segment.

Annex B: Twisted Star Quad Cable Model

This annex defines a crosstalk model (q-MIMO) developed for the MIMO applications with the crosstalk couplings present in the quad wiring. The model is built upon the measurement data from operators in the frequency range up to 300 MHz. Typical FEXT characteristics observed and noted in actual measurements, such as the time variation effects and the dual slope effect, the ripple effect or length dependence of a crosstalk, as well as the direct channel attenuation due to crosstalk present in the cable bundle are handled implicitly in the model. All this makes the q-MIMO model applicable for modeling of the twisted star quad cables in the full bandwidth of G.fast operation.

This annex also describes the two reference twisted star quad cables used for the access and in-home installations in the network deployment of operators and specifies the cable parameters according to the line models of ITU-T G.9701 [3] and ETSI VDSL2 [5].

Supplementary information to the quad cable modeling is providing in Appendix A and includes a short introduction on how to derive the transfer function of a cable based on the primary line parameters, as well as the reference inductance matrices for 0.5 mm and 0.6 mm twisted star quad cable.

B.1 Single Line Modeling of Quad Cables

Single line models describe a twisted pair in terms of primary or secondary line parameters. The two models which are proposed to be used for high frequency wireline modeling are based on the primary line parameters, the $Z_s(f)$ serial impedance and the parallel admittance $Y_p(f)$, which are approximated by nonlinear functions of frequency.

The secondary line parameters, the characteristic impedance $Z_c(f)$ and the propagation constant $\gamma(f)$ are given by these equations.

- Line (characteristic) impedance:

$$Z_c(f) = \sqrt{\frac{Z_s(f)}{Y_p(f)}}$$

- Propagation delay:

$$\gamma(f) = \sqrt{Z_s(f) \times Y_p(f)}$$

The direct channel transfer function $H(f)$ can be computed based on the secondary line parameters.

B.1.1 ITU-T Line Model

This model is defined in [3] as a reference model for G.fast loops. The model approximates the primary line parameters of a single line as a function of 10 parameters ($Z_{0\infty}$, η_{VF} , R_{s0} , q_L , q_H , q_c , q_x , q_y , ϕ , f_d).

The characteristics of this type of model are:

- good prediction of time domain characteristics
- designed for modeling at frequencies above 30 MHz
- impulse responses are always causal
- parameter fitting in the frequency domain is difficult

The computation of the primary line parameters is done by the following two equations with the parameters of the corresponding lines:

$$Z_s(j\omega) = j\omega \cdot L_{s\infty} + R_{s0} \times \left(1 - q_s \cdot q_x + \operatorname{sqr}t \left(q_s^2 \cdot q_x^2 + 2 \cdot \frac{j\omega}{\omega_s} \cdot \left(\frac{q_s^2 + j\omega / \omega_s \cdot q_y}{q_s^2 / q_x + j\omega / \omega_s \cdot q_y} \right) \right) \right)$$

$$Y_p(j\omega) = j\omega \cdot C_{p0} \times (1 - q_c) \times \left(1 + \frac{j\omega}{\omega_d} \right)^{-2 \cdot \phi / \pi} + j\omega \cdot C_{p0} \times q_c$$

$$L_{s\infty} = \frac{1}{\eta_{VF} \cdot c_0} \times Z_{0\infty}$$

$$C_{p0} = \frac{1}{\eta_{VF} \cdot c_0} \times \frac{1}{Z_{0\infty}}$$

$$q_s = \frac{1}{q_H^2 \cdot q_L}$$

$$\omega_s = q_H^2 \cdot \omega_{s0} = q_H^2 \cdot \left(\frac{4\pi \cdot R_{s0}}{\mu_0} \right)$$

$$\omega_d = 2\pi \cdot f_d$$

$$c_0 = 3 \cdot 10^8 \text{ [m/s]}$$

$$\mu_0 = 4\pi \cdot 10^{-7} \text{ [H/m]}$$

B.1.2 ETSI BT0 Line Model

Another model for a single twisted -pair line is the ETSI BT0 model, described in [5]. It is used for VDSL cable modeling up to 30 MHz, but with a proper selection of the parameters, it is possible to use the model beyond 30 MHz.

In general, it is easier to handle than the ITU-T model because resistance R, inductance L, capacitance C and conductance G are handled independently. This makes parameter fitting easier and leads to good results for frequency domain modeling.

But the disadvantage of this modeling approach is that, depending on the selected parameters, the impulse responses may not be causal. The model uses 11 parameters (R_{0C} , a_C , L_0 , L_∞ , N_b , f_m , g_0 , N_{ge} , C_0 , C_∞ , N_{ce}) to approximate the primary line parameters of a specific line.

The main characteristics of the model are:

- good prediction of frequency domain characteristics
- with a proper parameters selection, the model can be used above 30 MHz
- impulse response is not always causal
- easy parameter fitting in the frequency domain

The primary line parameters $Z_s(f) = R(f) + j\omega L(f)$ and $Y_p(f) = G(f) + j\omega C(f)$ are given by the following equations:

$$Z_s(f) = \sqrt[4]{(R^4_{0c} + ac \cdot f^2)} + j \cdot 2\pi f \cdot \left(\frac{L_0 + L_\infty \cdot \left(\frac{f}{f_m}\right)^{Nb}}{1 + \left(\frac{f}{f_m}\right)^{Nb}} \right)$$

$$Y_p(f) = (g_0 \cdot f^{Nge}) + j \cdot 2\pi f \cdot (C_\infty + C_0 \cdot f^{-Nce})$$

B.1.3 Reference Twisted Star Quad Cables

B.1.3.1 Cable Type 1: *I-O2YS(ST)H 10x2x0.5 STVI Bd*

The cable parameters according to the ITU-T and ETSI BT0 model are defined in Table 5 and Table 6, respectively.

Cable *I-O2YS(ST)H 10x2x0.5 STVI Bd* is currently used for installation purposes. This is a high quality 0.5 mm PE quad cable composed of five quads that build a 10-pair cable. The cable is continuously twisted and shows the 40dB/decade increasing in-quad crosstalk (also at frequencies below 30 MHz). It should be noted that the ELFEXT couplings between 70 MHz and 100 MHz (as per supplier lot and variant) exceed a level of -10dB. Partially, the coupling is even above 0dB, in resonances for frequencies above 100 MHz.

Note: The FEXT characteristic of this cable type is dominated by the 40 dB/decade slope behavior. Because of this the ELFEXT decreases by 6 dB for double loop length. This is caused by an indirect coupling path via the surrounding cable core. For longer loops this characteristic strongly impacts the achievable SNR. There are other cable types in use which have an additional 20 dB/decade slope (dual slope) and which show similar dominating systematic phase constant ELFEXT couplings.

Mechanical and material properties are as follows:

- Quad twist
 - Ø conductor 0.485 mm
 - Ø coating 1.1 mm
- Twist length
 - Quad 1: 45 mm
 - Quad 2: 43 mm
 - Quad 3: 39 mm
 - Quad 4: 50 mm
 - Quad 5: 41 mm

The following measurement shows the characteristic impedance $Z_C(f)$, measured on a 30m long cable and averaged over all cable pairs.

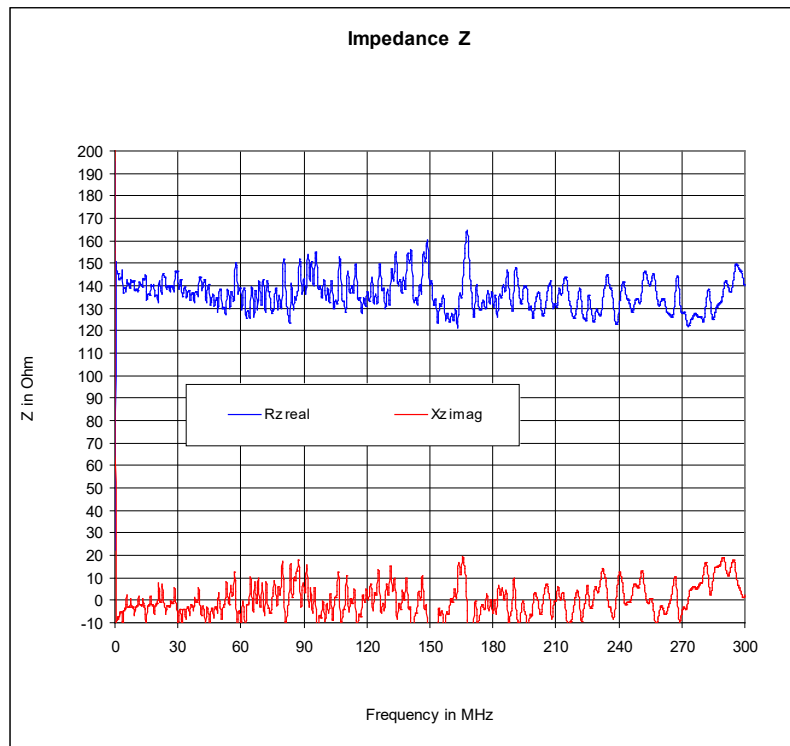


Figure 3 - Characteristic Impedance of I-O2YS(ST)H 10x2x0.5 STVI Bd Cable

Crosstalk measurements for all cable pairs, FEXT power sum and the equivalent FEXT power sum are shown in Figure 3.

The following notation is used:

- PS1-FEXT: FEXT power sum on pair 1
- EL-PS1-FEXT: equivalent FEXT power sum (FEXT minus transfer function) on pair 1
- aDA1: direct transfer function of pair 1
- 1-x: measured FEXT between pair 1 and pair x, $x=2, \dots, 10$

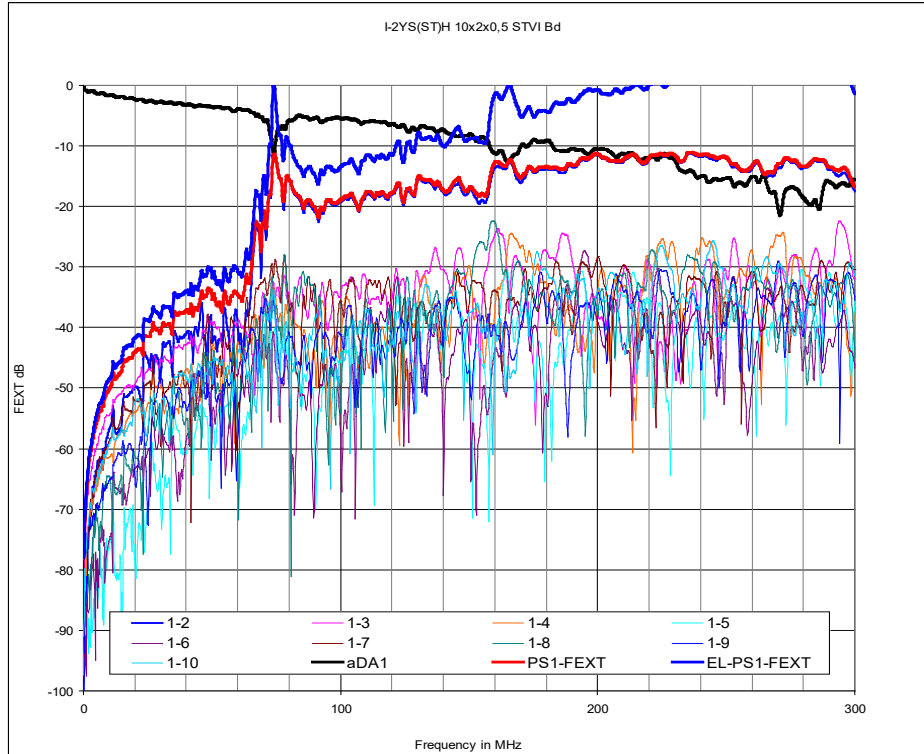


Figure 4 - FEXT measurements of I-O2YS(ST)H 10x2x0.5 STVI Bd cable

Measured transfer function and crosstalk of one of the ten pairs of a 30 m long cable is shown in Figure 5 and compared with the ITU-T and ETSI single line model.

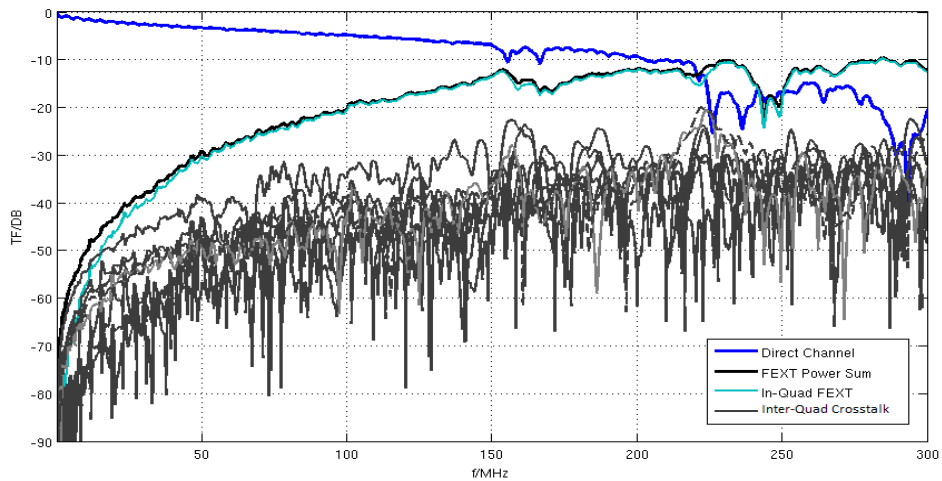


Figure 5 - Measurements and single line model of I-O2YS(ST)H 10x2x0.5 STVI Bd cable

Cable characteristic impedance is about 135 Ohm. The difference between the direct channel attenuation of the ETSI model and the measurement is caused by power loss due to the crosstalk. The measured cable clearly shows a characteristic 40dB/decade ELFEXT slope as well as some resonance effects.

The direct channel and crosstalk characteristics of the cable differ among different cable pairs. Figure 6 shows another cable pair where resonance effects are observable.

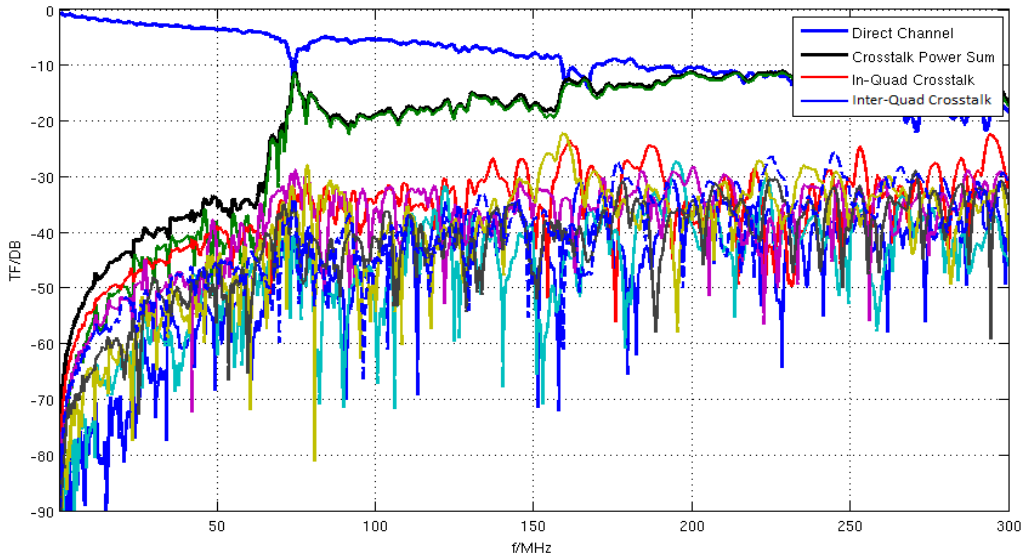


Figure 6 - Another 0.5 mm cable pair direct channel and crosstalk measurements

The 20dB/decade ELFEXT and 40dB/decade ELFEXT sections are shown in detail in Figure 7. While the crosstalk within the quad shows the 40dB/decade ELFEXT slope, the Inter-Quad crosstalk grows with 20dB/decade. At higher frequencies, the Inter-Quad ELFEXT also shows a different slope that is due to resonance effects and power loss of the direct channel due to crosstalk.

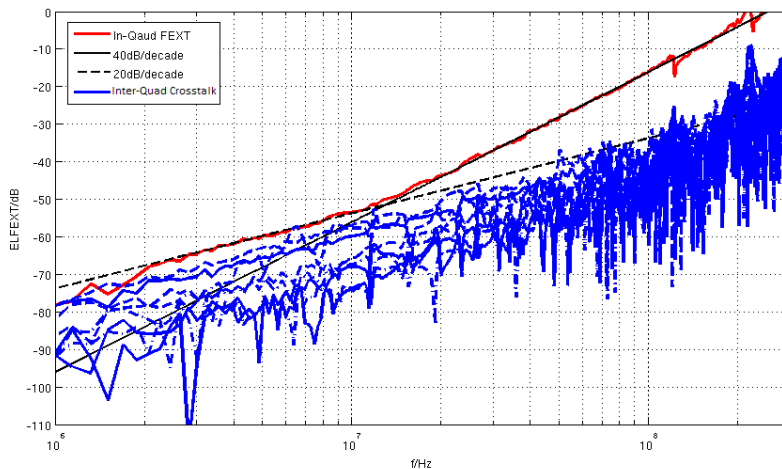


Figure 7 - Detailed In-and Inter-quad crosstalk measurements of 0.5 mm cable

B.1.3.2 I-O2YS(ST)H 10x2x0.5 STVI Bd Cable Parameters**Table 5 - ITU-T parameter values of cable type I-O2YS(ST)H 10x2x0.5 STVI Bd**

Cable type	Parameters of ITU model
I-O2YS(ST)H 10x2x0.5 STVI Bd	$Z_{0\infty} = 134.2196$ $\eta_{VF} = 0.7489$ $R_{s0} = 0.2145$ $q_L = 2.160729447$ $q_H = 0.7415$ $q_x = 1$ $q_y = 0$ $q_c = 1.0016$ $\phi = -0.03191108824$ $f_d = 1$

Table 6 - ETSI BT0 parameter values for cable type I-O2YS(ST)H 10x2x0.5 STVI Bd

Cable type	Parameters of ETSI BT0 model
I-O2YS(ST)H 10x2x0.5 STVI Bd	$R_{0C} = 20.16991764$ $a_C = 0.04294697418$ $L_0 = 0.000908779665$ $L_\infty = 0.0005998736085$ $N_b = 0.7139316783$ $f_m = 91895.48079$ $g_0 = 4.342153972e-12$ $N_{ge} = 1.105448975$ $C_0 = 7.760581191e-08$ $C_\infty = 3.237852447e-08$ $N_{ce} = 0.5674612531$

B.1.3.3 Cable Type 2: J-H(ST)H Bd 10x2x0.6

Cable *J-H(ST)H Bd 10x2x0.6* is a 0.6 mm PE quad cable of moderate but predictable quality. It is composed of five quads that build a 10-pair cable. Due to the alternating twist, it does not show the 40dB/decade ELFEXT that has been observed for the cable Type 1. This typically used for in house wiring and has an impedance of approximately 110 Ohms.

Mechanical and material properties are as follows:

- Quad twist
 - Ø conductor 0.58 mm
 - Ø coating 1.0 mm
- Twist length
 - Quad 1: 100 mm
 - Quad 2: 55 mm
 - Quad 3: 90 mm
 - Quad 4: 80 mm
 - Quad 5: 70 mm

The following measurement shows the characteristic impedance $Z_C(f)$, measured on a 20m long cable and averaged over all cable pairs.

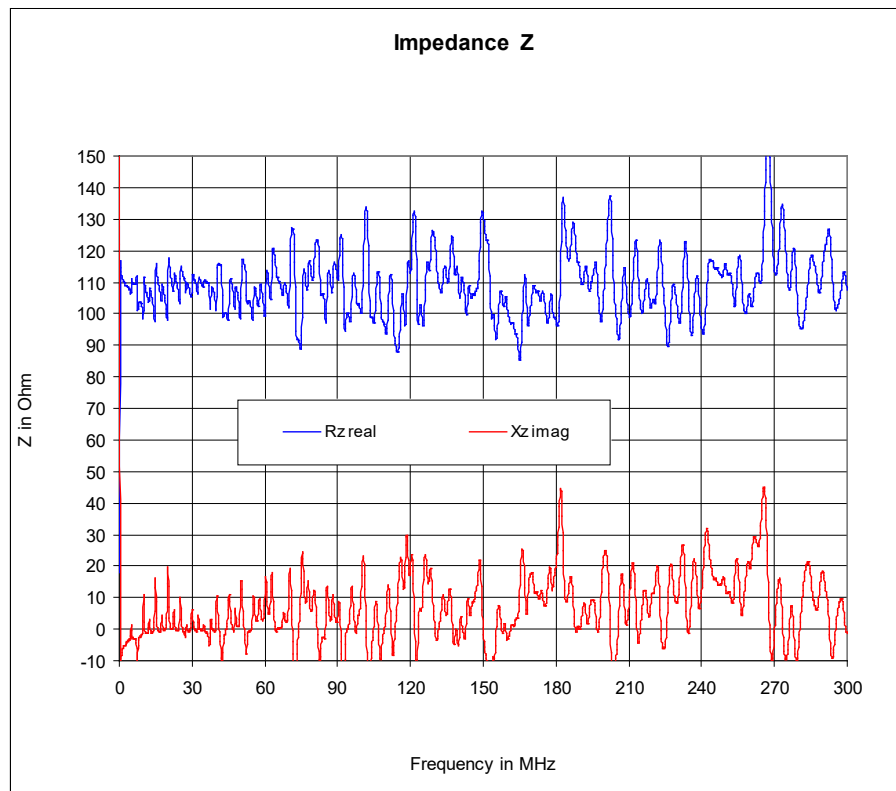


Figure 8 - Characteristic Impedance of J-H(ST)H Bd 10x2x0.6 cable

Crosstalk measurements for all cable pairs, FEXT power sum and the equivalent FEXT power sum are shown in Figure 9.

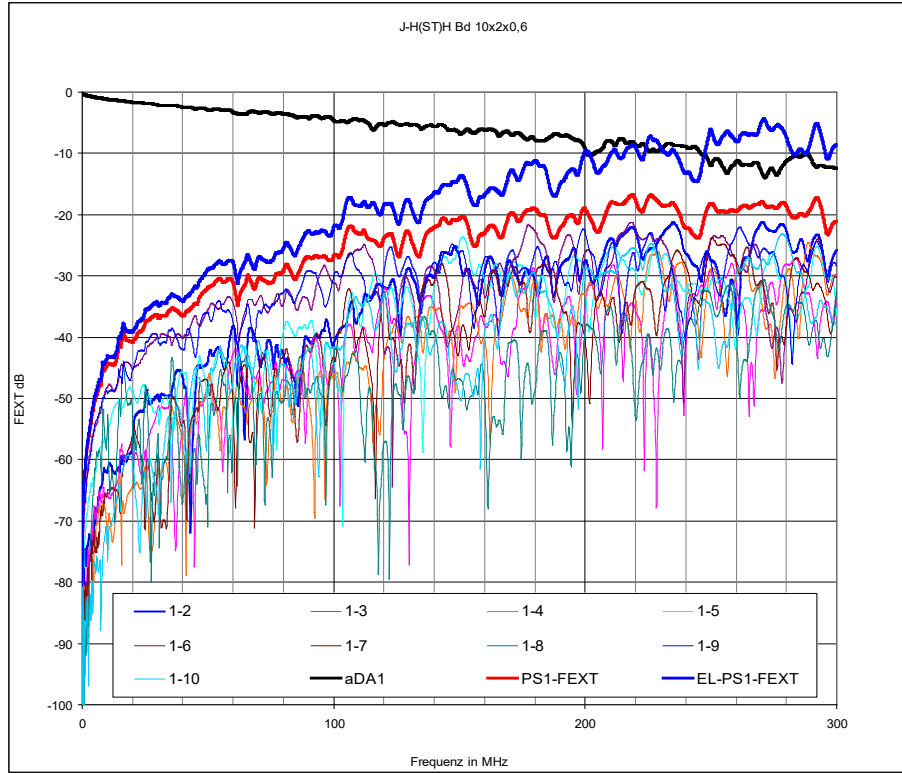


Figure 9 - FEXT measurements of J-H(ST)H Bd 10x2x0.6 cable

Figure 10 shows the measured direct channel transfer function and crosstalk in comparison with the ETSI and ITU-T model transfer function for the direct channel. The difference between measurement and model is again caused by crosstalk effects.

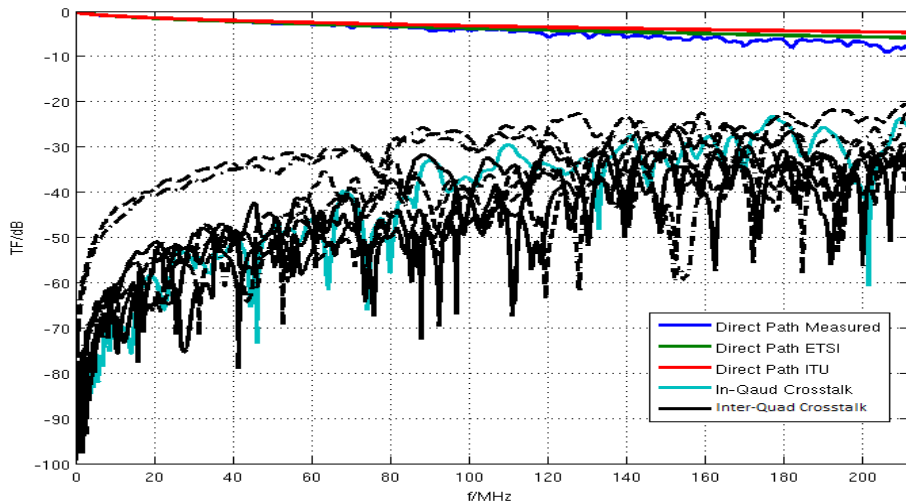


Figure 10 - Measurements and single line model of J-H(ST)H Bd 10x2x0.6 cable

The direct channel and crosstalk characteristics of another cable pair and the crosstalk power sum are shown in Figure 11. At higher frequencies, the direct channel attenuation becomes significant due to the crosstalk effects.

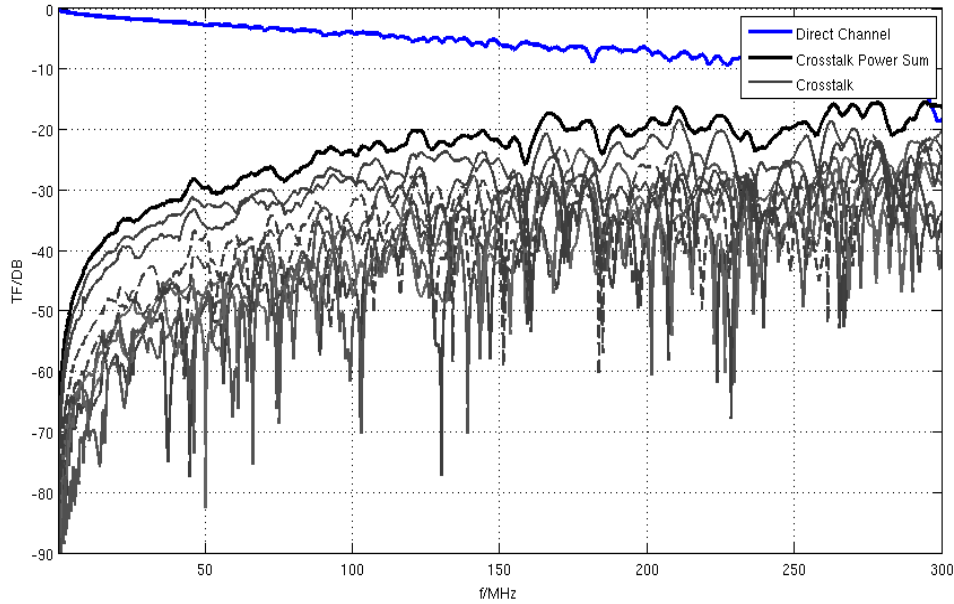


Figure 11 - Another 0.6 mm cable pair direct channel and crosstalk measurements

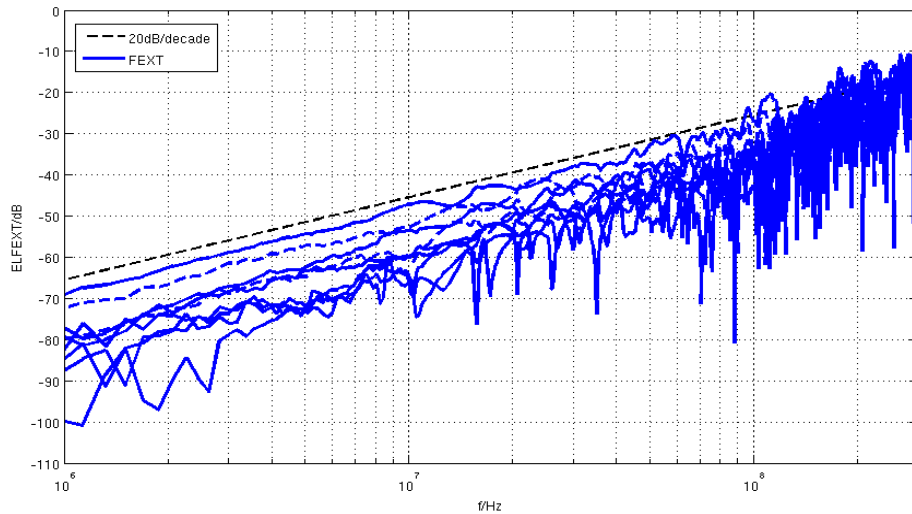


Figure 12 - Detailed Inter-Quad crosstalk measurements of 0.6 mm cable

The 20dB/decade ELFEXT curve is shown in detail in Figure 12. Similar to Figure 11, at higher frequencies, the high attenuation of the direct channel and resonance effects make the ELFEXT slope look different.

B.1.3.4 J-H(ST)H Bd 10x2x0.6 Cable Parameters

The cable parameters according to the ITU-T and ETSI BT0 model are defined in Table 7 and Table 8, respectively.

Table 7 - ITU-T parameter values for cable type J-H(ST)H Bd 10x2x0.6

Cable type	Parameters of ITU model
J-H(ST)H Bd 10x2x0.6	$Z_{0\infty} = 110.8$ $\eta_{VF} = 0.6810$ $R_{s0} = 0.1901$ $q_L = 9.17386$ $q_H = 0.60105$ $q_x = 1$ $q_y = 0$ $q_c = 1.0016$ $\phi = 0.05076227074$ $f_d = 1$

Table 8 - ETSI BT0 parameter values for cable type J-H(ST)H Bd 10x2x0.6

Cable type	Parameters of ETSI BT0 model
J-H(ST)H Bd 10x2x0.6	$R_{0C} = 160.16183$ $a_C = 0.03329$ $L_0 = 0.0009067942863$ $L_\infty = 0.0005342191844$ $N_b = 0.7218331678$ $f_m = 91895.48079$ $g_0 = 23.7312e-12$ $N_{ge} = 1.151833774$ $C_0 = 7.760763018e-08$ $C_\infty = 4.6143e-08$ $N_{ce} = 0.5463017537$

B.1.4 Multiline Quad Cable MIMO Crosstalk Model

The multiline quad cable MIMO Crosstalk Model (q-MIMO) described here works very similar to the single line models that are widely used for VDSL2 applications. The complete cable binder is described in terms of the primary line parameters, which are matrix-valued for a multi-pair binder.

B.1.4.1 Primary Line Parameters

Single lines are described as a cascade of circuit elements as shown in Figure 13. Each element consists of a series inductance L , a series resistance R , a parallel capacitance C and a parallel admittance G . The line is modeled either by the ETSI BT0 or the ITU-T model.

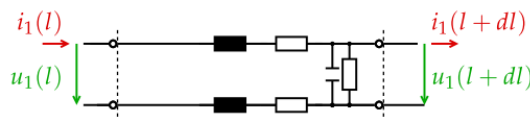


Figure 13: Single line circuit element

The q-MIMO crosstalk model uses the same primary line parameter description, but the circuit is extended according to Figure 14.

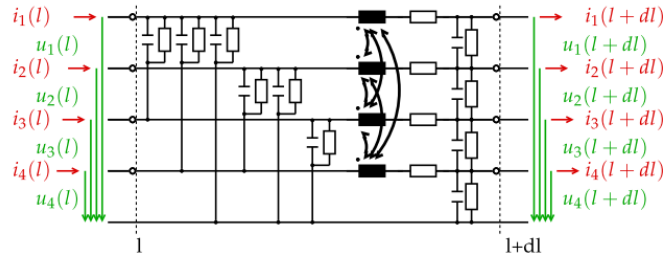


Figure 14 - Multiline circuit element

To describe this type of model, the primary line parameters are arranged as matrices. The notation is defined such that uppercase bold letters are matrices, lowercase bold letters are vectors.

There is the resistance $R(f)=\text{real}(Z_s(f))$, which is described by one of the single line models. It is also used in the MIMO model, where it forms the resistance matrix \mathbf{R} .

$$\mathbf{R}(f) = \begin{bmatrix} R(f)/2 & 0 & 0 & 0 \\ 0 & R(f)/2 & 0 & 0 \\ 0 & 0 & R(f)/2 & 0 \\ 0 & 0 & 0 & R(f)/2 \end{bmatrix}$$

From the single line model: $R(f)=\text{real}(Z_s(f))$

The resistance matrix \mathbf{R} contains only nonzero elements on the diagonal, which comes from the fact that in Figure 14, the serial resistance exists only in the series elements of the circuit element. Off-diagonal elements are zero. The multiline MIMO model uses a single-ended description of the cable where each single wire is described with respect to a common reference potential. Therefore, the factor $1/2$ is required.

The series resistance is assumed to be constant over the length of the cable and therefore, the same resistance matrix is used for all segments of the cable.

The series inductance is a dense matrix. The inductance matrix \mathbf{L} does not only describe the series resistance of the direct channels, but also describes the crosstalk. For this reason, it consists of the frequency dependent impedance $L(f)=\text{imag}(Z_s(f))/\omega$, which is again computed from the single line model and a frequency-independent matrix \mathbf{L}_{ref} . The matrix \mathbf{L}_{ref} changes over the cable length d and is therefore provided in multiple segments over the length of the cable.

$$\mathbf{L}(d, f) = L(f) \begin{bmatrix} L_{ref\ 1}(d) & L_{ref\ 12}(d) & L_{ref\ 13}(d) & L_{ref\ 14}(d) \\ L_{ref\ 21}(d) & L_{ref\ 2}(d) & L_{ref\ 23}(d) & L_{ref\ 24}(d) \\ L_{ref\ 31}(d) & L_{ref\ 32}(d) & L_{ref\ 3}(d) & L_{ref\ 34}(d) \\ L_{ref\ 41}(d) & L_{ref\ 42}(d) & L_{ref\ 43}(d) & L_{ref\ 4}(d) \end{bmatrix}$$

From the single line model: $L(f) = \text{imag}(Z_s(f))/\omega$

The capacitance matrix \mathbf{C} is again a dense matrix. However, it is not required to specify a new matrix, because the capacitance matrix can be computed from the inductance matrix and the single line model. \mathbf{L}_{ref}^{-1} is the matrix inverse of the reference inductance matrix. This is weighted with $C(f) = \text{imag}(Y_p(f))/\omega$ from the single line model to get the capacitance matrix

$$\mathbf{C}(d, f) = C(f) \mathbf{L}_{ref}^{-1}(d)$$

From the single line model: $C(f) = \text{imag}(Y_p(f))/\omega$

The conductance matrix \mathbf{G} is created similarly, as it depends on the capacitance matrix. The inverse reference inductance matrix is weighted by the admittance $G(f) = \text{real}(Y_p(f))$ from the single line model.

$$\mathbf{G}(d, f) = G(f) \mathbf{L}_{ref}^{-1}(d)$$

From the single line model: $G(f) = \text{real}(Y_p(f))$

This is the complete description of the primary line parameters of the q-MIMO crosstalk model.

B.1.4.2 Reference Inductance Matrices

For the reference matrices, the 10-pair cables (i.e. 5-quad cables) are extended to 30 pairs (i.e. 15-quad cables) by placing three 10-pair binders next to each other. The segments give an overall cable length of 20m and may be repeated to create longer cables. If cable of interest shall have less than 30 pairs, the size of the matrix may be reduced accordingly.

There is one reference matrix for each cable type (*Lref_pe06* and *Lref_pe05*). The reference matrices contain the information about cable geometry and crosstalk characteristics in the spectral region of up to 300 MHz. The reference inductance matrix defines the crosstalk values ($L_{ref}(d)$) normalized to the single line inductance ($L(f)$). Each reference matrix is composed of multiple segments as shown in Figure 17, because the crosstalk characteristics change over the length of the cable. To avoid regular structures, the length of the segments contains some variation. The segment lengths are given in meters and included in the reference matrix file (*PE06.zip* and *PE05.zip*) as a second variable (*dref_pe06* and *dref_pe05*).

B.1.4.3 Reference Inductance Matrix for cable type *J-H(ST)H Bd 10x2x0.6*

MATLAB-file *PE06.zip* in the *Reference Matrices 300MHz.zip* (Appendix II.3) contains the following arrays.

Variable Name	Dimension
Lref_pe06	60x60x250
dref_pe06	250x1

B.1.4.4 Reference Inductance Matrix for cable type *I-O2YS(ST)H 10x2x0.5 STVI Bd*

MATLAB-file *PE05.zip* in the *Reference_Matrices_300MHz.zip* (Appendix II.3) contains the following arrays.

Variable Name	Dimension
Lref_pe05	60x60x500
dref_pe05	500x1

B.1.4.5 Selection of the segment length

The average segment length which is used for the reference matrices is selected for optimal precision of the model. It is selected to be 10 segments per meter on average.

The rule of thumb for numeric cable modeling is to have 10 segments according to Figure 14 per wave length. At 300 MHz, the wave length is approximately 0.7m (0.667m) for a speed of the wave to be about 2×10^8 m/s in a PE cable which gives the 0.07m segment length of the reference matrices.

For simulation purposes, this is a good compromise in terms of speed and complexity. For emulator device, the segment length will remain the same, but the cable characteristics are kept constant for some cable length to reduce the number of different component values. Furthermore, the segments may not contain the complete set of coupling elements to reduce the number of circuit elements. Details are for further study.

B.1.4.6 Reference matrix for other cable types

When cables with a different crosstalk behavior than the PE 0.5 mm and 0.6 mm analyzed above need to be characterized for the q-MIMO model, a new reference matrix must be created. The details are shown in Appendix I - Quad Cable Model Supplementary Information.

B.1.5 Characteristic Features on the q-MIMO model

B.1.5.1 Topologies

The model can be used for any topology where the binders in the topology have less than 30 pairs. In case that the topology consists of different sections, one chain matrix is created for each section. They are multiplied to create the overall chain matrix of the network.

B.1.5.2 Time variations of the termination impedance

Due to the fact that the model is based on the equivalent network of a cable bundle, impedance changes are handled implicitly in the model. A change of the termination impedance is performed by multiplying the corresponding chain matrix with a chain matrix containing the corresponding resistance value.

For the example of two twisted pairs, where the impedance of line 1 is increased by R, the following chain matrix is added to provide typical resistance values for analog telephones (during call and between calls).

$$A_{\text{impedance change}} = \begin{bmatrix} 1 & 0 & \dots & 0 & R/2 & 0 & 0 & 0 \\ 0 & \ddots & & \vdots & 0 & R/2 & 0 & 0 \\ \vdots & & \ddots & 0 & 0 & 0 & 0 & 0 \\ 0 & \dots & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & \dots & & 0 & 1 & 0 & \dots & 0 \\ \vdots & & & \vdots & 0 & \ddots & & \vdots \\ & & & & & \vdots & \ddots & 0 \\ 0 & \dots & & 0 & 0 & \dots & 0 & 1 \end{bmatrix}$$

The changes of the crosstalk matrix and the changes of the direct channels of other lines will then change accordingly.

B.1.5.3 Model Ripples

Ripple structure of crosstalk is modeled correctly in the model due to the algorithm construction based on multiple shorter segments.

B.1.5.4 Length Dependence of Crosstalk

In general, in-quad crosstalk does not depend on length as $H_{FEXT} \sim \sqrt{d}$, but as $H_{FEXT} \sim d$. Similar length dependence has been observed on strong Inter-Quad crosstalk couplings. This effect is modeled correctly when multiple binder segments of the model are cascaded.

Annex C: Cable Models for Quad Cable Deployed by European Operators.

C.1 Cable Model for PE4D-ALT 4x10x0.6 mm Quad Cable

The PE4D-ALT 4x10x0.6 mm is a polyethylene-foam insulated 2-layered star quad cable with aluminum cable mantle deployed since the early 1990's. It consists of 2 core and 8 outer quads.

C.1.1 Insertion Loss

Insertion Loss (IL) is described by the ITU-T single line model. The parameter values for the multi-pair approximation are given in Table 9. The model describes accurately magnitude and phase of the Insertion Loss.

Table 9 - ITU-T single line model for PE4D-ALT 10x4x0.6 mm

ITU-T Model	$Z_{0\infty}$	η_{VF}	R_{s0}	q_L	q_H	q_x	q_y	q_c	ϕ	f_d
PE4D-ALT 10x4x0.6 mm	130	0.735	0.125	2.5	0.75	1	0	0	0.0071	1

C.1.2 ELFEXT

The ELFEXT magnitude depending on the frequency is described by a dual slope model with an upper bound of 0dB. The lower slope has 20dB/decade steepness; the upper slope has 40dB/decade steepness. The model assumes homogeneity and linearity over the full cable length. It is expressed by the following formula:

$$|ELFEXT| = \begin{cases} \min(20dB \cdot \log_{10}(f) + 10dB \cdot \log_{10}(x) + C_{20dB}, 0) & 0 < f < f_T \\ \min(40dB \cdot \log_{10}(f) + 20dB \cdot \log_{10}(x) + C_{40dB}, 0) & f \geq f_T \end{cases}$$

Where

$$f_T = 10^{\frac{-10 \cdot \log(x) + C_{20dB} - C_{40dB}}{20dB}} \cdot \text{MHz}$$

f : Frequency in [MHz]

f_T : Transition frequency from 20 to 40dB per decade slope in [MHz]

C_{20dB} : Offset magnitude at 1MHz for 20dB per decade slope for $x = 1m$ in [dB]

C_{40dB} : Offset magnitude at 1MHz for 40dB per decade slope for $x = 1m$ in [dB]

x : Cable length in [m]

The ELFEXT phase is described by the following model.

For inductive coupling:

- ELFEXT phase from pair k to pair l : $\varphi_{c,k \rightarrow l}(f) = \frac{\pi}{2} \cdot e^{-f/F_{kl}}$

- ELFEXT phase from pair l to pair k: $\varphi_{c,l \rightarrow k}(f) = \pi - \varphi_{c,k \rightarrow l}(f)$

For capacitive coupling:

- ELFEXT phase from pair k to pair l: $\varphi_{c,k \rightarrow l}(f) = -\frac{\pi}{2} \cdot e^{-f/F_{kl}}$
- ELFEXT phase from pair l to pair k: $\varphi_{c,l \rightarrow k}(f) = -\pi - \varphi_{c,k \rightarrow l}(f)$

Where

- for in-quad pairings: $F_{kl} = 10MHz$
- for inter-quad pairings: $F_{kl} = 50MHz$
- one half of the pairings have capacitive coupling and the other half inductive coupling.

The figure below illustrates the ELFEXT phase model.

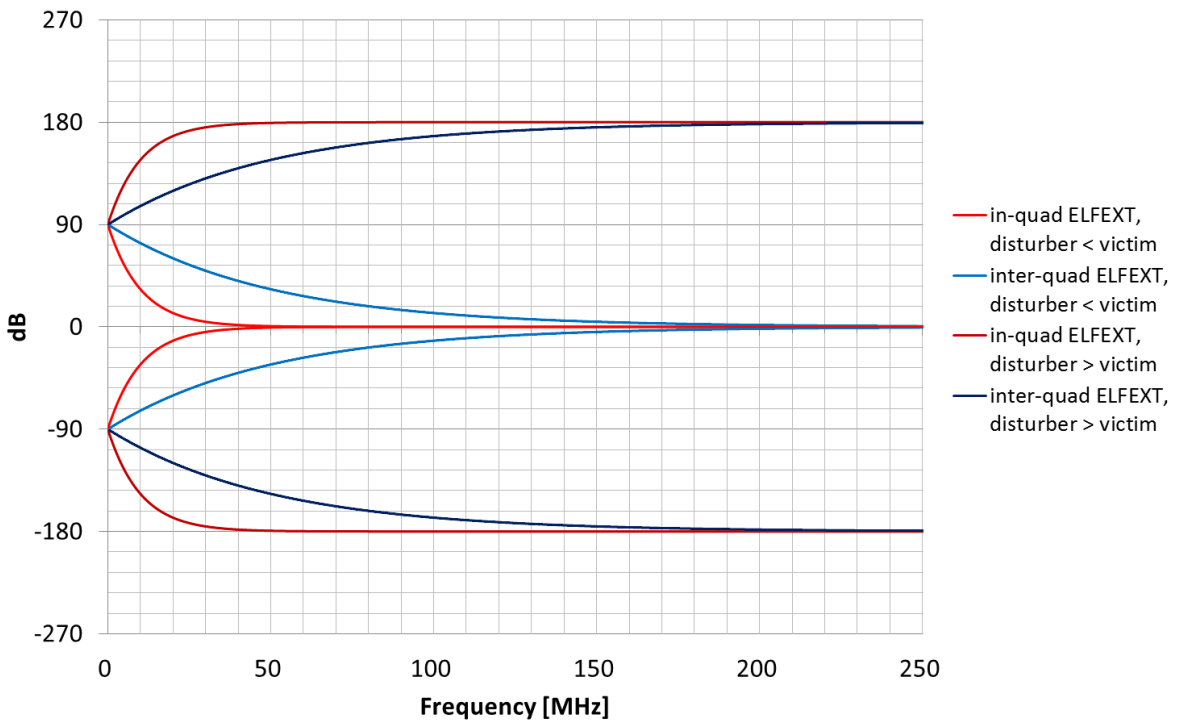


Figure 15 - ELFEXT Phases for PE4D-ALT 10x40x0.6 mm, 100m cable

Given by the large variability of crosstalk observed between different crosstalk pairings in the cable, a statistical approach is used by indicating mean and 95-percentile parameter values. Since in-quad and inter-quad crosstalk differ considerably, parameter values are indicated separately for both cases. For the PE4D-ALT 4x10x0.6 mm cable model all parameters are given in Table 10.

Table 10 - PE4D-ALT 4x10x0.6 mm cable parameters

parameter	ELFEXT inter-quad pairings		ELFEXT in-quad pairings	
	mean	95-percentile	mean	95-percentile
C_{20dB}	-98 dB	-82 dB	-89 dB	-80 dB
C_{40dB}	-150 dB	-127 dB	-127 dB	-122 dB

For both, inter-quad and in-quad pairings, independent normal distributions for the values of C_{20dB} and C_{40dB} in dB can be assumed.

From the model parameters given above f_T is calculated as an example for the two cable lengths 50 and 100 m:

Table 11 - Calculated f_T from the parameters in Table 10

parameter	ELFEXT inter-quad pairings		ELFEXT in-quad pairings	
	mean	95-percentile	mean	95-percentile
f_T at 50m	56 MHz	25 MHz	11 MHz	18 MHz
f_T at 100m	40 MHz	18 MHz	9 MHz	13 MHz

Since the number of inter-quad pairings is dominant in the 4x10x0.6 mm PE4D cable, the statistical parameter values over all pairings of the PE4D-ALT 4x10x0.6 mm cable, compared to those over inter-quad pairings only, are approximately equal.

To build a complete quad cable ELFEXT model, both, an in-quad and an inter-quad crosstalk model is necessary. Even if the share of in-quad crosstalk pairings in a cable is small, in-quad crosstalk still plays a dominant role for self-FEXT cancellation systems (vectoring).

Figure 16 shows the model curves for 100m cable length:

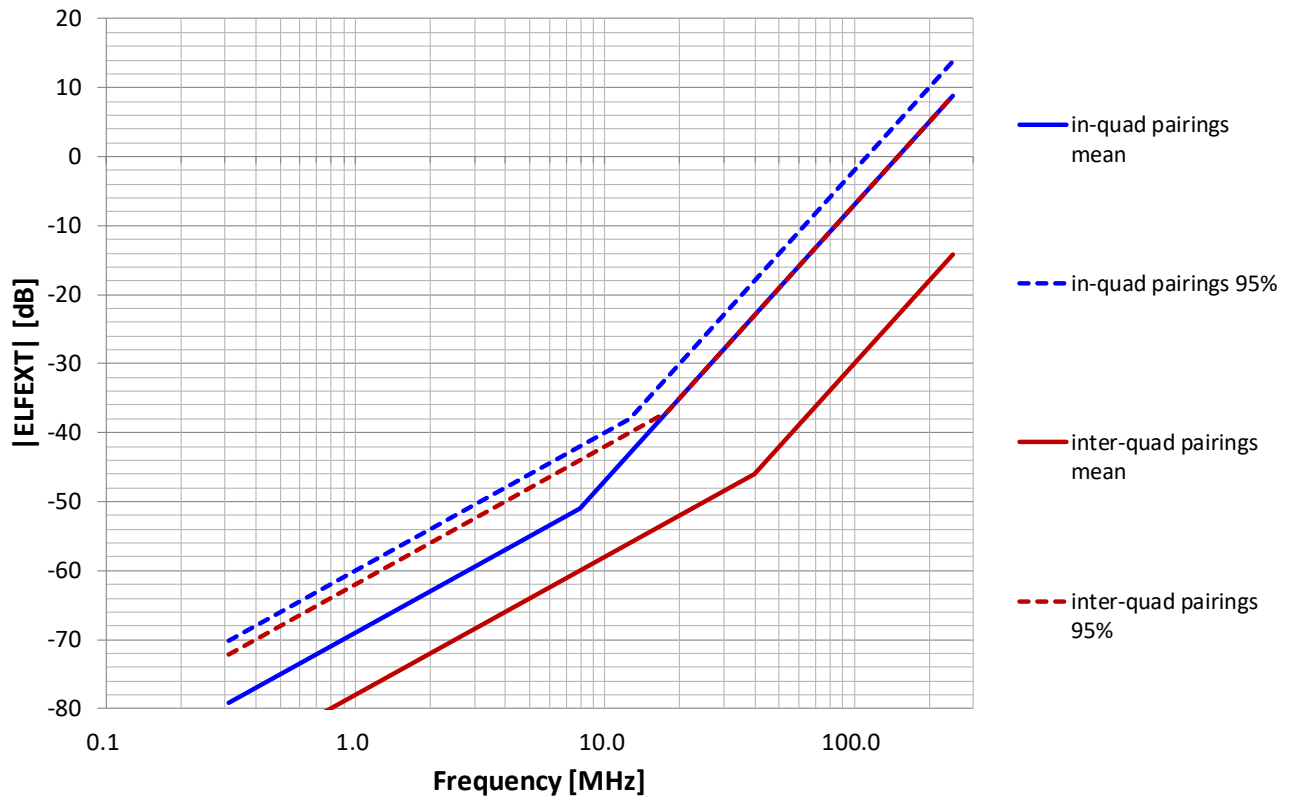


Figure 16 - Statistical Dual Slope ELFEXT Model for 100m PE4D-ALT 4x10x0.6 mm Cable

Figure 17 compares the mean value model curves for 50m and 100m cable length:

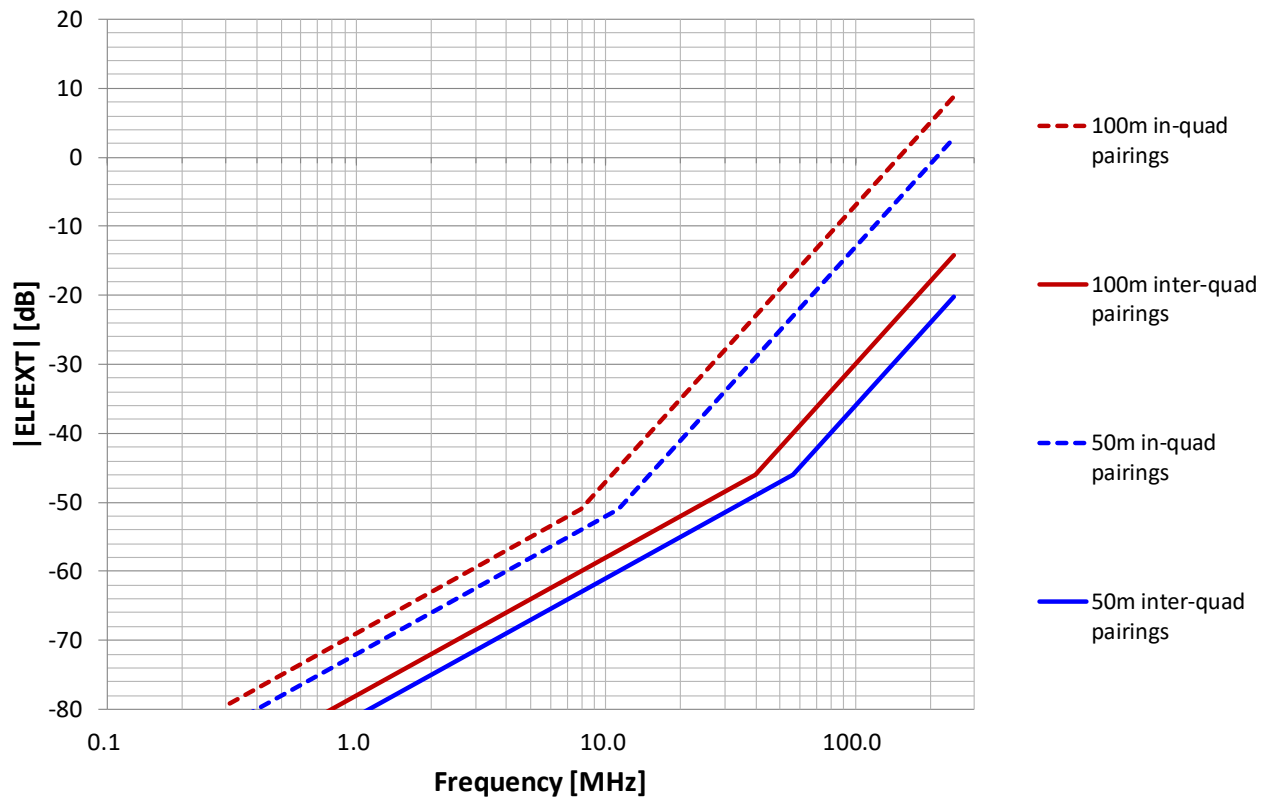


Figure 17 - Statistical Dual Slope ELFEXT Model for PE4D-ALT 4x10x.06 mm Cable. Mean Values for 50m and 100m

The ELFEXT model given reflects the following quad cable crosstalk characteristics, consistently found in experimental cable data:

- In-quad crosstalk is typically higher than inter-quad crosstalk
- The dual slope transition frequency f_T of in-quad crosstalk is typically lower than that for inter-quad crosstalk
- The dual slope transition frequency f_T decreases with cable length

Overall, higher electromagnetic coupling between two pairs means lower dual slope transition frequency f_T .

C.2 Cable Model for P-Pb 4x10x0.6 mm Quad Cable

The P-Pb 4x10x0.6 mm is a paper-air insulated 2-layered star quad cable with lead cable mantle, which used to be deployed mostly in European networks until the 1990's. It consists of 2 core and 8 outer quads.

C.2.1 Insertion Loss

Insertion Loss (IL) is described by the ITU-T single line model. The parameter values for the multi-pair approximation are given in Table 12. The model describes accurately magnitude and phase of Insertion Loss.

Table 12 - ITU-T single line model for P-Pb 10x4x0.6 mm cable

ITU-T Model	$Z_{0\infty}$	η_{VF}	R_{s0}	q_L	q_H	q_x	q_y	q_c	ϕ	f_d
P-Pb 10x4x0.6 mm	130	0.735	0.125	1.5	0.75	2	0	0	0.013	1

Note: The parameters given above correspond to non-deployed cables under lab conditions. It is however known that Insertion Loss of paper-air insulated cables may increase considerably when deployed and not protected sufficiently from humidity.

C.2.2 ELFEXT

The ELFEXT magnitude depending on the frequency is described by a dual slope model with an upper bound of 0dB. The lower slope has 20dB/decade steepness; the upper slope has 40dB/decade steepness. The model assumes homogeneity and linearity over the full cable length. It is expressed by the following formula:

$$|ELFEXT| = \begin{cases} \min(20dB \cdot \log_{10}(f) + 10dB \cdot \log_{10}(x) + C_{20dB}, 0) & 0 < f < f_T \\ \min(40dB \cdot \log_{10}(f) + 20dB \cdot \log_{10}(x) + C_{40dB}, 0) & f \geq f_T \end{cases}$$

Where

$$f_T = 10^{\frac{-10 \cdot \log(x) + C_{20dB} - C_{40dB}}{20dB}} \cdot \text{MHz}$$

f : Frequency in [Hz]

f_T : Transition frequency from 20 to 40dB per decade slope in [MHz]

C_{20dB} : Offset magnitude at 1MHz for 20dB per decade slope for $x = 1m$ in [dB]

C_{40dB} : Offset magnitude at 1MHz for 40dB per decade slope for $x = 1m$ in [dB]

x : Cable length in [m]

The ELFEXT phase is described by the following model:

For inductive coupling:

- ELFEXT phase from pair k to pair l : $\varphi_{c,k \rightarrow l}(f) = \frac{\pi}{2} \cdot e^{-f/F_{kl}}$

- ELFEXT phase from pair l to pair k: $\varphi_{c,l \rightarrow k}(f) = \pi - \varphi_{c,k \rightarrow l}(f)$

For capacitive coupling:

- ELFEXT phase from pair k to pair l: $\varphi_{c,k \rightarrow l}(f) = -\frac{\pi}{2} \cdot e^{-f/F_{kl}}$
- ELFEXT phase from pair l to pair k: $\varphi_{c,l \rightarrow k}(f) = -\pi - \varphi_{c,k \rightarrow l}(f)$

Where

- for in-quad pairings: $F_{kl} = 10 \text{ MHz}$
- for inter-quad pairings: $F_{kl} = 50 \text{ MHz}$
- one half of the pairings have capacitive coupling and the other half inductive coupling.

The figure below illustrates the ELFEXT phase model.

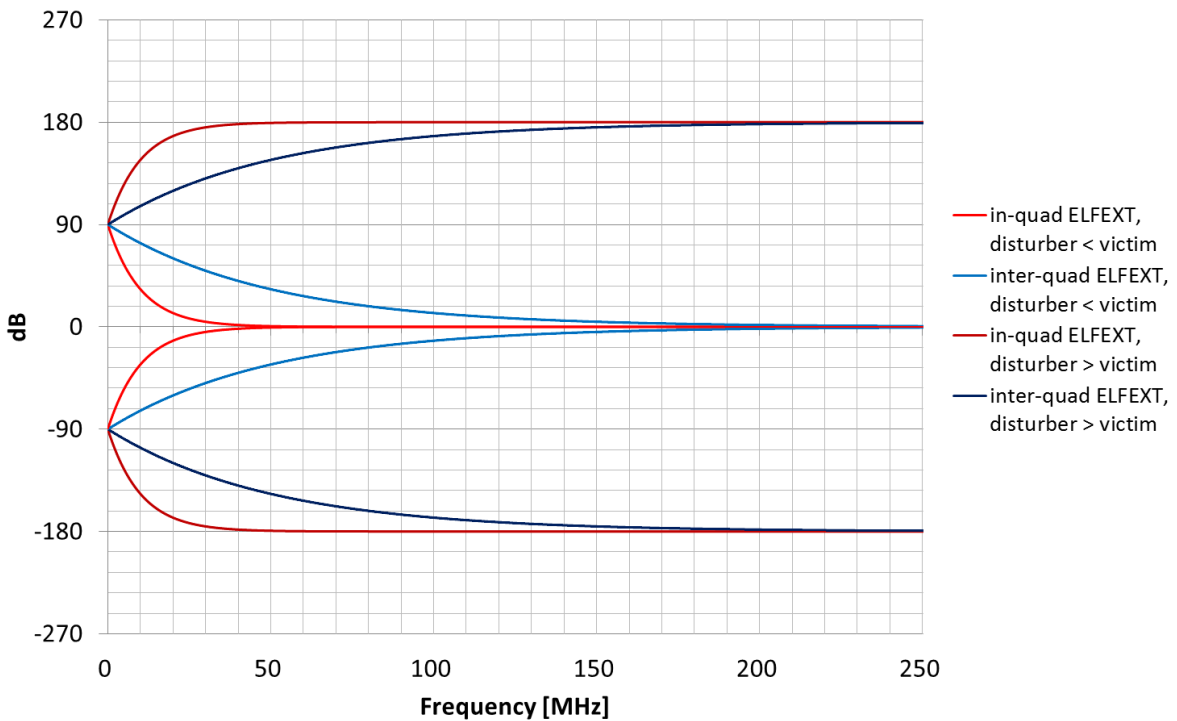


Figure 18 - ELFEXT Phases for the P-Pb 1-x4x0.6 mm, 100m cable

Since the number of inter-quad pairings is dominant in the P-Pb 4x10x0.6 mm cable, the statistical parameter values over all pairings of the P-Pb 4x10x0.6 mm cable, compared to those over inter-quad pairings only, are approximately equal. However, to build a complete quad cable ELFEXT model, both, an in-quad and an inter-quad crosstalk model is necessary. Even if the share of in-quad crosstalk pairings in a cable is small, in-quad crosstalk still plays a dominant role for self-FEXT cancellation systems (vectoring).

Given by the large variability of crosstalk observed between different crosstalk pairings in the cable, a statistical approach is used by indicating mean and 95-percentile parameter values.

For the P-Pb 4x10x0.6 mm cable model all parameters are given in Table 13.

Table 13 - P-Pb 4x10x0.6 mm cable parameters

parameter	ELFEXT inter-quad pairings		ELFEXT in-quad pairings	
	mean	95-percentile	mean	95-percentile
C_{20dB}	-89 dB	-71 dB	-83 dB	-73 dB
C_{40dB}	-136 dB	-121 dB	-116 dB	-89 dB

Note: The parameters given above correspond to a non-deployed cable under lab conditions. It is however known that Crosstalk of paper-air insulated cables may increase considerably when deployed and not protected sufficiently from humidity.

For both, inter-quad and in-quad pairings, independent normal distributions for the values of C_{20dB} and C_{40dB} in dB can be assumed.

From the model parameters given above f_T is calculated as an example for the two cable lengths 50 and 100m:

Table 14 - Calculated f_T from the parameters in Table 13

parameter	ELFEXT inter-quad pairings		ELFEXT in-quad pairings	
	mean	95-percentile	mean	95-percentile
f_T at 50m	32 MHz	45 MHz	6 MHz	1 MHz
f_T at 100m	22 MHz	32 MHz	4 MHz	1 MHz

Figure 19 shows the model curves for 100m cable length:

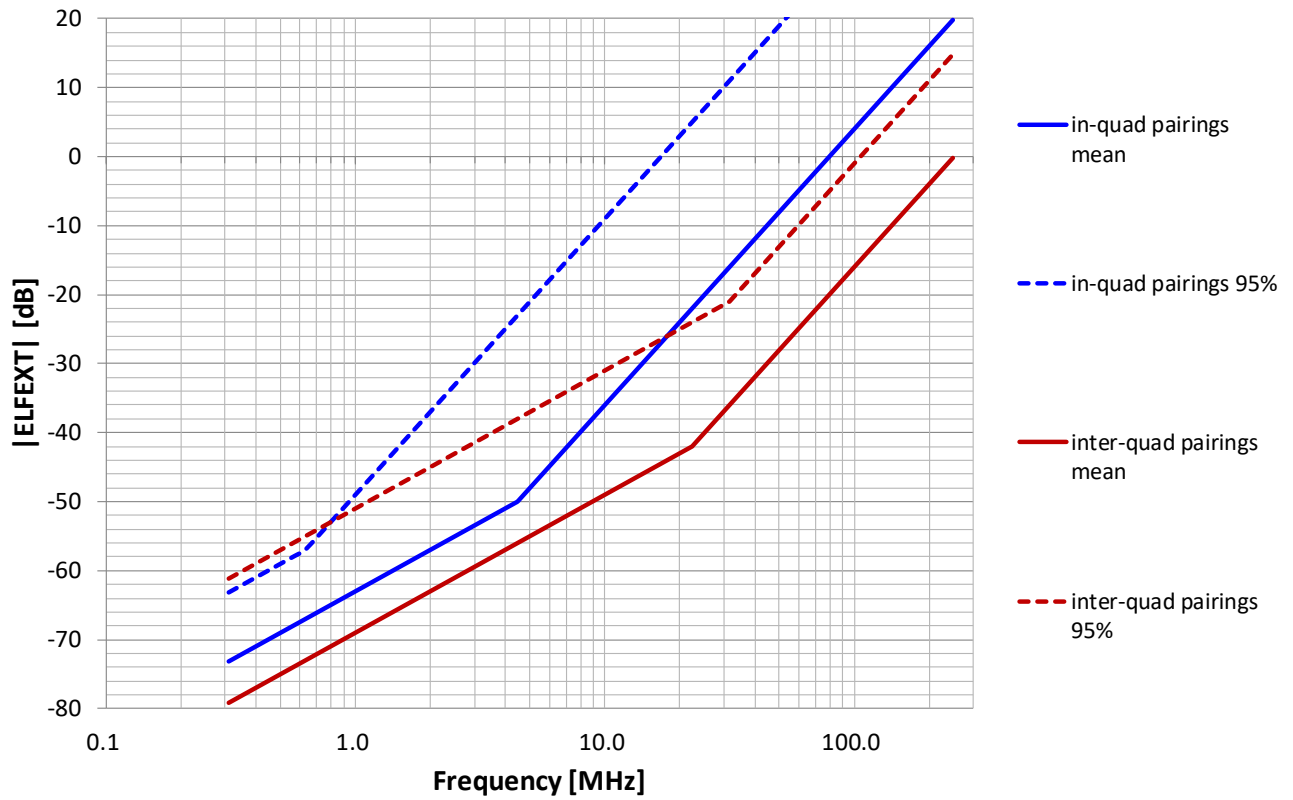


Figure 19 - Statistical Dual Slope ELFEXT Model for 100m P-Pb 4x10x0.6 mm Cable

Figure 20 compares the mean value model curves for 50m and 100m cable length:

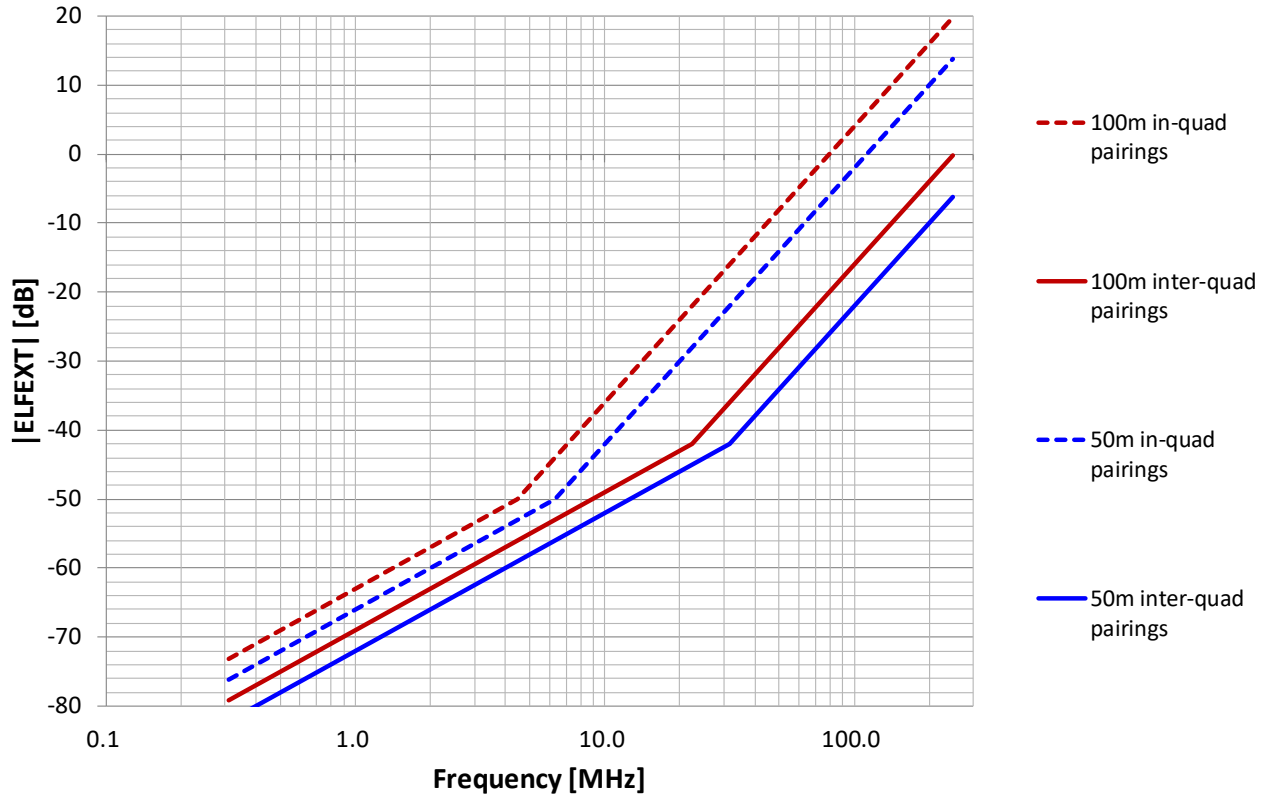


Figure 20 - Statistical Dual Slope ELFEXT Model for P-Pb 4x10x0.6 mm Cable

The ELFEXT model given reflects the following quad cable crosstalk characteristics, consistently found in experimental cable data:

- In-quad crosstalk is typically higher than inter-quad crosstalk
- The dual slope transition frequency f_T of in-quad crosstalk is typically lower than that for inter-quad crosstalk
- The dual slope transition frequency f_T decreases with cable length

Overall, higher electromagnetic coupling between two pairs means lower dual slope transition frequency f_T .

C.3 ELFEXT Cable Models for Swiss In-House Cables

C.3.1 Background

To provide the higher bandwidths required, G.fast and possible follow-up technologies like G.mgfast are using larger frequency spectra (106 MHz, 212 MHz etc. up to 1 GHz). This reduces the loop lengths where such systems can be used. FTTB would then be a typical use case. Consequently, the influence of the in-house part of the copper loop on these systems is becoming more dominant.

In Switzerland, the outdoor plant copper cable enters the building and ends at the in-house patch panel usually on the ground level. In the figure below, a typical in-house phone cabling can be seen: Starting from the patch panel, different (in-house) cables are distributed to the apartments of the building. Each apartment is connected to the patch panel by a dedicated cable. In the vertical riser of the building the in-house cables run through a common duct/tube. Leaving the vertical riser, the cables run through horizontal ducts to the dedicated apartments terminating at the respective phone sockets. Consequently, in-house cables run through common ducts over certain distances (5-20m) in a building. Unlike outdoor plant cables, in-house cables are not shielded and there will be interaction between them (crosstalk, coupling).

For illustration, a figure of a typical FTTB installation of an MDU is shown. In this case the remaining copper loop mostly consists of legacy in-house cable.

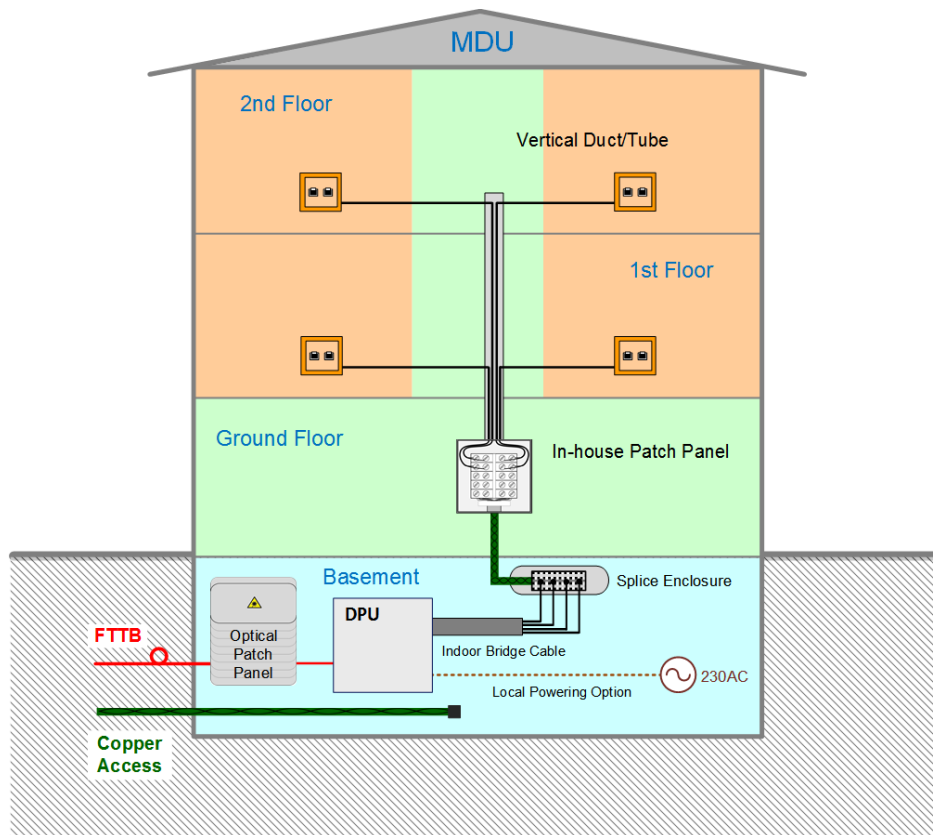


Figure 21 - Typical FTTB Installation of a Swiss MDU

For testing and simulation purposes, it is therefore crucial to have accurate cable models for in-house cables.

C.3.2 In-House Cable Types Models.

ELFEXT parameters were extracted from measurement data up to 1 GHz for the following typical Swiss in-house cables:

Table 15 - In house cable models

Name	Description
I51 1x2x0.8	Un-twisted double wire cable consisting of 0.8 mm PVC insulated copper wires
I83 1x2x0.6	Low quality twisted pair cable consisting of 0.6 mm PVC insulated copper wires, no cover
U72 1x4x0.5	Single-quad cable consisting of 4 twisted 0.5 mm PVC insulated copper wires, LSZH cover, un-shielded

To reproduce the real in-house situation, a single loop of 25 mm diameter tube of 25m length was considered, loaded alternatively with

- 8 I51 cables,
- 8 I83 cables or
- 4 U72 cables (4 quads equiv. 8 pairs)

The data measured for this setup was fitted by the dual slope model for ELFEXT of TR-285 amendment 1, annex C1.2.

Whereas the ELFEXT data of the I83 and U72 cables returned parameter values for the dual slope fit, the (un-twisted) I51 cable data did not reveal the second (40 dB per decade) slope. Thus, the I51 ELFEXT data were fitted with a single (20 dB per decade) slope. Since the U72 is a quad cable, a separate fit for in-quad ELFEXT was extracted.

The offset values found for each slope are given in the following table. For the model, the statistical distributions of the offset values can be assumed Gaussian.

Table 16 - Offset values for the in-house cables models

ELFEXT slope	offset@1 MHz 20dB/decade	offset@1 MHz 40dB/decade
8x I51, mean	-56 dB	-
8x I51, 95%	-52 dB	-
8x I83, mean	-78 dB	-121 dB
8x I83, 95%	-67 dB	-116 dB
4x U72 all, mean	-79 dB	-129 dB
4x U72 all, 95%	-70 dB	-117 dB
4x U72 in-quad, mean	-76 dB	-120 dB
4x U72 in-quad, 95%	-70 dB	-117 dB

The curves of the extracted models are represented in the graph below:

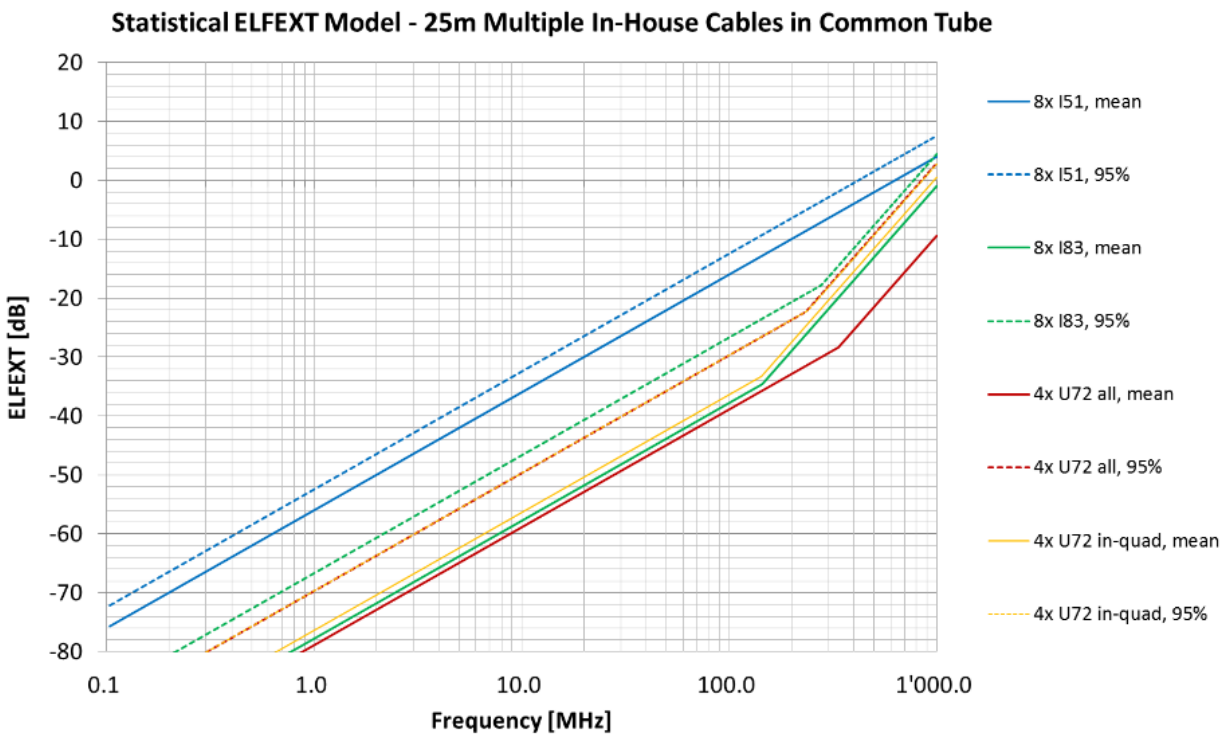


Figure 22 - Statistical ELFEXT Model – 25m Multiple In-House Cables is a Common Tube

Whereas the twisted I83 and U72 have a similar ELFEXT level, the ELFEXT level of the un-twisted I51 is about 20 dB higher.

Annex D: Coax Cable Configuration Based on North American Use Cases / Applications.

This section defines the reference cable models, configuration and characteristics of the main functional blocks of the point-to-point G.fast over coaxial cable use cases.

D.1.1 Coax Cable Configuration – No Baluns

In Figure 23 and Figure 24 all cable sections are RG6 type coax and all connectors are F type. Polyethylene foam is used for coax insulation; the center conductor may be copper-clad steel.

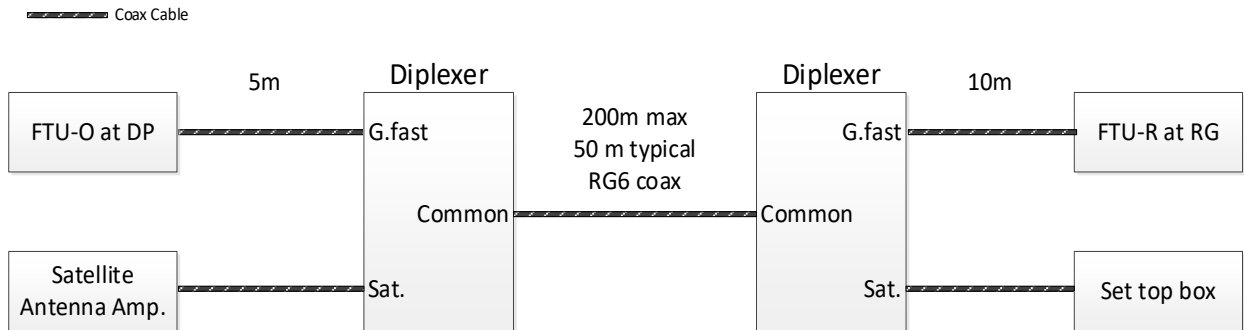


Figure 23 - Coax configuration for G.fast with Satellite TV

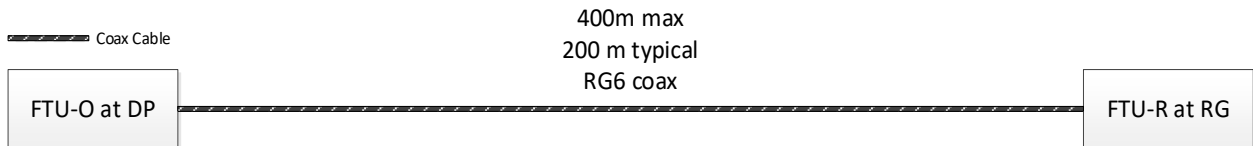


Figure 24 - Coax configuration with G.fast only

Both diplexers have identical characteristics. There are typically no splitters or bridged taps in the G.fast path. There are no in-line amplification devices in the G.fast or satellite signal path. The signals at the Satellite port reside at 2.3 MHz and 950 to 2150 MHz.

Typical diplexer characteristics are as follows:

- a) From G.fast port to common port:

Passband:	0-0.5 and 5-806 MHz
Insertion loss:	≤ 5 dB from 30 kHz to 500 kHz
	≤ 4 dB from 4 to 5 MHz
	≤ 2 dB from 6 to 7 MHz
	≤ 1.5 dB from 8 to 212 MHz
	≤ 2.5 dB 212 to 860 MHz
	> 40 dB out of band

Return loss with all ports terminated with 75 ohms: 10 dB

- b) The diplexer provides DC isolation between the satellite port and the common and G.fast ports

D.1.2 Coax Cable Configuration – With Baluns

All cable sections in Figure 25 and Figure 26 are RG6 type coax except as shown in the figures. All coax connections are F type.

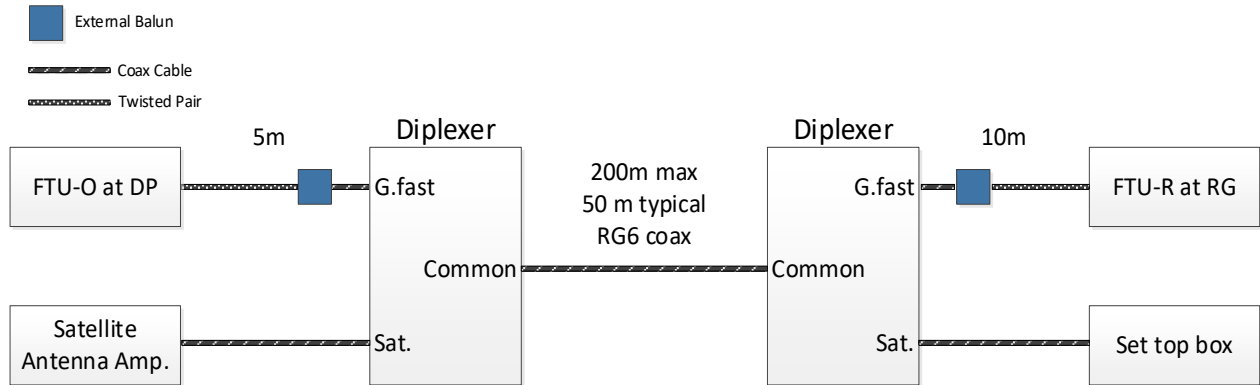


Figure 25 - Coax configuration for G.fast with Satellite TV (With Baluns)

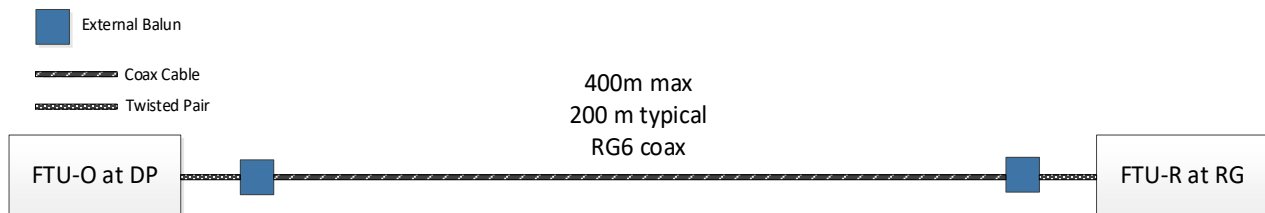


Figure 26 - Coax configuration with G.fast only (With Baluns)

Typical characteristics of the external balun are:

- DC pass SHALL be provided for the reverse powering.
- Impact on performance of the G.fast link SHOULD be negligible.

D.1.3 Coax Cable Model / Characteristics

The coax cable signal loss characteristics in dB per 100m are shown in Table 17:

Table 17 - Inseration loss characteristic of coax cable types [6]

	RG-59	RG-6	RG-11
1 MHz	1.31	0.66	0.66
10 MHz	4.59	1.97	1.31
50 MHz	5.90	4.59	3.28
100 MHz	8.86	6.56	5.25
200 MHz	11.81	9.18	7.54
400 MHz	16.07	14.10	11.48
700 MHz	22.63	18.37	15.42
900 MHz	25.58	19.68	17.71
1000 MHz	27.22	20.00	18.37
2150 MHz	39.69	32.47	21.65
IL (dB)/ 100m			

The maximum distance of the coax deployment is modelled by RG-6 cable is shown in Figure 23 and Figure 24. A longer coax deployment distance is possible by utilizing the lower loss RG-11 cable. Conversely, the maximum coax distance could be reduced with RG-59 cable to the equivalent loss distance of the RG-6.

The exponential approximation of the coax insertion loss characteristic is given by:

$$IL = a f^b + c f + d \quad (\text{dB}/100\text{m})$$

$$f = \text{Frequency in MHz}$$

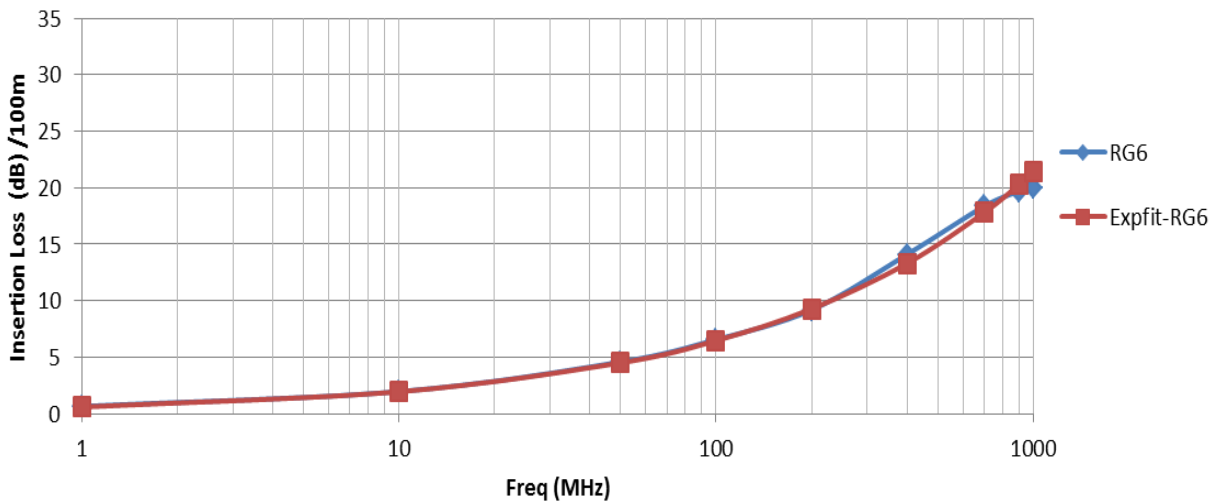


Figure 27 - Exponential Approximation of Coax Insertion Loss vs. Frequency for RG-6.

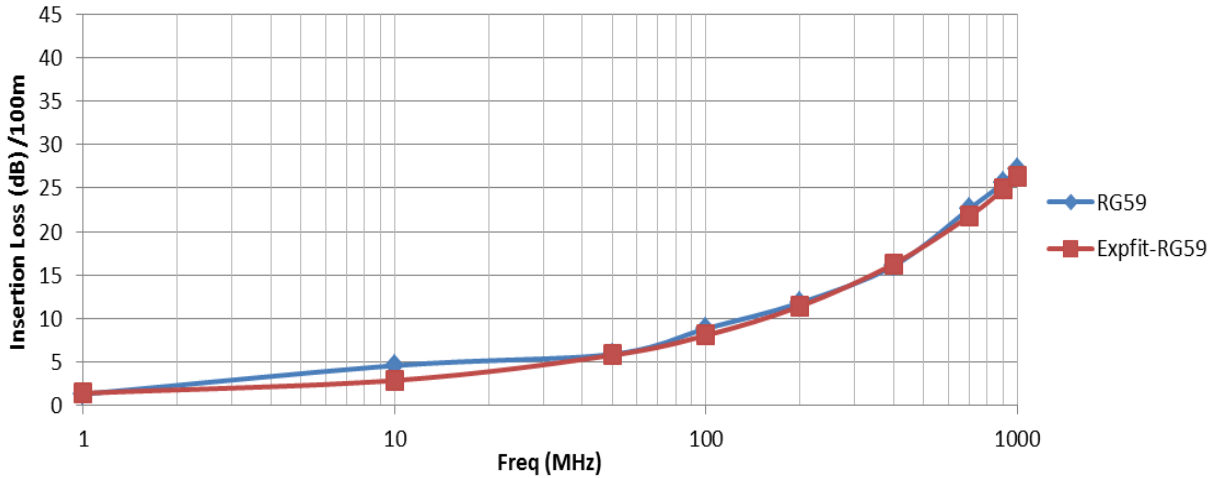


Figure 28 - Exponential Approximation of Coax Insertion Loss vs. Frequency for RG-59.

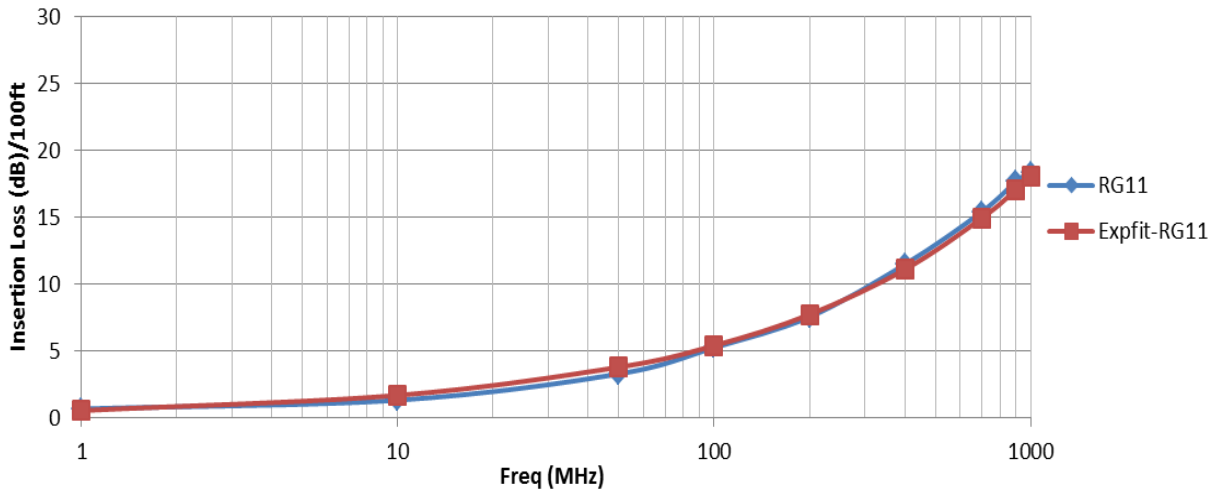


Figure 29 - Exponential Approximation of Coax Insertion Loss vs. Frequency for RG-59.

The approximation coefficients for each of the coax cable are given in Table 18 below with MAE (Mean Absolute Error) < 0.5 dB within 1 GHz band.

Table 18 - Exponential approximation of coax cable insertion loss coefficients.

Cable Type/Coefficients	a	b	c	d
RG-6	0.5904	0.525	0	0
RG-59	0.5904	0.545	0	0.82
RG-11	0.5248	0.5	0.0015	0

In addition to the attenuation approximation, there are interests in simulating the time domain models of the coaxial cable based on circuit analysis.

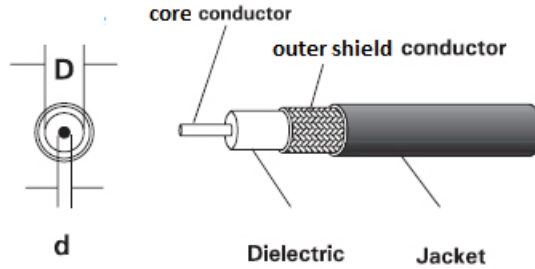


Figure 30 - Typical Cable Construction [7]

D = the inner diameter of the shield

d = the outer diameter of the core conductor

The characteristic impedance of the coaxial cable can be calculated as

$$Z_0 = \frac{138}{\sqrt{\epsilon_r}} \log\left(\frac{D}{d}\right)$$

Where

ϵ_r = the **relative** dielectric constant of the dielectric between the outer shield and the core

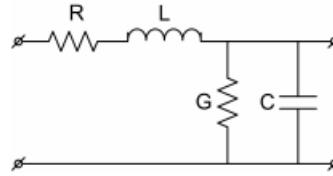
Table 19 - Typical coax characteristic [7]

Cable Type	d (mm)	D (mm)	Z ₀ (ohm)	R _{DC} (ohm/km)	C(pF/m)	V _p
RG-6	1.024	4.7	75	18.04	53	0.83
RG-59	0.58	3.7	75	33.292	67	0.68
RG-11	1.63	7.25	75	5.6	66	0.84

The relative propagation velocity is the ratio between velocity in cable and the free-space velocity which is near the speed of light at 3×10^8 m/sec or 984 ft / μ s.

$$V_p = \frac{1}{\sqrt{\epsilon_r}}$$

The R,L,G,C parameters could be derived from these basic circuit elements for construction of the impulse response of the coaxial cable similar to what is done for the twisted-pair cable.



$$L = \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{D}{d}\right); C = \frac{2\pi \epsilon_0 \epsilon_r}{\ln\left(\frac{D}{d}\right)}; G \sim 0$$

Figure 31 - RLGC Circuit model for Coax Cable

Note: The relative permeability (μ_r) of the copper and aluminum used in typical coax cable (such as RG-6, RG-11 and RG-59) approximately equals to 1

Annex E: TP100 Line Model up to 215 MHz

E.1 Line Model for single pair TP100 for frequencies up to approximately 250 MHz

$$[Z_s, Y_p] = Model(Z_{0\infty}, \eta_{VF}, R_{s0}, q_L, q_H, q_c, q_x, q_y, \phi, f_d)$$

$Z_s(j\omega) = j\omega \cdot L_{s\infty} + R_{s0} \times \left(1 - q_s \cdot q_x + \text{sqrt} \left(q_s^2 \cdot q_x^2 + 2 \cdot \frac{j\omega}{\omega_s} \cdot \left(\frac{q_s^2 + j\omega / \omega_s \cdot q_y}{q_s^2 / q_x + j\omega / \omega_s \cdot q_y} \right) \right) \right)$ $Y_p(j\omega) = j\omega \cdot C_{p0} \times (1 - q_c) \times \left(1 + \frac{j\omega}{\omega_d} \right)^{-2\phi/\pi} + j\omega \cdot C_{p0} \times q_c$	$L_{s\infty} = \frac{1}{\eta_{VF} \cdot c_0} \times Z_{0\infty}$ $C_{p0} = \frac{1}{\eta_{VF} \cdot c_0} \times \frac{1}{Z_{0\infty}}$ $q_s = \frac{1}{q_H^2 \cdot q_L}$ $\omega_s = q_H^2 \cdot \omega_{s0} = q_H^2 \cdot \left(\frac{4\pi \cdot R_{s0}}{\mu_0} \right)$ $\omega_d = 2\pi \cdot f_d$
$c_0 = 3 \cdot 10^8 \text{ [m/s]}$ $\mu_0 = 4\pi \cdot 10^{-7} \text{ [H/m]}$	

Table 20 - TP100 cable parameters

Cable Line type	Parameters of model
TP100	$Z_{0\infty} = 97.561$ $\eta_{VF} = 0.73193$ $R_{s0} = 0.17876$ $q_L = 1.2692$ $q_H = 0.78886$ $q_x = 0.87734$ $q_y = -0.24741$ $q_c = 1.1678$ $\phi = -0.015866$ $f_d = 2.5353$

E.2 TP100 / G.fast - Insertion Loss table

For illustration: the insertion loss calculated for a length of 100m with 100Ω terminations
 - up to 99 dB attenuation that is reached at 1 GHz.

Table 21 - TP100 insertion loss

frequency	TP100 insertion loss
10 kHz	744.7 mdB
14.68 kHz	745.6 mdB
21.54 kHz	747.6 mdB
31.62 kHz	751.5 mdB
46.42 kHz	759.5 mdB
68.13 kHz	775.2 mdB
100 kHz	804.8 mdB
146.8 kHz	855.9 mdB
215.4 kHz	936.5 mdB
316.2 kHz	1.053 dB
464.2 kHz	1.218 dB
681.3 kHz	1.455 dB
1 MHz	1.798 dB
1.468 MHz	2.214 dB
2.154 MHz	2.718 dB
3.162 MHz	3.331 dB
4.642 MHz	4.082 dB
6.813 MHz	5.005 dB
10 MHz	6.147 dB
14.68 MHz	7.567 dB
21.54 MHz	9.339 dB
31.62 MHz	11.56 dB
46.42 MHz	14.36 dB

68.13 MHz	17.91 dB
100 MHz	22.44 dB
146.8 MHz	28.28 dB
215.4 MHz	35.84 dB
316.2 MHz	45.74 dB
464.2 MHz	58.81 dB
681.3 MHz	76.26 dB
1 GHz	99.74 dB

E.3 TP100 / G.fast Impedance and group delay

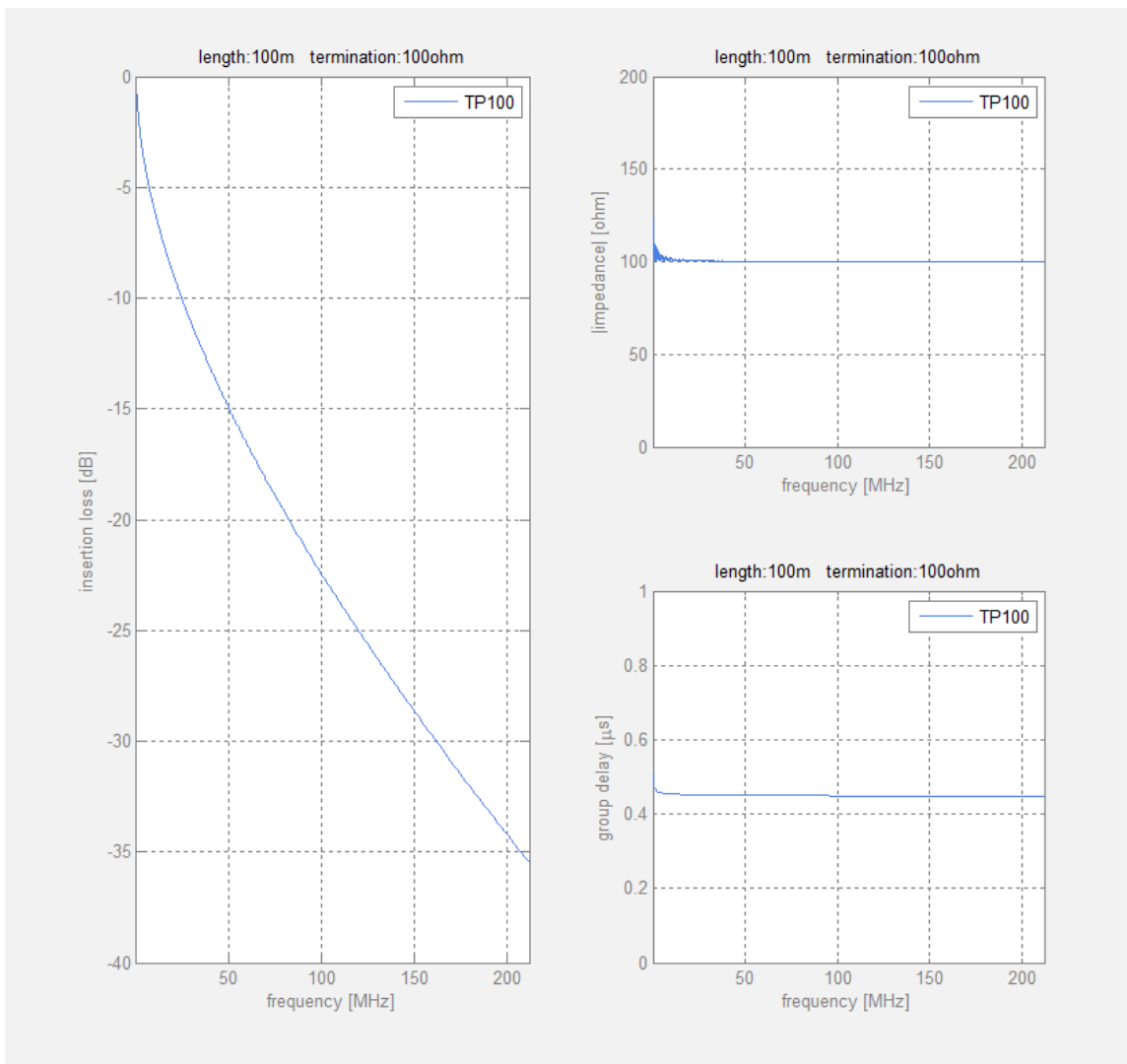


Figure 32 - Insertion loss, impedance and group delay on linear frequency grid.

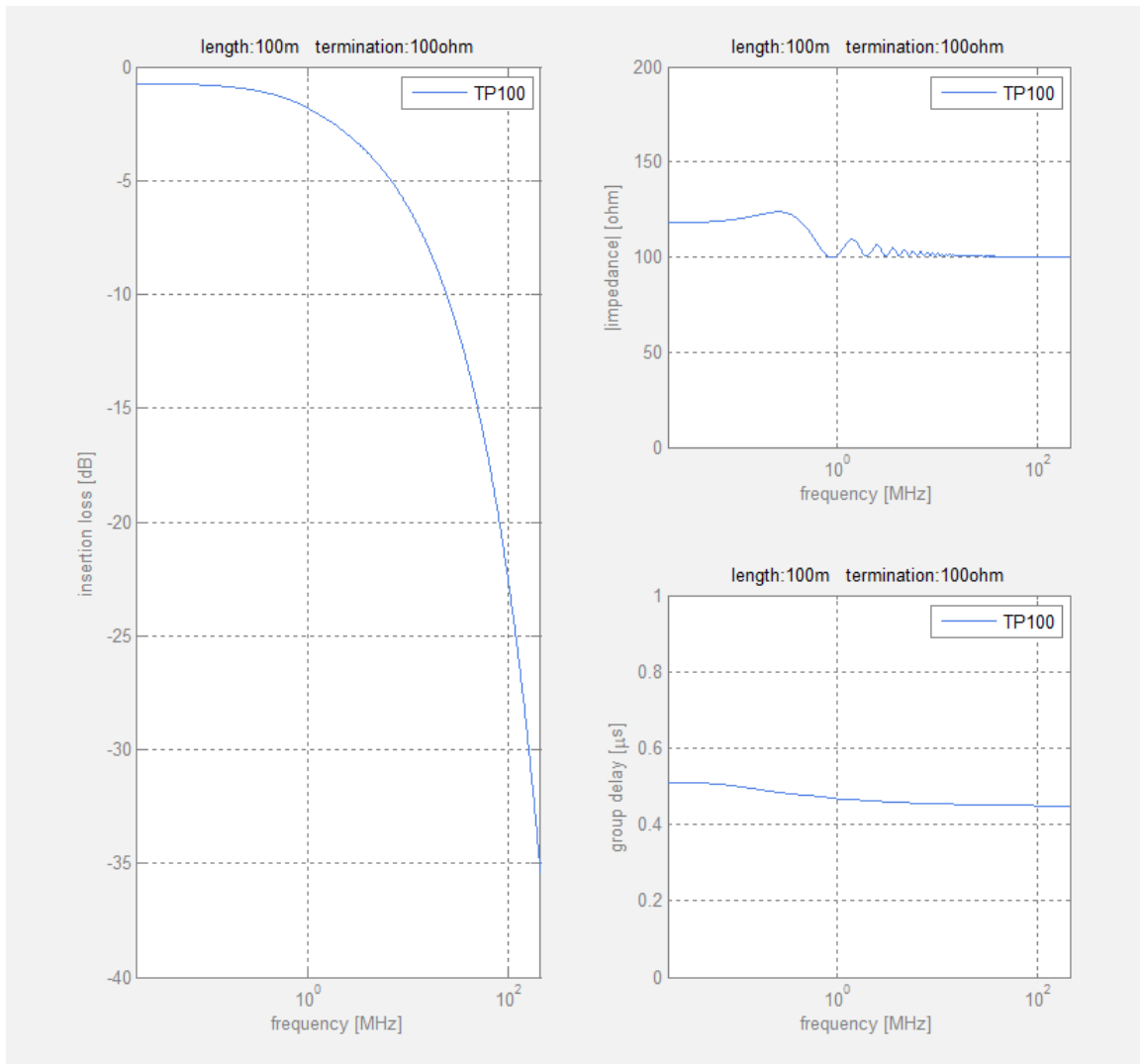


Figure 33 - Insertion loss, impedance and group delay on logarithmic frequency grid:

E.4 ELFEXT of Twisted pair TP100

Figure 34 shows the ELFEXT for 100 m loop length of one pair as victim and the adjacent pair as disturber in a twisted pair cable of 50 pairs. This curve represents the 'averaged highest' crosstalk level within the TP100 twisted multi-pair bundle.

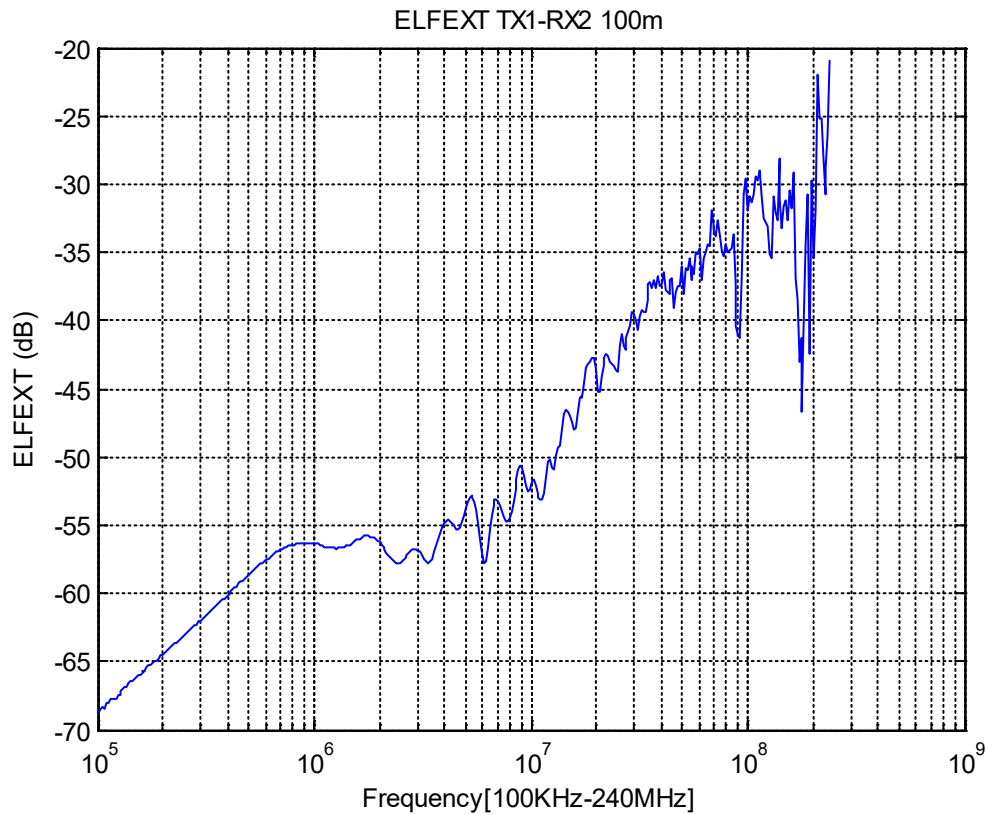


Figure 34 - TP100 twisted pair ELFEXT of one pair victim and adjacent pair as disturber.

E.4.1 Power Sum ELFEXT of Twisted pair TP100

Figure 35 shows the measured sum of ELFEXT for 100m loop length of one pair as victim and all other pairs as disturbers. It represents the 'highest' crosstalk level within a TP100 twisted multi-pair bundle.

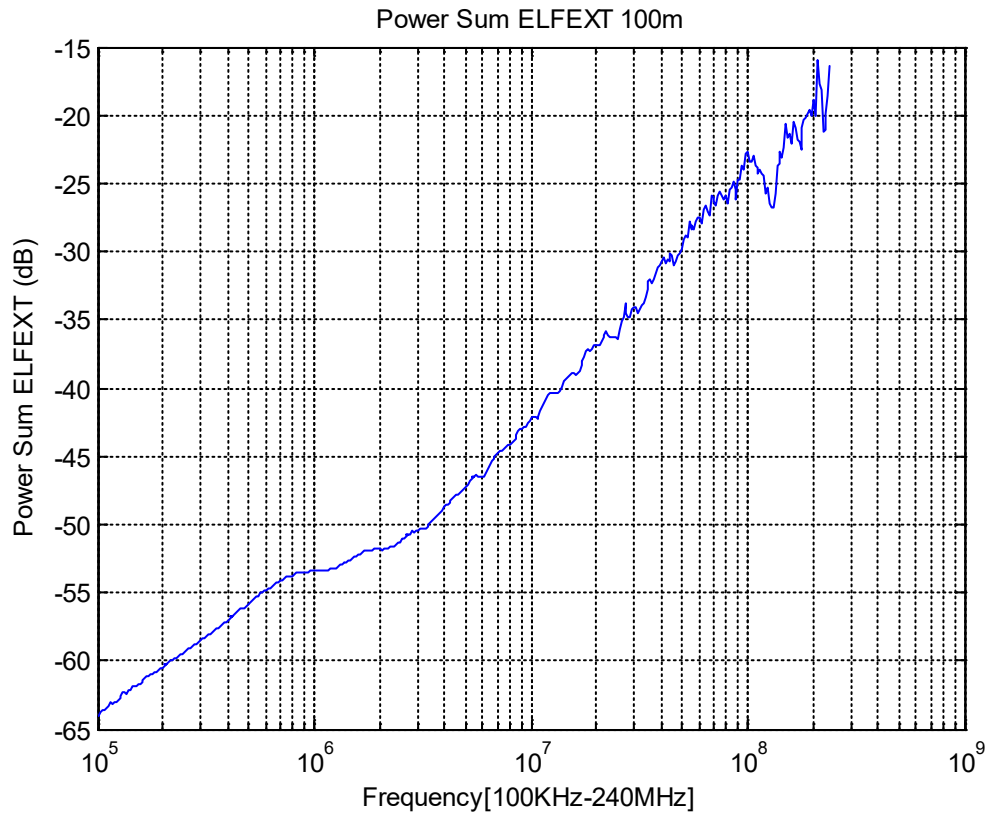


Figure 35 - Averaged Power Sum level of ELFEXT of one pair victim with all other pairs as disturbers in a TP100 multi-pair QUAD

E.4.2 Crosstalk Model

A crosstalk model is not provided.

E.5 ELFEXT of QUAD TP100

Figure 36 shows the ELFEXT for 100m loop length of one pair as victim and the adjacent pair as disturber in a 5 QUAD cable. This curve represents the 'averaged highest' crosstalk level within the TP100 QUAD multi-pair bundle.

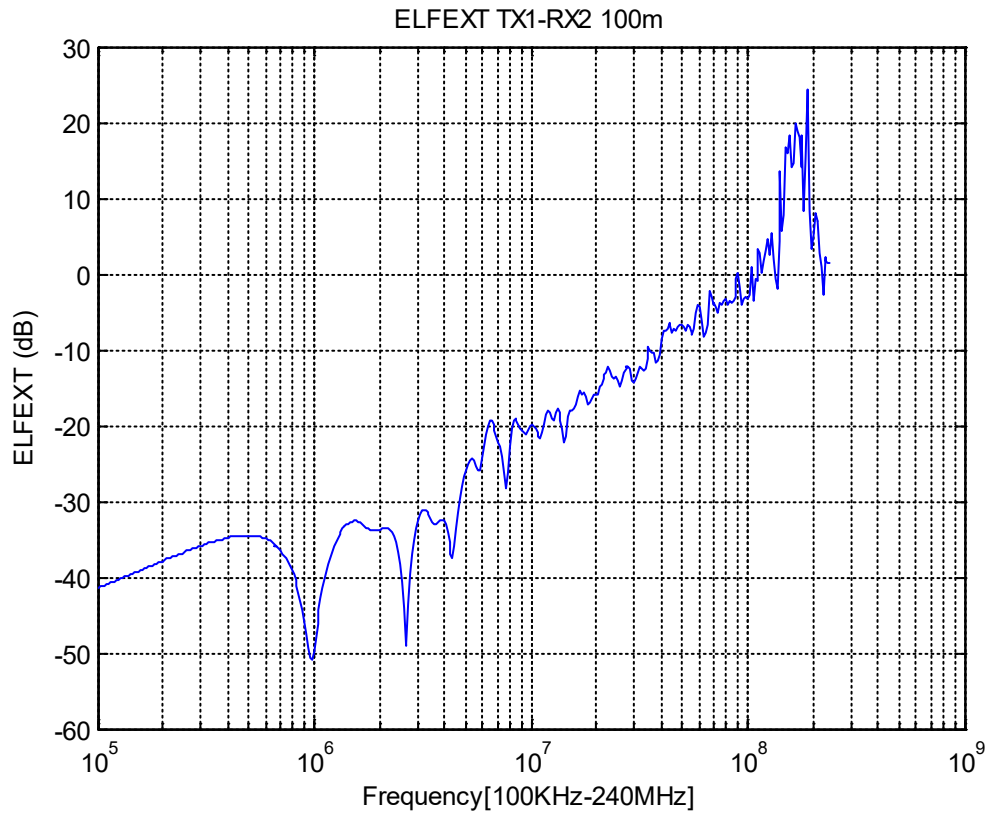


Figure 36 - TP100 QUAD ELFEXT of one pair victim and adjacent pair as disturber.

E.5.1 Power Sum ELFEXT of QUAD TP100

Figure 37 shows the highest measured Sum of ELFEXT for 100m loop length of one pair as victim and all other pairs as disturbers. It represents the 'highest' crosstalk level within a TP100 QUAD multi-pair bundle.

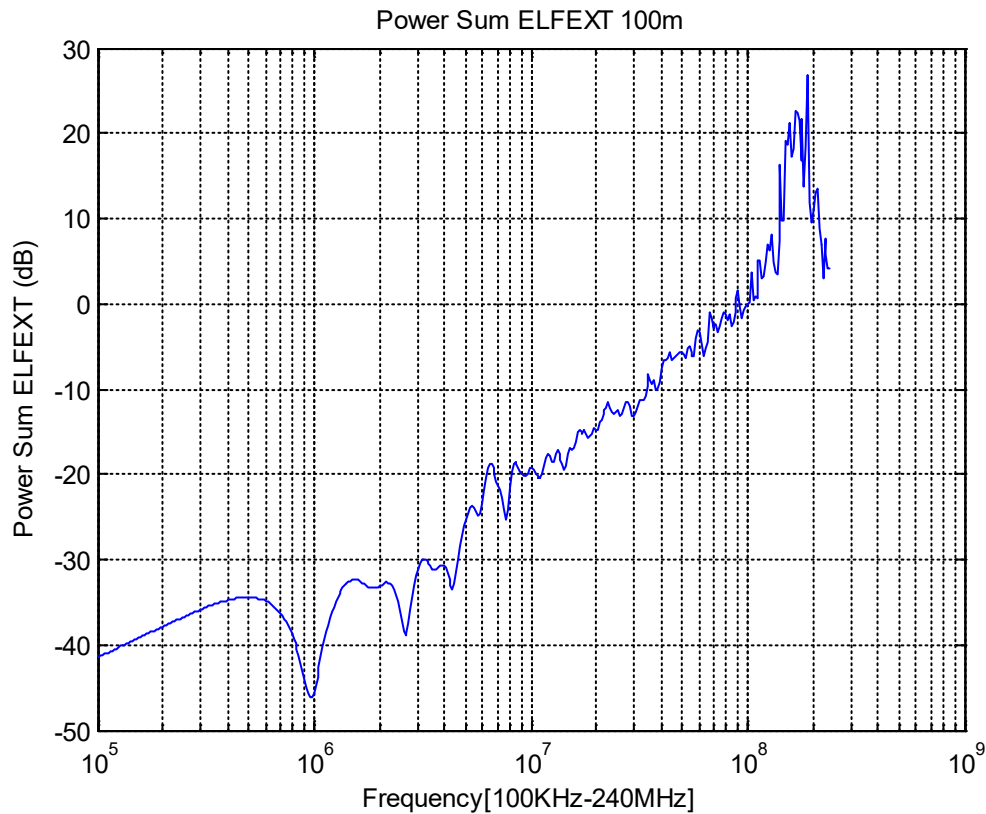


Figure 37 - Sum of ELFEXT on one pair victim and all other pairs as disturbers in a TP100 QUAD cable.

E.5.2 Crosstalk Model

A crosstalk model is not provided.

Annex F: 24AWG Twisted Pair Cable Model

F.1 Model Specification

This section provides a cable model for 24 AWG twisted pair cable.

F.2 Single Line -Direct Path Specification

F.2.1 Nomenclature

The following nomenclature will be used:

d = the length of Single Line- Direct Path in meters.

$R(f)$, $L(f)$, $C(f)$, $G(f)$ are the distributed transmission line resistance, inductance, inductance per meter. Note these are each a function of frequency where the frequency is in units of Hz. The units respectfully are Ω , H, F, Mhos per meter.

$Z(f)$ and $Y(f)$ are the distributed transmission line series impedance and shunt admittance per meter. These are defined as:

$$Z(f) = R(f) + j2\pi f L(f) \quad (1)$$

$$Y(f) = G(f) + j2\pi f C(f) \quad (2)$$

where $j = \sqrt{-1}$.

$\gamma(f)$ is the complex transmission line exponent defined as:

$$\gamma(f) = \alpha(f) + j \beta (f) \quad (3)$$

and is given by the formula:

$$\gamma(f) = [Z(f) Y(f)]^{0.5} \quad (4)$$

Z_0 = The characteristic impedance and is given by the formula:

$$Z_0 = [Z(f)/Y(f)]^{0.5} \quad (5)$$

Z_s = The internal impedance of the modem. Note: for computational purposes this is often set =100 Ohms

Z_L =The load impedance of the receiving modem. Note: for computational purposes this is often set = 100 Ohms.

F.2.2 Specification of the Transmission Line Parameters

The direct path transmission line characteristics; The Input Impedance and the Transfer Function- which provides the Attenuation, Phase and Group Delay, are dependent upon the complex transmission line exponent, γ . The Input Impedance is dependent upon γ and the Characteristic Impedance, Z_0 . As evident from the previous section the complex transmission line exponent, γ , and The Characteristic Impedance, Z_0 are direct functions of $R(f)$, $L(f)$, $C(f)$, $G(f)$. For the model presented herein these are specified precisely in this section.

The specification is based upon measurements made using the Superior Essex cable 02-097-03 which has 25 pairs and has a cable diameter of 0.51 mm- because this is a representative multi-pair cable type used in an actual service area. These measurements have been over a frequency band which extends to 500 MHz so to assure that the resultant model is applicable to G.fast testing.

$R(f)$, $L(f)$, $C(f)$ and $G(f)$ are specified by the following formulas- constants in the formulas are given in Table 22.

$$R(f) = [1/((1/R_i(f)) + (1/R_r(f)))]/1000 \quad (6)$$

Where:

$$R_i(f) = [r_{oc}^4 + a_c f^{2.3}]^{0.25} \quad (7)$$

$$R_r(f) = [r_{os}^4 + a_s f^2]^{0.25} \quad (8)$$

$$L(f) = ([L_{num}(f) / L_{den}(f)]/1000) \times 10^{-6} \quad (9)$$

Where:

$$L_{num} = l_0 + l_\infty (f/f_m)^b \quad (10)$$

$$L_{den}(f) = 1 + (f/f_m)^b \quad (11)$$

$$C(f) = ([C_\infty + C_0 f^{cc}]/1000) \times 10^{-9} \quad (12)$$

$$G(f) = ([G_0 f^{gc}]/1000) \times 10^{-12} \quad (13)$$

Table 22 - 24 AWG twisted pair cable constants

Resistance	r_{oc} Ω/km	r_{os} Ω/km	a_c	a_s
(value)	(174.559)	∞	0.05307	0.0
Inductance	l_0 $\mu\text{H}/\text{km}$	l_∞ $\mu\text{H}/\text{km}$	b	f_m
(value)	(617.295)	478.971	1.15298	553,760
Capacitance	C_∞ nF/km	C_0 nF/km	ce	
(value)	50	0	0	
Conductance	G_0 pMho/km	ge		
(value)	0.234875	1.38		

F.2.3 Input Impedance, Z_{in}

This is specified as:

$$Z_{in} = Z_0 [(Z_L + Z_0 \tanh(\gamma d)) / [(Z_0 + Z_L \tanh(\gamma d))] \quad (14)$$

Both γ and Z_0 are functions of frequency, “f” in Hz and are computable from the specifications provided in Section F.2.1 and Section F.2.2. For purposes of simplifying the expression this dependence on “f” has been suppressed in the expression.

F.2.4 Transfer Function

The end-to-end transfer function of the direct path is given by:

$$H_{DP}(f, d) = [Z_{in} / (Z_{in} + Z_S)] T_{DP} \quad (15)$$

Here:

$$T_{DP}(f, d) = [\cosh(\gamma d) + (Z_0 / Z_L) \sinh(\gamma d)]^{-1} \quad (16)$$

$Z_{in}(f, d)$ = the input impedance specified in Section F.2.3

H_{DP} , T_{DP} and Z_{in} are, in general, complex quantities. When convenient, for simplification in the sequel, the functional dependence upon “f” and “d” will be suppressed.

The end-to-end attenuation is given by $|H_{DP}|$. The “dB” version will be $|H_{DP}| \text{ dB} = 20 \text{ Log } |H_{DP}|$.

The insertion loss is given by $|T_{DP}|$. The “dB” version will be $|T_D| \text{ dB} = 20 \text{ Log by } |T_{DP}|$.

Logarithms are to base 10 unless otherwise noted.

The end-to-end phase, “Phase_{DP},” in radians is given by $\text{Angle}(H_{DP})$. (17)

The end- to -end Group delay in nano= seconds is given by:

$$\text{Group Delay}_{DP} = - ((\partial\text{Phase}_{DP}/\partial f)/(2\pi)) 10^9. \tag{18}$$

Again, the expressions above are dependent upon both γ and Z_0 . These are functions of frequency, “f” in Hz and are computable from the specifications provided in Section F.2.1 and Section F.2.2. For purposes of simplifying the expression this dependence on “f” has been suppressed in the expression.

F.2.5 FEXT Specification

Detailed measurements as well as corresponding analysis of measurements have been carried out with regards to the FEXT using a binder of the 24 AWG Twisted Pair Reference Cables. The analysis considered the attenuation of the magnitude of FEXT, its variation with frequency and with exposure length. The model presented herein is the result of this effort.

The specific FEXT model for a grouping (binder or multiple binders) of 24 AWG Twisted Pair Reference Cables is now presented.

Consider a grouping of direct path loops of 24 AWG Twisted Pair Reference Cables consisting of as many of 25 pairs with Loop i having a length of d_i meters and Loop j having a length of d_j meters and the exposure length (overlap) between Loop i and Loop j being Lo_{ij} meters.

For a transmitted signal originating on Loop i with FEXT generated at the receiver on Loop. j for the model presented the transfer function is given by the general formula:

$$H_{FEXT}(f, d_i) = H_{DP}(f, d_i) |ELFEXT| e^{j\phi_{ij}} 10^{\theta_{ij}} \tag{19}$$

Where $H_{DP}(f, d_i)$ is specified in Section F.2.4.

$|ELFEXT|$, - “the magnitude of the coupling between loops”- is in nepers. It is more convenient to specify it in ‘dB’ notation

$$|ELFEXT(f, Lo_{ij})| \text{ dB} = [KFEXT]_{\text{dB}} + \Gamma_L(Lo_{ij}) \text{ dB} + \Gamma_f(f) \text{ dB} \tag{20}$$

$\Gamma_L[Lo_{ij}] \text{ dB}$ principally represents the dependence upon “ Lo_{ij} ” and is defined by:

$$\Gamma_L(\text{Loij}) \text{ dB} = 20\text{Log}(\text{Loij}) \quad (21)$$

For purposes of the model presented the dependence is linear with Loij “in nepers.”

$\Gamma_f(f)$ dB principally represents the dependence upon “f” and is given below with F_L , F_I and F_H given by;

$$F_L=10 \text{ MHz.}, F_I=70 \text{ MHz.} \quad F_H = 400 \text{ MHz} \quad (22)$$

Low Frequency Segment

$$\Gamma_f(f) \text{ dB} = 10 \text{ Log}(f) \text{ for } f \leq F_L \quad (23)$$

Intermediate Frequency Segment

$$\Gamma_f(f) \text{ dB} = \Gamma_f(F_L) \text{ dB} + 20 \text{ Log}(f) \text{ for } F_L < f \leq F_I \quad (24)$$

High Frequency Segment

$$\Gamma_f(f) \text{ dB} = \Gamma_f(F_I) \text{ dB} + 40 \text{ Log}(f) \text{ for } F_I < f \leq F_H \quad (25)$$

Very High Frequency Segment

$$\Gamma_f(f) \text{ dB} = \Gamma_f(F_H) \text{ dB for } f > F_H .$$

$$[\text{KFEXT}]_{\text{dB}} = -196 \quad (27)$$

The first term on the right-hand side of (24), (25) and (26) comes from the previous segment to have continuity. The “slope discontinuity” between the Intermediate Frequency Segment and the High Frequency Segment represents the “Dual Slope Effect.” The constant in (27) makes the model consistent with Reference [2].

For the model presented ϕ , the phase difference caused by the coupling between loops, is specified in radians as follows:

ϕ_{ij} is constant over the entire frequency band of interest. However, ϕ_{ij} is chosen randomly under a uniform distribution over the interval $[0, 2\pi]$, with this being done separately for each pair of loops i, j .

It is noted that for repeatability of testing results when this model is used the same realization of the matrix $[\phi_{ij}]$ should be used. The specification of this $[\phi_{ij}]$ is TBD.

For the model presented the parameter, θ_{ij} , is usually referred to as “the Amplitude Offset.” It provides a “deviation” to mean behaviour of ELFEXT due to the spacial position of the cable pair with respect to other cable pairs in the grouping. $[\theta_{ij}]$ is assumed to be independent of frequency and loop length. The value of θ_{ij} is a function of the physical separation between cable pairs as well as blockage from other cables. For the purposes of simplification of the present model its dependence upon frequency and exposure length is ignored.

Experimental measurements taken indicate that for the model presented (in “dB” notation) $[\theta_{ij} \text{ dB}]$ the representative values in Reference [2] are applicable and accordingly will be used. For repeatability the exact example matrix in Reference [2] will be used. In dealing with this model the top left 25 x 25 submatrix of this example matrix will be used for a 25 pair binder and this specified in Table 23.

Table 23 - Specification of Amplitude Offset matrix. $[\theta_{ij} \text{ dB}]$

0	-17.4	-15.2	-16.2	-13	2.19	-13	-15.5	-29.2	-6.24	-11.9	-10.8	-28.5	-11.1	-21.6	-4.81	-20.6	-17	-7.69	-26.4	-2.79	-5.17	-14.7	-19.6	-12
-17.2	0	-7.32	-24.2	-15.3	-8.12	-21.6	-13	-14.9	-13.3	-18.4	-15	-29.4	-9.24	-5.58	-15.6	-6.17	-24.2	-24.8	-27.9	-9.39	-20.9	-21.4	-5.87	-14.2
-14.7	-8.74	0	-12.4	-12	-6.33	-5.63	-18.3	-13.4	-21.1	-26.7	-9.34	-14.2	-14.8	-16.4	-15.4	-29.4	-5.29	-24.8	-12.2	-8.99	-4.79	-16.3	-9.29	-14
-15.5	-25.1	-13.8	0	-15.7	-37.7	-2.86	-10.3	-30.3	-22.1	-6.3	-11.9	-35.1	-21.9	-20.6	-22.1	-15.2	-3.94	-26.7	-10.9	-25.5	1.494	-24.9	-23.6	-24.8
-13.7	-15.1	-10.6	-16.8	0	-14.5	-7.94	-17.6	-17.3	-12.6	-9.27	-23.5	-8.45	-23	-21.4	-15.8	-27.7	-15.3	-2.64	-9.45	-7.78	-12	-15.8	-7.08	-10.1
3.256	-9.13	-6.09	-39	-13.6	0	-27.3	-20.6	-10.9	-16.7	-12.6	-10.4	-3.7	-23.2	-10.4	-25.5	-17.8	-23.6	-20.2	-22.1	-21.5	-18.5	-8.5	-18.9	-19.7
-13.2	-22.7	-5.64	-3.76	-7.17	-26.2	0	-18.7	-10.2	-20.8	-15.1	-9.11	-19.6	-16.3	-11.1	-18.5	-12.7	-18.8	-11.5	-15.3	-8.65	-22.6	-13.8	-14.3	-25.4
-14.5	-13.3	-19.7	-8.99	-17.3	-19.2	-18.4	0	-15.9	-22.4	-5.23	-25.8	-10.8	-21.5	-8.47	-13.9	-0.01	-21.5	-12.6	-27.9	-4.04	-36	-4.42	-13.2	-5.56
-27.2	-14.6	-12.8	-29.4	-18	-11.5	-9.62	-16.4	0	-11.5	-19.4	-13.7	-11.6	-3.03	-4.13	-5.63	3.948	-17.2	-5.62	-11.7	-24.8	-18.3	-14.7	-22.3	-16.9
-6.13	-13.6	-23.1	-22.6	-13.9	-15	-21.1	-21.3	-10.8	0	-27.6	-10.9	-22.2	-36.4	-13.3	-14.1	-10.5	-0.83	-9.52	-6.25	-29.8	-8.25	-20.4	-14.8	-30.2
-10.7	-18.7	-24.5	-4.42	-7.6	-12	-15.1	-6.73	-19.4	-28.9	0	-21	-25.7	-4.82	-15.6	-6.91	-19.8	-7.46	-7.5	-26.2	-22	-16.2	-12.6	-23.2	-21.7
-12	-15.9	-9.79	-11.4	-23.1	-11.9	-10.6	-26.5	-13.2	-12.1	-20.8	0	-16.1	-11.5	-8.25	-13.2	-20.4	-6.96	-7.57	-27.5	-24.2	-20.3	-14.4	-15.4	-27.9
-28.6	-30.6	-14.6	-33.6	-7.25	-4.4	-20	-12.2	-10.9	-21.4	-25.9	-15.1	0	-29.5	-10.7	-21.1	-18.4	-24.2	-21.9	-22.4	-16.1	-4.81	-8.39	-8.28	-9.44
-10.4	-9.89	-13.2	-21.4	-23.3	-21.5	-15.4	-20.8	-2.29	-37.9	-2.26	-10.5	-28.6	0	-14.5	-25.5	-13.7	-19.9	-14.7	-14.4	-14.8	-27.8	-5.86	-17.5	-7.65
-21.7	-5.28	-17.6	-20.1	-20.7	-8.73	-10.3	-8.91	-3.48	-12.7	-16.6	-9.67	-11.1	-13.9	0	-16.4	-24.9	-2.4	-15.3	-15	-4.2	-19.4	-18.5	-11.4	-14.1
-4.44	-16.7	-15.7	-21.2	-16	-26.1	-18.3	-13.3	-4.51	-13.2	-5.04	-13.3	-21	-25.5	-16.5	0	-15.4	-26.7	-19.1	-13.6	-4.61	-13.9	-25.6	-25.6	-10.1
-21.7	-6.03	-29.4	-14.6	-27.5	-17	-15	-0.19	3.587	-11.1	-18.3	-19.4	-17.4	-12.4	-24.8	-16.5	0	-10.7	-14.6	-12.5	-4.51	-9.55	-22.5	-19.2	-19.6
-17.7	-25.2	-6.94	-5	-14.5	-25.1	-19.3	-20.4	-18.8	0.36	-8.59	-6.08	-24.6	-20.2	-2.04	-27.3	-12.9	0	-20.7	-10.2	-12.1	-16.8	-10.8	-11.1	-16.6
-8.17	-25.4	-24.1	-25.6	-3.41	-21.3	-11.3	-13	-5.24	-9.32	-8.43	-8.18	-23.2	-14.5	-15.7	-20	-13.2	-21.5	0	-17.3	-16.9	-31.6	-24.5	-19.8	-18.3
-26.6	-27.8	-11	-10.5	-7.29	-19.6	-16.3	-28.3	-11.7	-4.45	-26.1	-28	-23	-15.9	-15	-15.5	-11.4	-10.3	-18.4	0	-14.6	-35.1	-13.9	-18.8	-28.1
-1.76	-9.55	-10.2	-26.5	-8.7	-21.2	-8.44	-4.57	-25.5	-28.5	-21.4	-25.6	-16.5	-15.4	-4.43	-3.37	-4.56	-11.6	-16.4	-13.6	0	-14.1	-7.07	-5.11	-24.6
-4.65	-21.5	-5.09	1.789	-10.7	-16.3	-23.3	-34.5	-18.8	-8.79	-15.9	-18.2	-4.1	-28.9	-19.3	-12.9	-10.5	-15.3	-32.6	-36.6	-13.8	0	-14	-16.4	-10.6
-14.2	-20.7	-16.6	-24.9	-15.2	-9.21	-12.8	-3.77	-12.6	-19.9	-12.5	-14.4	-9.35	-7.17	-19.5	-27.1	-23.5	-9.44	-24	-15.4	-8.06	-13.8	0	-28.6	-14
-19.9	-7.34	-9.29	-21.6	-5.64	-17.6	-13.4	-15	-22.3	-12.7	-23.8	-12.6	-8.99	-15.6	-10.4	-25.4	-19	-10.6	-17.8	-18.2	-4.02	-16.8	-27.2	0	-17.3
-12.8	-14.4	-13.3	-25.3	-11.2	-18.5	-24.2	-6.08	-15.7	-30.9	-22.3	-27.3	-10	-9.34	-12.8	-11.8	-20	-16.7	-19.9	-27.1	-25.6	-9.72	-13	-17.9	0

Appendix I - Quad Cable Model Supplementary Information

I.1 Direct channel Transfer Function – Definition and Calculation

For the single line models as well as for the multiline model, a chain matrix constructed from the primary line parameters.

For a single twisted pair, the chain matrix is defined as:

$$\begin{bmatrix} u(0) \\ i(0) \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} u(l) \\ i(l) \end{bmatrix}$$

While for the MIMO model, it is defined as:

$$\begin{bmatrix} \mathbf{u}(0) \\ \mathbf{i}(0) \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{A}_{21} & \mathbf{A}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{u}(l) \\ \mathbf{i}(l) \end{bmatrix}$$

Where \mathbf{u} and \mathbf{i} are voltage and current vectors and \mathbf{A}_{11} to \mathbf{A}_{22} are block matrices, which are calculated from the secondary line parameters.

The *primary* line parameters are:

- Serial impedance: $Z_s = R(f) + j\omega L$
- Parallel admittance: $Y_p = G(f) + j\omega C$

And, for multiple lines, the corresponding matrices are used:

- Serial impedance: $Z_s = R(f) + j\omega L$
- Parallel admittance: $Y_p = G(f) + j\omega C$

The *secondary* line parameters are constructed as follows:

Single line characteristic impedance

$$Z_c(f) = \sqrt{\frac{Z_s(f)}{Y_p(f)}}$$

Single line propagation term

$$\gamma(f) = \sqrt{Z_s(f) \times Y_p(f)}$$

The multiline propagation constant is defined by the eigenvalue decomposition of $\mathbf{Y}_p \mathbf{Z}_s$:

$$\mathbf{Y}_p \cdot \mathbf{Z}_s = \mathbf{T}_l \cdot \gamma^2 \cdot \mathbf{T}_l^{-1}$$

(Often used in linear algebra http://en.wikipedia.org/wiki/Eigenvalue_decomposition)

Propagation constant diagonal matrix:

$$\boldsymbol{\gamma} = \sqrt{\boldsymbol{\gamma}^2}$$

Impedance Matrix:

$$\mathbf{Z}_c = \mathbf{Z}_s \mathbf{T}_l \boldsymbol{\gamma}^{-1} \mathbf{T}_l^{-1}$$

(this is a matrix square root http://en.wikipedia.org/wiki/Square_root_of_a_matrix)

Admittance Matrix:

$$Y_c = T_l \gamma^{-1} T_l^{-1} Y_p$$

Finally, the single line chain matrix is given by:

$$A = \begin{bmatrix} \cosh(\gamma d) & Z_c \sinh(\gamma d) \\ \sinh(\gamma d) Y_c & \cosh(\gamma d) \end{bmatrix}$$

And the multiline chain matrix is constructed as:

$$A = \begin{bmatrix} Z_c T_l \cosh(\gamma d) T_l^{-1} Y_c & Z_c T_l \sinh(\gamma d) T_l^{-1} \\ T_l \sinh(\gamma d) T_l^{-1} Y_c & T_l \cosh(\gamma d) T_l^{-1} \end{bmatrix}$$

The chain matrix 'A' can then be transformed into an S-parameter matrix:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

$$S_{11} = U_{21} U_{11}^{-1}$$

$$S_{12} = U_{22} - U_{21} U_{11}^{-1} U_{12}$$

$$S_{21} = U_{11}^{-1}$$

$$S_{22} = -U_{11}^{-1} U_{12}$$

where

$$U_{11} = \frac{1}{2} (A_{11} + A_{12} Z_0^{-1} + A_{21} Z_0 + A_{22})$$

$$U_{12} = \frac{1}{2} (A_{11} - A_{12} Z_0^{-1} + A_{21} Z_0 - A_{22})$$

$$U_{21} = \frac{1}{2} (A_{11} + A_{12} Z_0^{-1} - A_{21} Z_0 - A_{22})$$

$$U_{22} = \frac{1}{2} (A_{11} - A_{12} Z_0^{-1} - A_{21} Z_0 + A_{22})$$

This equation holds for both, single line and multiline S matrix.

For the single line case, A_{11} to A_{22} are scalar values. Z_0 is the reference impedance, usually 100 Ohm resistive.

For the multiline S matrix, Z_0 is a matrix of termination impedances. Due to the fact that the matrices use the single-ended description, the diagonal elements are set to $Z_0/2$.

$$Z_0 = \begin{bmatrix} Z_0/2 & 0 & 0 & 0 \\ 0 & Z_0/2 & 0 & 0 \\ 0 & 0 & Z_0/2 & 0 \\ 0 & 0 & 0 & Z_0/2 \end{bmatrix}$$

The parameter \mathbf{S}_{21} contains the transfer functions which are needed for transmission simulations. The multiline \mathbf{S} matrix describes the single-ended modes of the cable bundle. Therefore, it is converted into a mixed mode matrix \mathbf{S}_{mm} which is defined as follows.

$$\mathbf{S}_{mm} = \begin{bmatrix} \mathbf{S}_{dd} & \mathbf{S}_{dc} \\ \mathbf{S}_{cd} & \mathbf{S}_{cc} \end{bmatrix}$$

\mathbf{S}_{dd} is the differential mode matrix, which is of interest for data transmission. The other matrices are the common mode matrix \mathbf{S}_{cc} and the mode conversion matrices \mathbf{S}_{cd} and \mathbf{S}_{dc} . This is done using two conversion matrices \mathbf{M} and \mathbf{M}_{inv} .

$$\mathbf{M} = \begin{bmatrix} 1 & -1 & 0 & \dots & \dots & \dots & 0 \\ 0 & & 1 & -1 & & & \vdots \\ \vdots & & & & 1 & -1 & 0 \\ 0 & & \dots & \dots & & 0 & 1 & -1 \\ 1 & 1 & 0 & & \dots & \dots & & 0 \\ 0 & & 1 & 1 & & & & \vdots \\ \vdots & & & & 1 & 1 & & 0 \\ 0 & & \dots & \dots & & 0 & 1 & 1 \end{bmatrix}$$

$$\mathbf{M}_{inv} = \begin{bmatrix} 1 & 0 & \dots & 0 & 1 & 0 & \dots & 0 \\ -1 & & & & 1 & & & \\ 0 & 1 & & \vdots & 0 & 1 & & \vdots \\ & -1 & & \vdots & & 1 & & \vdots \\ \vdots & & 1 & & \vdots & & 1 & \\ \vdots & & -1 & 0 & \vdots & & 1 & 0 \\ & & & 1 & & & & 1 \\ 0 & \dots & 0 & -1 & 0 & \dots & 0 & 1 \end{bmatrix}$$

The conversion is done using the following equation:

$$\mathbf{S}_{mm} = \frac{1}{2} \mathbf{M} \mathbf{S} \mathbf{M}_{inv}$$

The differential mode matrix itself consists of four block matrices, where the matrix \mathbf{S}_{21} contains the direct channel and FEXT transfer functions.

$$\mathbf{S}_{dd} = \begin{bmatrix} \mathbf{S}_{dd11} & \mathbf{S}_{dd12} \\ \mathbf{S}_{dd21} & \mathbf{S}_{dd22} \end{bmatrix}$$

therefore, \mathbf{S}_{dd21} is equal to the channel matrix $\mathbf{S}_{dd21}=\mathbf{H}$ for downstream direction while \mathbf{S}_{dd12} is the channel matrix for upstream direction. The direct channel transfer functions are the diagonal elements of the matrix \mathbf{H} .

I.2 Reference Matrix Calculator

An example of typical quad cable is shown here.

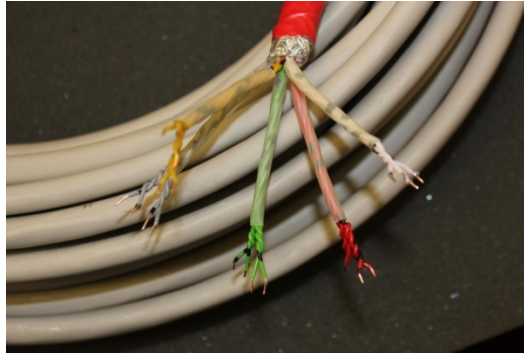


Figure 38 - A Typical quad cable.

The inductance matrix is constructed from the reference geometry.

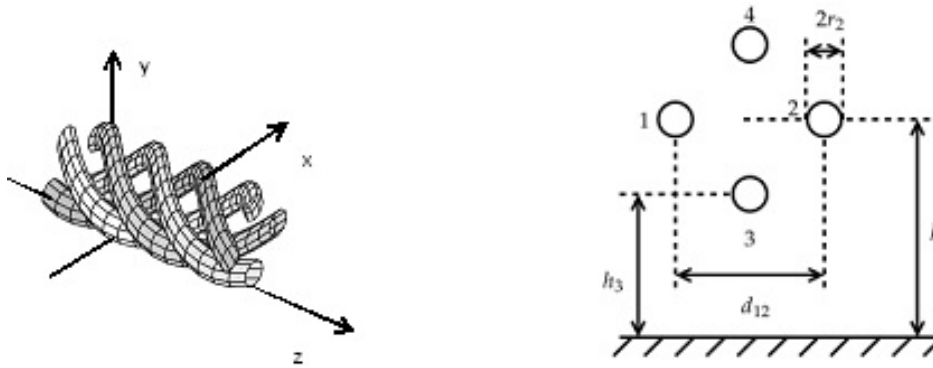


Figure 39 - Quad Cable reference geometry

$$\begin{aligned}
 x_1 &= -\cos\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} & y_1 &= -\sin\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} + h \\
 x_2 &= \cos\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} & y_2 &= \sin\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} + h \\
 x_3 &= -\sin\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} & y_3 &= -\cos\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} + h \\
 x_4 &= \sin\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} & y_4 &= \cos\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} + h
 \end{aligned}$$

Distance between the wire i and k: d_{ik} (e.g. d_{12})
 Distance between the wire and the ground plane: h (e.g. h_3)
 Twist length: d_{twist} .

Inductance matrix, perfect geometry (for known permittivity ϵ and permeability μ of the medium between the conductors):

$$l_{ik} = \begin{cases} \frac{\mu}{2\pi} \times \log\left(\frac{2h_i}{r_i}\right) & \text{for } i = k \\ \frac{\mu}{4\pi} \times \log\left(1 + \frac{4h_i h_k}{d_{ik}^2}\right) & \text{for } i \neq k \end{cases}$$

Inductance matrix, random model:

$$l_{ik} = \begin{cases} \frac{\mu}{2\pi} \times \log\left(\frac{2h_i}{r_i}\right) + l_{r \text{ direct}} & \text{for } i = k \\ \frac{\mu}{4\pi} \times \log\left(1 + \frac{4h_i h_k}{d_{ik}^2}\right) + l_{r \text{ xt}} & \text{for } i \neq k \end{cases}$$

$l_{r \text{ direct}}$ and $l_{r \text{ xt}}$ are both Gaussian zero-mean random variable with different variances which can be taken from measurements of a cable.

I.3 Reference Matrices (*PE06.zip* and *PE05.zip*)

The following MATLAB files are contained in TR-285.05.zip:

PE05 Reference Matrices 300 MHz

PE06 Reference Matrices 300 MHz

MATLAB-file *PE06.zip* contains the reference matrix cable type *J-H(ST)H Bd 10x2x0.6*.

MATLAB-file *PE05.zip* contains the reference matrix cable type *I-O2YS(ST)H 10x2x0.5 STVI Bd*.

Figure 40 illustrates the reference matrix structure (60x60) for one segment length (*dref*) comprised of the in-quad (In-q) and inter-quad (Inter-q) crosstalk ($L_{ref}(d)$) matrices (4x4).

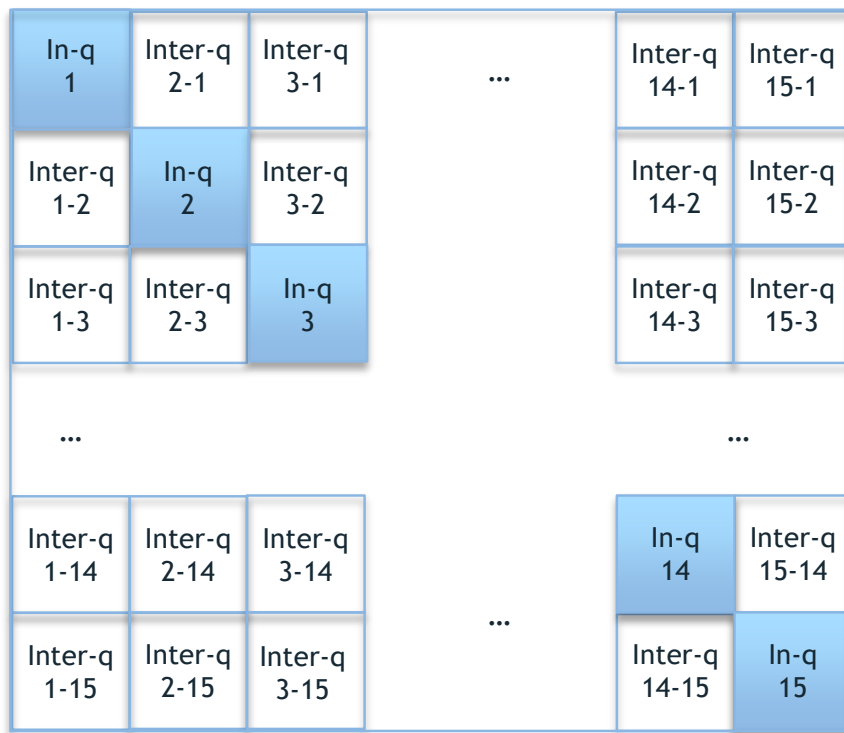


Figure 40 - Reference Crosstalk Matrix Structure

As an example, Table 24 to Table 27 show the corresponding *Lref_pe06* in-quad and inter-quad crosstalk coefficients (rounded to two decimal points) for the first cable segment (0.2220 m in *dref_pe06*).

Table 24 - In-q1 to In-q4 and corresponding Inter-q crosstalk coefficients

	1				2				3				4			
1	2,44	1,94	2,07	2,07	1,83	1,83	1,83	1,83	1,65	1,64	1,65	1,64	1,64	1,65	1,65	1,63
	1,94	2,47	2,07	2,07	1,83	1,83	1,83	1,83	1,66	1,64	1,65	1,64	1,64	1,65	1,65	1,64
	2,07	2,07	2,40	1,94	1,83	1,83	1,83	1,83	1,66	1,64	1,65	1,65	1,64	1,65	1,65	1,64
	2,07	2,07	1,94	2,39	1,83	1,83	1,83	1,82	1,65	1,64	1,65	1,64	1,64	1,65	1,65	1,64
2	1,83	1,83	1,83	1,83	2,47	1,94	2,07	2,07	1,84	1,83	1,85	1,82	1,64	1,66	1,65	1,64
	1,83	1,83	1,83	1,83	1,94	2,46	2,07	2,07	1,83	1,82	1,84	1,81	1,64	1,65	1,65	1,64
	1,83	1,83	1,83	1,83	2,07	2,07	2,42	1,94	1,84	1,82	1,84	1,82	1,64	1,66	1,65	1,64
	1,83	1,83	1,83	1,82	2,07	2,07	1,94	2,43	1,83	1,83	1,84	1,81	1,64	1,66	1,65	1,64
3	1,65	1,66	1,66	1,65	1,84	1,83	1,84	1,83	2,42	1,94	2,07	2,07	1,82	1,85	1,83	1,84
	1,64	1,64	1,64	1,64	1,83	1,82	1,82	1,83	1,94	2,39	2,07	2,07	1,80	1,83	1,81	1,82
	1,65	1,65	1,65	1,65	1,85	1,84	1,84	1,84	2,07	2,07	2,42	1,94	1,80	1,83	1,81	1,82
	1,64	1,64	1,65	1,64	1,82	1,81	1,82	1,81	2,07	2,07	1,94	2,43	1,82	1,85	1,83	1,84
4	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,82	1,80	1,80	1,82	2,46	1,93	2,06	2,06
	1,65	1,65	1,65	1,65	1,66	1,65	1,66	1,66	1,85	1,83	1,83	1,85	1,93	2,57	2,06	2,06
	1,65	1,65	1,65	1,65	1,65	1,65	1,65	1,65	1,83	1,81	1,81	1,83	2,06	2,06	2,41	1,93
	1,63	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,84	1,82	1,82	1,84	2,06	2,06	1,93	2,44
5	1,82	1,82	1,82	1,82	1,65	1,64	1,65	1,64	1,65	1,64	1,64	1,65	1,83	1,82	1,85	1,81
	1,83	1,83	1,83	1,83	1,65	1,65	1,65	1,65	1,65	1,63	1,64	1,64	1,82	1,82	1,83	1,80
	1,82	1,82	1,82	1,82	1,64	1,64	1,64	1,64	1,65	1,63	1,64	1,64	1,82	1,81	1,83	1,80
	1,83	1,83	1,82	1,83	1,65	1,65	1,65	1,65	1,66	1,64	1,65	1,65	1,82	1,83	1,85	1,81
6	1,46	1,46	1,46	1,46	1,35	1,35	1,35	1,35	1,34	1,33	1,34	1,34	1,43	1,42	1,43	1,42
	1,46	1,46	1,46	1,46	1,35	1,35	1,35	1,35	1,34	1,33	1,34	1,34	1,43	1,42	1,43	1,42
	1,46	1,46	1,46	1,46	1,35	1,35	1,35	1,35	1,34	1,33	1,34	1,34	1,43	1,42	1,43	1,42
	1,46	1,46	1,46	1,46	1,35	1,35	1,35	1,35	1,34	1,33	1,34	1,34	1,43	1,42	1,43	1,42
7	1,60	1,60	1,60	1,60	1,46	1,46	1,47	1,46	1,46	1,45	1,46	1,46	1,59	1,58	1,59	1,58
	1,61	1,61	1,61	1,61	1,47	1,46	1,47	1,46	1,46	1,45	1,45	1,46	1,58	1,58	1,59	1,57
	1,60	1,60	1,60	1,60	1,46	1,46	1,46	1,46	1,46	1,45	1,45	1,46	1,58	1,57	1,59	1,57
	1,61	1,61	1,61	1,61	1,47	1,47	1,47	1,46	1,46	1,45	1,46	1,46	1,59	1,58	1,60	1,58
8	1,51	1,51	1,51	1,51	1,42	1,42	1,42	1,42	1,46	1,45	1,46	1,46	1,63	1,61	1,63	1,62
	1,51	1,51	1,51	1,51	1,43	1,42	1,43	1,42	1,47	1,46	1,46	1,47	1,64	1,62	1,63	1,62
	1,51	1,51	1,51	1,51	1,43	1,42	1,43	1,42	1,47	1,46	1,46	1,47	1,64	1,62	1,63	1,62
	1,51	1,50	1,50	1,50	1,42	1,42	1,42	1,42	1,46	1,46	1,46	1,46	1,63	1,61	1,63	1,62
9	1,37	1,37	1,37	1,37	1,31	1,31	1,31	1,31	1,34	1,33	1,33	1,34	1,46	1,44	1,45	1,45
	1,39	1,39	1,39	1,39	1,32	1,32	1,32	1,32	1,35	1,34	1,34	1,35	1,47	1,46	1,47	1,46
	1,38	1,38	1,38	1,38	1,31	1,31	1,31	1,31	1,34	1,34	1,34	1,34	1,46	1,45	1,46	1,45
	1,38	1,38	1,38	1,38	1,31	1,31	1,31	1,31	1,34	1,34	1,34	1,34	1,46	1,45	1,46	1,46

	1				2				3				4			
10	1,36	1,36	1,36	1,36	1,28	1,28	1,28	1,28	1,29	1,29	1,29	1,29	1,38	1,38	1,38	1,38
	1,37	1,37	1,37	1,37	1,29	1,28	1,29	1,28	1,29	1,29	1,29	1,29	1,38	1,38	1,38	1,38
	1,36	1,36	1,36	1,36	1,28	1,28	1,28	1,28	1,29	1,28	1,29	1,29	1,38	1,37	1,38	1,37
	1,37	1,37	1,37	1,37	1,29	1,29	1,29	1,29	1,30	1,29	1,29	1,29	1,39	1,38	1,39	1,38
11	1,46	1,46	1,46	1,46	1,35	1,36	1,36	1,35	1,29	1,28	1,28	1,28	1,30	1,30	1,31	1,30
	1,46	1,46	1,46	1,46	1,35	1,36	1,36	1,35	1,29	1,28	1,28	1,28	1,30	1,30	1,31	1,30
	1,46	1,46	1,46	1,46	1,35	1,36	1,36	1,35	1,29	1,28	1,28	1,28	1,30	1,30	1,31	1,30
	1,46	1,46	1,46	1,46	1,35	1,36	1,36	1,35	1,29	1,28	1,28	1,28	1,30	1,30	1,31	1,30
12	1,58	1,58	1,58	1,58	1,46	1,46	1,46	1,46	1,36	1,36	1,36	1,36	1,36	1,37	1,37	1,36
	1,57	1,58	1,57	1,58	1,46	1,46	1,46	1,46	1,36	1,35	1,36	1,36	1,36	1,36	1,36	1,36
	1,58	1,58	1,58	1,58	1,46	1,46	1,46	1,46	1,36	1,36	1,36	1,36	1,36	1,36	1,37	1,36
	1,58	1,58	1,58	1,58	1,46	1,46	1,46	1,46	1,36	1,36	1,36	1,36	1,36	1,36	1,37	1,36
13	1,77	1,77	1,77	1,77	1,56	1,56	1,57	1,56	1,46	1,45	1,46	1,45	1,47	1,48	1,48	1,47
	1,77	1,78	1,78	1,77	1,57	1,57	1,57	1,57	1,46	1,46	1,46	1,46	1,48	1,48	1,49	1,48
	1,77	1,78	1,77	1,77	1,56	1,57	1,57	1,56	1,46	1,45	1,46	1,45	1,48	1,48	1,48	1,47
	1,77	1,78	1,78	1,77	1,57	1,57	1,57	1,56	1,46	1,46	1,46	1,46	1,48	1,48	1,49	1,48
14	1,61	1,61	1,61	1,61	1,45	1,45	1,45	1,45	1,39	1,39	1,39	1,39	1,45	1,45	1,46	1,44
	1,62	1,62	1,63	1,62	1,46	1,46	1,46	1,45	1,40	1,39	1,40	1,39	1,45	1,45	1,46	1,45
	1,61	1,61	1,61	1,61	1,45	1,45	1,45	1,44	1,39	1,38	1,39	1,39	1,45	1,44	1,45	1,44
	1,63	1,63	1,63	1,62	1,46	1,46	1,46	1,45	1,40	1,40	1,40	1,40	1,46	1,46	1,46	1,45
15	1,47	1,47	1,47	1,47	1,35	1,35	1,35	1,35	1,30	1,29	1,30	1,30	1,34	1,34	1,34	1,33
	1,47	1,47	1,47	1,47	1,35	1,35	1,35	1,35	1,30	1,29	1,30	1,29	1,33	1,33	1,34	1,33
	1,46	1,46	1,46	1,46	1,35	1,35	1,35	1,35	1,30	1,29	1,29	1,29	1,33	1,33	1,34	1,33
	1,47	1,47	1,47	1,47	1,35	1,35	1,36	1,35	1,30	1,30	1,30	1,30	1,34	1,34	1,34	1,33

Table 25 - In-q5 to In-q8 and corresponding Inter-q crosstalk coefficients

	5				6				7				8			
1	1,82	1,83	1,82	1,83	1,46	1,46	1,46	1,46	1,60	1,61	1,60	1,61	1,51	1,51	1,51	1,51
	1,82	1,83	1,82	1,83	1,46	1,46	1,46	1,46	1,60	1,61	1,60	1,61	1,51	1,51	1,51	1,50
	1,82	1,83	1,82	1,82	1,46	1,46	1,46	1,46	1,60	1,61	1,60	1,61	1,51	1,51	1,51	1,50
	1,82	1,83	1,82	1,83	1,46	1,46	1,46	1,46	1,60	1,61	1,60	1,61	1,51	1,51	1,51	1,50
2	1,65	1,65	1,64	1,65	1,35	1,35	1,35	1,35	1,46	1,47	1,46	1,47	1,42	1,43	1,43	1,42
	1,64	1,65	1,64	1,65	1,35	1,35	1,35	1,35	1,46	1,46	1,46	1,47	1,42	1,42	1,42	1,42
	1,65	1,65	1,64	1,65	1,35	1,35	1,35	1,35	1,47	1,47	1,46	1,47	1,42	1,43	1,43	1,42
	1,64	1,65	1,64	1,65	1,35	1,35	1,35	1,35	1,46	1,46	1,46	1,46	1,42	1,42	1,42	1,42
3	1,65	1,65	1,65	1,66	1,34	1,34	1,34	1,34	1,46	1,46	1,46	1,46	1,46	1,47	1,47	1,46
	1,64	1,63	1,63	1,64	1,33	1,33	1,33	1,33	1,45	1,45	1,45	1,45	1,45	1,46	1,46	1,46
	1,64	1,64	1,64	1,65	1,34	1,34	1,34	1,34	1,46	1,45	1,45	1,46	1,46	1,46	1,46	1,46
	1,65	1,64	1,64	1,65	1,34	1,34	1,34	1,34	1,46	1,46	1,46	1,46	1,46	1,47	1,47	1,46
4	1,83	1,82	1,82	1,82	1,43	1,43	1,43	1,43	1,59	1,58	1,58	1,59	1,63	1,64	1,64	1,63
	1,82	1,82	1,81	1,83	1,42	1,42	1,42	1,42	1,58	1,58	1,57	1,58	1,61	1,62	1,62	1,61
	1,85	1,83	1,83	1,85	1,43	1,43	1,43	1,43	1,59	1,59	1,59	1,60	1,63	1,63	1,63	1,63
	1,81	1,80	1,80	1,81	1,42	1,42	1,42	1,42	1,58	1,57	1,57	1,58	1,62	1,62	1,62	1,62
5	2,42	1,93	2,06	2,06	1,55	1,55	1,55	1,55	1,78	1,77	1,77	1,79	1,71	1,72	1,71	1,71
	1,93	2,40	2,06	2,06	1,55	1,55	1,55	1,55	1,77	1,77	1,76	1,78	1,69	1,70	1,70	1,69
	2,06	2,06	2,37	1,93	1,56	1,55	1,55	1,56	1,79	1,79	1,78	1,80	1,70	1,72	1,71	1,71
	2,06	2,06	1,93	2,45	1,54	1,54	1,54	1,54	1,76	1,76	1,76	1,77	1,69	1,70	1,70	1,69
6	1,55	1,55	1,56	1,54	2,41	1,93	2,06	2,06	1,81	1,82	1,82	1,81	1,64	1,62	1,64	1,63
	1,55	1,55	1,55	1,54	1,93	2,42	2,06	2,06	1,82	1,82	1,82	1,81	1,64	1,63	1,64	1,63
	1,55	1,55	1,55	1,54	2,06	2,06	2,39	1,93	1,82	1,82	1,82	1,82	1,64	1,63	1,64	1,63
	1,55	1,55	1,56	1,54	2,06	2,06	1,93	2,46	1,81	1,81	1,82	1,81	1,64	1,63	1,64	1,63
7	1,78	1,77	1,79	1,76	1,81	1,82	1,82	1,81	2,43	1,93	2,06	2,06	1,83	1,81	1,83	1,80
	1,77	1,77	1,79	1,76	1,82	1,82	1,82	1,81	1,93	2,44	2,06	2,06	1,82	1,81	1,82	1,80
	1,77	1,76	1,78	1,76	1,82	1,82	1,82	1,82	2,06	2,06	2,41	1,93	1,82	1,81	1,83	1,80
	1,79	1,78	1,80	1,77	1,81	1,81	1,82	1,81	2,06	2,06	1,93	2,42	1,82	1,81	1,83	1,80
8	1,71	1,69	1,70	1,69	1,64	1,64	1,64	1,64	1,83	1,82	1,82	1,82	2,45	1,93	2,06	2,06
	1,72	1,70	1,72	1,70	1,62	1,63	1,63	1,63	1,81	1,81	1,81	1,81	1,93	2,36	2,06	2,06
	1,71	1,70	1,71	1,70	1,64	1,64	1,64	1,64	1,83	1,82	1,83	1,83	2,06	2,06	2,41	1,93
	1,71	1,69	1,71	1,69	1,63	1,63	1,63	1,63	1,80	1,80	1,80	1,80	2,06	2,06	1,93	2,47
9	1,50	1,49	1,50	1,49	1,62	1,63	1,63	1,63	1,62	1,62	1,62	1,62	1,81	1,79	1,79	1,81
	1,51	1,51	1,52	1,51	1,64	1,64	1,64	1,64	1,65	1,64	1,64	1,64	1,84	1,82	1,82	1,84
	1,51	1,50	1,51	1,50	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,82	1,79	1,80	1,82
	1,51	1,50	1,51	1,50	1,62	1,63	1,62	1,62	1,63	1,63	1,63	1,63	1,83	1,80	1,80	1,82

	5				6				7				8			
10	1,46	1,45	1,46	1,45	1,80	1,81	1,80	1,81	1,63	1,63	1,63	1,63	1,64	1,62	1,63	1,63
	1,46	1,46	1,46	1,45	1,82	1,82	1,82	1,82	1,64	1,64	1,64	1,63	1,64	1,62	1,63	1,63
	1,45	1,45	1,46	1,45	1,81	1,81	1,81	1,81	1,63	1,63	1,63	1,63	1,64	1,62	1,63	1,63
	1,46	1,46	1,47	1,46	1,81	1,82	1,81	1,82	1,64	1,64	1,64	1,64	1,65	1,63	1,64	1,64
11	1,40	1,41	1,40	1,40	1,46	1,46	1,46	1,46	1,44	1,45	1,45	1,44	1,33	1,33	1,33	1,32
	1,40	1,41	1,40	1,40	1,46	1,46	1,46	1,46	1,44	1,45	1,45	1,44	1,33	1,33	1,33	1,33
	1,40	1,41	1,40	1,40	1,46	1,46	1,46	1,46	1,44	1,45	1,45	1,44	1,33	1,33	1,33	1,32
	1,40	1,41	1,40	1,40	1,46	1,46	1,46	1,46	1,44	1,45	1,45	1,44	1,33	1,33	1,33	1,33
12	1,47	1,48	1,47	1,47	1,44	1,44	1,43	1,44	1,46	1,47	1,47	1,47	1,35	1,35	1,35	1,35
	1,46	1,47	1,47	1,47	1,43	1,43	1,43	1,43	1,46	1,46	1,46	1,46	1,35	1,35	1,35	1,34
	1,47	1,48	1,47	1,47	1,44	1,44	1,43	1,44	1,46	1,47	1,46	1,47	1,35	1,35	1,35	1,34
	1,47	1,48	1,47	1,47	1,43	1,43	1,43	1,43	1,46	1,47	1,46	1,46	1,35	1,35	1,35	1,34
13	1,63	1,65	1,64	1,64	1,53	1,53	1,53	1,53	1,61	1,62	1,61	1,62	1,46	1,46	1,46	1,46
	1,64	1,66	1,65	1,65	1,53	1,53	1,53	1,53	1,61	1,62	1,61	1,62	1,46	1,46	1,47	1,46
	1,63	1,66	1,65	1,64	1,53	1,53	1,53	1,53	1,61	1,61	1,61	1,61	1,46	1,46	1,46	1,45
	1,64	1,66	1,65	1,65	1,54	1,54	1,54	1,54	1,62	1,62	1,62	1,62	1,47	1,46	1,47	1,46
14	1,61	1,62	1,62	1,61	1,74	1,74	1,74	1,75	1,76	1,78	1,77	1,76	1,54	1,54	1,54	1,53
	1,61	1,62	1,63	1,61	1,72	1,72	1,71	1,72	1,74	1,76	1,75	1,75	1,53	1,53	1,53	1,52
	1,60	1,61	1,61	1,60	1,72	1,73	1,72	1,73	1,74	1,76	1,75	1,74	1,53	1,53	1,53	1,52
	1,62	1,63	1,63	1,62	1,74	1,74	1,73	1,74	1,76	1,77	1,77	1,76	1,54	1,54	1,54	1,54
15	1,45	1,46	1,46	1,45	1,63	1,63	1,63	1,63	1,56	1,57	1,57	1,56	1,41	1,41	1,42	1,41
	1,45	1,45	1,45	1,45	1,61	1,61	1,61	1,61	1,55	1,55	1,55	1,55	1,41	1,40	1,41	1,40
	1,45	1,45	1,45	1,44	1,62	1,62	1,62	1,62	1,55	1,55	1,55	1,55	1,41	1,40	1,41	1,40
	1,45	1,46	1,46	1,45	1,62	1,62	1,62	1,62	1,56	1,56	1,56	1,56	1,41	1,41	1,41	1,41

Table 26 - In-q9 to In-q12 and corresponding Inter-q crosstalk coefficients

	9				10				11				12			
1	1,37	1,39	1,38	1,38	1,36	1,37	1,36	1,37	1,46	1,46	1,46	1,46	1,58	1,57	1,58	1,58
	1,37	1,39	1,38	1,38	1,36	1,37	1,36	1,37	1,46	1,46	1,46	1,46	1,58	1,58	1,58	1,58
	1,37	1,39	1,38	1,38	1,36	1,37	1,36	1,37	1,46	1,46	1,46	1,46	1,58	1,57	1,58	1,58
	1,37	1,39	1,38	1,38	1,36	1,37	1,36	1,37	1,46	1,46	1,46	1,46	1,58	1,58	1,58	1,58
2	1,31	1,32	1,31	1,31	1,28	1,29	1,28	1,29	1,35	1,35	1,35	1,35	1,46	1,46	1,46	1,46
	1,31	1,32	1,31	1,31	1,28	1,28	1,28	1,29	1,36	1,36	1,36	1,36	1,46	1,46	1,46	1,46
	1,31	1,32	1,31	1,31	1,28	1,29	1,28	1,29	1,36	1,36	1,36	1,36	1,46	1,46	1,46	1,46
	1,31	1,32	1,31	1,31	1,28	1,28	1,28	1,29	1,35	1,35	1,35	1,35	1,46	1,46	1,46	1,46
3	1,34	1,35	1,34	1,34	1,29	1,29	1,29	1,30	1,29	1,29	1,29	1,29	1,36	1,36	1,36	1,36
	1,33	1,34	1,34	1,34	1,29	1,29	1,28	1,29	1,28	1,28	1,28	1,28	1,36	1,35	1,36	1,36
	1,33	1,34	1,34	1,34	1,29	1,29	1,29	1,29	1,28	1,28	1,28	1,28	1,36	1,36	1,36	1,36
	1,34	1,35	1,34	1,34	1,29	1,29	1,29	1,29	1,28	1,28	1,28	1,28	1,36	1,36	1,36	1,36
4	1,46	1,47	1,46	1,46	1,38	1,38	1,38	1,39	1,30	1,30	1,30	1,30	1,36	1,36	1,36	1,36
	1,44	1,46	1,45	1,45	1,38	1,38	1,37	1,38	1,30	1,30	1,30	1,30	1,37	1,36	1,36	1,36
	1,45	1,47	1,46	1,46	1,38	1,38	1,38	1,39	1,31	1,31	1,31	1,31	1,37	1,36	1,37	1,37
	1,45	1,46	1,45	1,46	1,38	1,38	1,37	1,38	1,30	1,30	1,30	1,30	1,36	1,36	1,36	1,36
5	1,50	1,51	1,51	1,51	1,46	1,46	1,45	1,46	1,40	1,40	1,40	1,40	1,47	1,46	1,47	1,47
	1,49	1,51	1,50	1,50	1,45	1,46	1,45	1,46	1,41	1,41	1,41	1,41	1,48	1,47	1,48	1,48
	1,50	1,52	1,51	1,51	1,46	1,46	1,46	1,47	1,40	1,40	1,40	1,40	1,47	1,47	1,47	1,47
	1,49	1,51	1,50	1,50	1,45	1,45	1,45	1,46	1,40	1,40	1,40	1,40	1,47	1,47	1,47	1,47
6	1,62	1,64	1,64	1,62	1,80	1,82	1,81	1,81	1,46	1,46	1,46	1,46	1,44	1,43	1,44	1,43
	1,63	1,64	1,64	1,63	1,81	1,82	1,81	1,82	1,46	1,46	1,46	1,46	1,44	1,43	1,44	1,43
	1,63	1,64	1,64	1,62	1,80	1,82	1,81	1,81	1,46	1,46	1,46	1,46	1,43	1,43	1,43	1,43
	1,63	1,64	1,64	1,62	1,81	1,82	1,81	1,82	1,46	1,46	1,46	1,46	1,44	1,43	1,44	1,43
7	1,62	1,65	1,64	1,63	1,63	1,64	1,63	1,64	1,44	1,44	1,44	1,44	1,46	1,46	1,46	1,46
	1,62	1,64	1,64	1,63	1,63	1,64	1,63	1,64	1,45	1,45	1,45	1,45	1,47	1,46	1,47	1,47
	1,62	1,64	1,64	1,63	1,63	1,64	1,63	1,64	1,45	1,45	1,45	1,45	1,47	1,46	1,46	1,46
	1,62	1,64	1,64	1,63	1,63	1,63	1,63	1,64	1,44	1,44	1,44	1,44	1,47	1,46	1,47	1,46
8	1,81	1,84	1,82	1,83	1,64	1,64	1,64	1,65	1,33	1,33	1,33	1,33	1,35	1,35	1,35	1,35
	1,79	1,82	1,79	1,80	1,62	1,62	1,62	1,63	1,33	1,33	1,33	1,33	1,35	1,35	1,35	1,35
	1,79	1,82	1,80	1,80	1,63	1,63	1,63	1,64	1,33	1,33	1,33	1,33	1,35	1,35	1,35	1,35
	1,81	1,84	1,82	1,82	1,63	1,63	1,63	1,64	1,32	1,33	1,32	1,33	1,35	1,34	1,34	1,34
9	2,48	1,92	2,05	2,05	1,82	1,80	1,81	1,81	1,28	1,28	1,28	1,28	1,28	1,28	1,28	1,28
	1,92	2,44	2,05	2,05	1,81	1,80	1,80	1,82	1,29	1,29	1,29	1,29	1,29	1,29	1,29	1,29
	2,05	2,05	2,37	1,92	1,83	1,82	1,82	1,84	1,29	1,29	1,29	1,29	1,29	1,29	1,29	1,29
	2,05	2,05	1,92	2,43	1,80	1,79	1,79	1,80	1,28	1,28	1,28	1,28	1,28	1,28	1,28	1,28

	9				10				11				12			
10	1,82	1,81	1,83	1,80	2,46	1,92	2,05	2,05	1,34	1,34	1,34	1,34	1,32	1,32	1,32	1,32
	1,80	1,80	1,82	1,79	1,92	2,46	2,05	2,05	1,35	1,35	1,35	1,35	1,32	1,32	1,32	1,32
	1,81	1,80	1,82	1,79	2,05	2,05	2,44	1,92	1,34	1,34	1,34	1,34	1,32	1,32	1,32	1,32
	1,81	1,82	1,84	1,80	2,05	2,05	1,92	2,45	1,34	1,34	1,34	1,34	1,32	1,32	1,32	1,32
11	1,28	1,29	1,29	1,28	1,34	1,35	1,34	1,34	2,45	1,94	2,07	2,07	1,83	1,83	1,83	1,83
	1,28	1,29	1,29	1,28	1,34	1,35	1,34	1,34	1,94	2,38	2,07	2,07	1,83	1,83	1,83	1,83
	1,28	1,29	1,29	1,28	1,34	1,35	1,34	1,34	2,07	2,07	2,46	1,94	1,83	1,83	1,83	1,83
	1,28	1,29	1,29	1,28	1,34	1,35	1,34	1,34	2,07	2,07	1,94	2,36	1,83	1,83	1,83	1,82
12	1,28	1,29	1,29	1,28	1,32	1,32	1,32	1,32	1,83	1,83	1,83	1,83	2,44	1,94	2,07	2,07
	1,28	1,29	1,29	1,28	1,32	1,32	1,32	1,32	1,83	1,83	1,83	1,83	1,94	2,43	2,07	2,07
	1,28	1,29	1,29	1,28	1,32	1,32	1,32	1,32	1,83	1,83	1,83	1,83	2,07	2,07	2,36	1,94
	1,28	1,29	1,29	1,28	1,32	1,32	1,32	1,32	1,83	1,83	1,83	1,82	2,07	2,07	1,94	2,46
13	1,37	1,38	1,37	1,37	1,39	1,40	1,39	1,40	1,65	1,66	1,66	1,65	1,84	1,83	1,84	1,83
	1,36	1,37	1,37	1,37	1,39	1,40	1,39	1,40	1,64	1,64	1,64	1,64	1,83	1,82	1,82	1,83
	1,36	1,37	1,37	1,36	1,39	1,39	1,39	1,39	1,65	1,65	1,65	1,65	1,85	1,84	1,84	1,84
	1,37	1,38	1,38	1,37	1,39	1,40	1,39	1,40	1,64	1,64	1,65	1,64	1,82	1,81	1,82	1,81
14	1,46	1,47	1,47	1,46	1,52	1,53	1,52	1,53	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64
	1,44	1,46	1,45	1,45	1,50	1,51	1,51	1,51	1,65	1,65	1,65	1,65	1,66	1,65	1,66	1,66
	1,45	1,46	1,46	1,45	1,51	1,52	1,51	1,52	1,65	1,65	1,65	1,65	1,65	1,65	1,65	1,65
	1,45	1,47	1,46	1,46	1,51	1,52	1,51	1,52	1,63	1,64	1,64	1,64	1,64	1,64	1,64	1,64
15	1,37	1,38	1,38	1,37	1,46	1,47	1,46	1,46	1,82	1,82	1,82	1,82	1,65	1,64	1,65	1,64
	1,37	1,37	1,37	1,37	1,45	1,46	1,45	1,45	1,83	1,83	1,83	1,83	1,65	1,65	1,65	1,65
	1,37	1,38	1,38	1,37	1,45	1,46	1,46	1,46	1,82	1,82	1,82	1,82	1,64	1,64	1,64	1,64
	1,37	1,38	1,38	1,37	1,45	1,46	1,45	1,46	1,83	1,83	1,82	1,83	1,65	1,65	1,65	1,65

Table 27 - In-q13 to In-q15 and corresponding Inter-q crosstalk coefficients

	13				14				15			
1	1,77	1,77	1,77	1,77	1,61	1,62	1,61	1,63	1,47	1,47	1,46	1,47
	1,77	1,78	1,78	1,78	1,61	1,62	1,61	1,63	1,47	1,47	1,46	1,47
	1,77	1,78	1,77	1,78	1,61	1,63	1,61	1,63	1,47	1,47	1,46	1,47
	1,77	1,77	1,77	1,77	1,61	1,62	1,61	1,62	1,47	1,47	1,46	1,47
2	1,56	1,57	1,56	1,57	1,45	1,46	1,45	1,46	1,35	1,35	1,35	1,35
	1,56	1,57	1,57	1,57	1,45	1,46	1,45	1,46	1,35	1,35	1,35	1,35
	1,57	1,57	1,57	1,57	1,45	1,46	1,45	1,46	1,35	1,35	1,35	1,36
	1,56	1,57	1,56	1,56	1,45	1,45	1,44	1,45	1,35	1,35	1,35	1,35
3	1,46	1,46	1,46	1,46	1,39	1,40	1,39	1,40	1,30	1,30	1,30	1,30
	1,45	1,46	1,45	1,46	1,39	1,39	1,38	1,40	1,29	1,29	1,29	1,30
	1,46	1,46	1,46	1,46	1,39	1,40	1,39	1,40	1,30	1,30	1,29	1,30
	1,45	1,46	1,45	1,46	1,39	1,39	1,39	1,40	1,30	1,29	1,29	1,30
4	1,47	1,48	1,48	1,48	1,45	1,45	1,45	1,46	1,34	1,33	1,33	1,34
	1,48	1,48	1,48	1,48	1,45	1,45	1,44	1,46	1,34	1,33	1,33	1,34
	1,48	1,49	1,48	1,49	1,46	1,46	1,45	1,46	1,34	1,34	1,34	1,34
	1,47	1,48	1,47	1,48	1,44	1,45	1,44	1,45	1,33	1,33	1,33	1,33
5	1,63	1,64	1,63	1,64	1,61	1,61	1,60	1,62	1,45	1,45	1,45	1,45
	1,65	1,66	1,66	1,66	1,62	1,62	1,61	1,63	1,46	1,45	1,45	1,46
	1,64	1,65	1,65	1,65	1,62	1,63	1,61	1,63	1,46	1,45	1,45	1,46
	1,64	1,65	1,64	1,65	1,61	1,61	1,60	1,62	1,45	1,45	1,44	1,45
6	1,53	1,53	1,53	1,54	1,74	1,72	1,72	1,74	1,63	1,61	1,62	1,62
	1,53	1,53	1,53	1,54	1,74	1,72	1,73	1,74	1,63	1,61	1,62	1,62
	1,53	1,53	1,53	1,54	1,74	1,71	1,72	1,73	1,63	1,61	1,62	1,62
	1,53	1,53	1,53	1,54	1,75	1,72	1,73	1,74	1,63	1,61	1,62	1,62
7	1,61	1,61	1,61	1,62	1,76	1,74	1,74	1,76	1,56	1,55	1,55	1,56
	1,62	1,62	1,61	1,62	1,78	1,76	1,76	1,77	1,57	1,55	1,55	1,56
	1,61	1,61	1,61	1,62	1,77	1,75	1,75	1,77	1,57	1,55	1,55	1,56
	1,62	1,62	1,61	1,62	1,76	1,75	1,74	1,76	1,56	1,55	1,55	1,56
8	1,46	1,46	1,46	1,47	1,54	1,53	1,53	1,54	1,41	1,41	1,41	1,41
	1,46	1,46	1,46	1,46	1,54	1,53	1,53	1,54	1,41	1,40	1,40	1,41
	1,46	1,47	1,46	1,47	1,54	1,53	1,53	1,54	1,42	1,41	1,41	1,41
	1,46	1,46	1,45	1,46	1,53	1,52	1,52	1,54	1,41	1,40	1,40	1,41
9	1,37	1,36	1,36	1,37	1,46	1,44	1,45	1,45	1,37	1,37	1,37	1,37
	1,38	1,37	1,37	1,38	1,47	1,46	1,46	1,47	1,38	1,37	1,38	1,38
	1,37	1,37	1,37	1,38	1,47	1,45	1,46	1,46	1,38	1,37	1,38	1,38
	1,37	1,37	1,36	1,37	1,46	1,45	1,45	1,46	1,37	1,37	1,37	1,37

	13				14				15			
10	1,39	1,39	1,39	1,39	1,52	1,50	1,51	1,51	1,46	1,45	1,45	1,45
	1,40	1,40	1,39	1,40	1,53	1,51	1,52	1,52	1,47	1,46	1,46	1,46
	1,39	1,39	1,39	1,39	1,52	1,51	1,51	1,51	1,46	1,45	1,46	1,45
	1,40	1,40	1,39	1,40	1,53	1,51	1,52	1,52	1,46	1,45	1,46	1,46
11	1,65	1,64	1,65	1,64	1,64	1,65	1,65	1,63	1,82	1,83	1,82	1,83
	1,66	1,64	1,65	1,64	1,64	1,65	1,65	1,64	1,82	1,83	1,82	1,83
	1,66	1,64	1,65	1,65	1,64	1,65	1,65	1,64	1,82	1,83	1,82	1,82
	1,65	1,64	1,65	1,64	1,64	1,65	1,65	1,64	1,82	1,83	1,82	1,83
12	1,84	1,83	1,85	1,82	1,64	1,66	1,65	1,64	1,65	1,65	1,64	1,65
	1,83	1,82	1,84	1,81	1,64	1,65	1,65	1,64	1,64	1,65	1,64	1,65
	1,84	1,82	1,84	1,82	1,64	1,66	1,65	1,64	1,65	1,65	1,64	1,65
	1,83	1,83	1,84	1,81	1,64	1,66	1,65	1,64	1,64	1,65	1,64	1,65
13	2,44	1,94	2,07	2,07	1,82	1,85	1,83	1,84	1,65	1,65	1,65	1,66
	1,94	2,35	2,07	2,07	1,80	1,83	1,81	1,82	1,64	1,63	1,63	1,64
	2,07	2,07	2,33	1,94	1,80	1,83	1,81	1,82	1,64	1,64	1,64	1,65
	2,07	2,07	1,94	2,44	1,82	1,85	1,83	1,84	1,65	1,64	1,64	1,65
14	1,82	1,80	1,80	1,82	2,50	1,93	2,06	2,06	1,83	1,82	1,82	1,82
	1,85	1,83	1,83	1,85	1,93	2,45	2,06	2,06	1,82	1,82	1,81	1,83
	1,83	1,81	1,81	1,83	2,06	2,06	2,34	1,93	1,85	1,83	1,83	1,85
	1,84	1,82	1,82	1,84	2,06	2,06	1,93	2,46	1,81	1,80	1,80	1,81
15	1,65	1,64	1,64	1,65	1,83	1,82	1,85	1,81	2,39	1,93	2,06	2,06
	1,65	1,63	1,64	1,64	1,82	1,82	1,83	1,80	1,93	2,37	2,06	2,06
	1,65	1,63	1,64	1,64	1,82	1,81	1,83	1,80	2,06	2,06	2,45	1,93
	1,66	1,64	1,65	1,65	1,82	1,83	1,85	1,81	2,06	2,06	1,93	2,40

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