

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 used 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.

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 FTTP 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.
- SHOULD** This word, or the term “RECOMMENDED”, means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
- SHOULD NOT** This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
- 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] 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

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
DP	Distribution Point
DPU	Distribution Point Unit
ELFEXT	Equal Level Far End Crosstalk
ETSI	European Telecommunications Standards Institute
FEXT	Far End Crosstalk
ITU-T	International Telecommunications Union Telecommunications Standardization Sector
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
TR	Technical Report

Technical Report Impact

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TR-285 has no impact on energy efficiency.

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TR-285 has no impact on security.

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

Physical Layer Topology

Overview of the Loop End Access Network

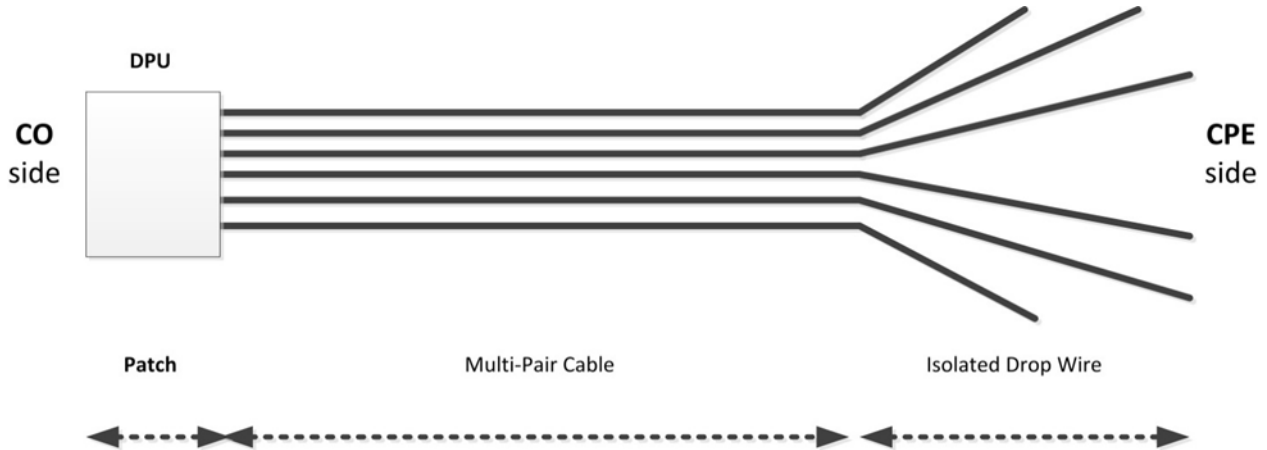


Figure 1: Overview of the Loop End Access Network – The Final Drop

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

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

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

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:

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

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 0.6m.

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

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

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_{s0D} ”
 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)

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

“ 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:

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

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

The equation for the region of $f \leq 75 \text{ MHz}$ 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.

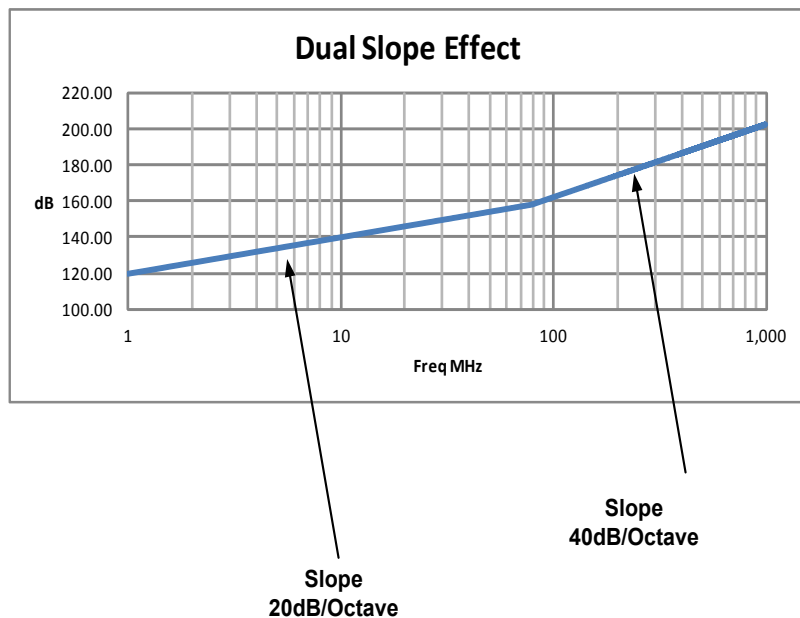


Figure 2: Illustration of the Dual Slope Effect

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 (CADD55 Amplitude Offset Matrix.xlsx) is contained in TR-285.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 $H_{ijFX\ T-V}(f,d)$ which is defined below as:

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

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

Completion of the definition of $H_{ijFX\ T-V}(f,d)$ 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 $Hp(f)$ 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:

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

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

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

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

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:

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

“ 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 [4].

Supplementary information to the quad cable modeling is provided 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 0.5mm 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:

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

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

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

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

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

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

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

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

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

B.1.2 ETSI BT0 Line Model

Another model for a single twisted -pair line is the ETSI BT0 model, described in [4]. 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 30MHz.

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 30MHz
- impulse response is not always
- 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:

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

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

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 0.5mm 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 70MHz and 100MHz (as per supplier lot and variant) exceed a level of -10dB. Partially, the coupling is even above 0dB, in resonances for frequencies above 100MHz.

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: 45mm
 - Quad 2: 43mm
 - Quad 3: 39mm
 - Quad 4: 50mm
 - Quad 5: 41mm

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

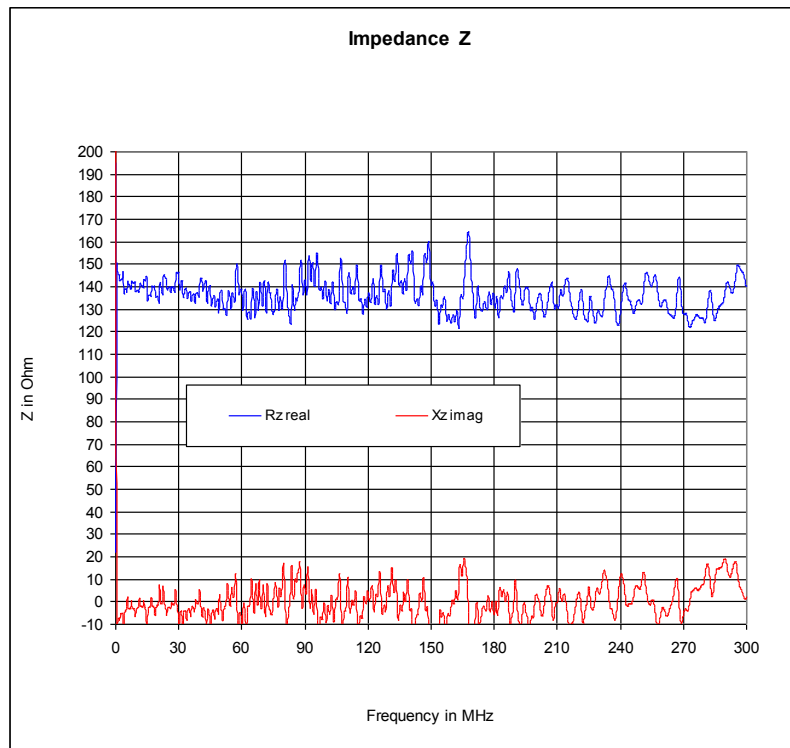


Figure 3: Characteristic Impedance of I-O2YS(ST)H 10x2x0.5 STVI Bd Cable

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, $x=2, \dots, 10$

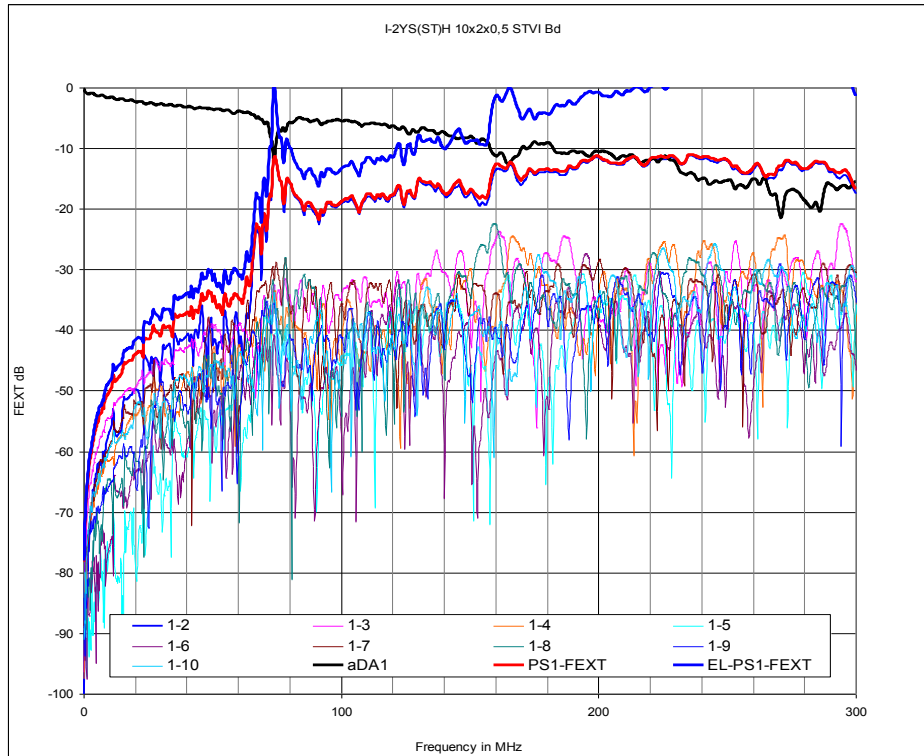


Figure 4: FEXT measurements of I-O2YS(ST)H 10x2x0.5 STVI Bd cable

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

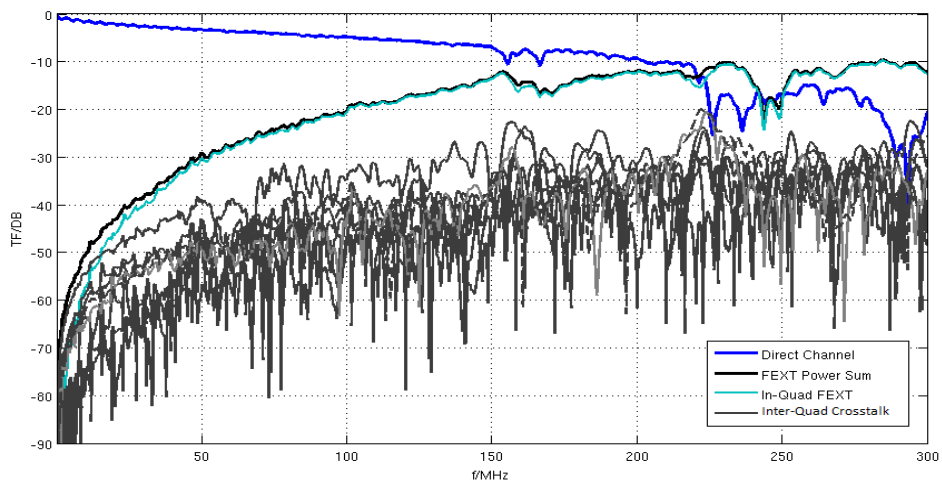


Figure 5: Measurements and single line model of I-O2YS(ST)H 10x2x0.5 STVI Bd cable

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.

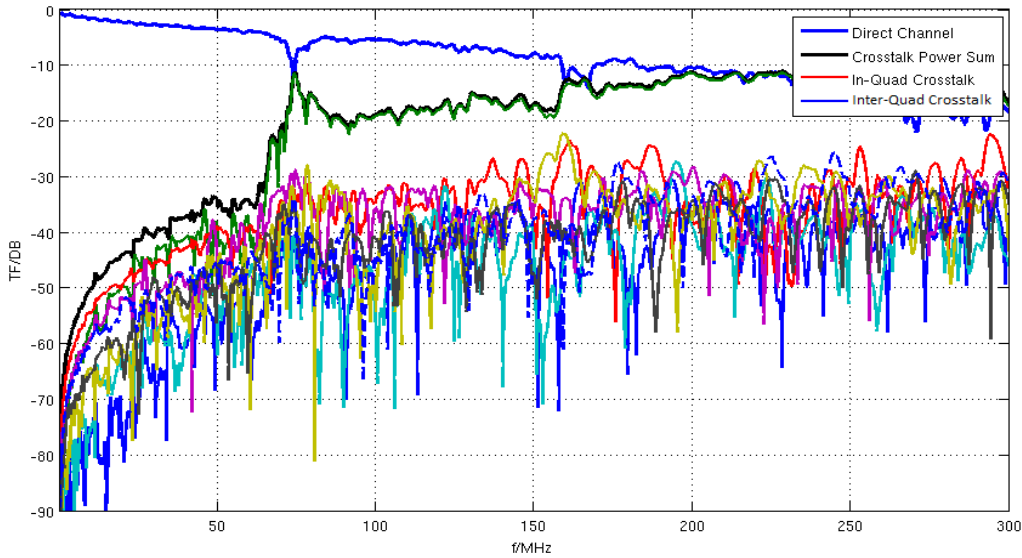


Figure 6: Another 0.5mm cable pair direct channel and crosstalk measurements

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.

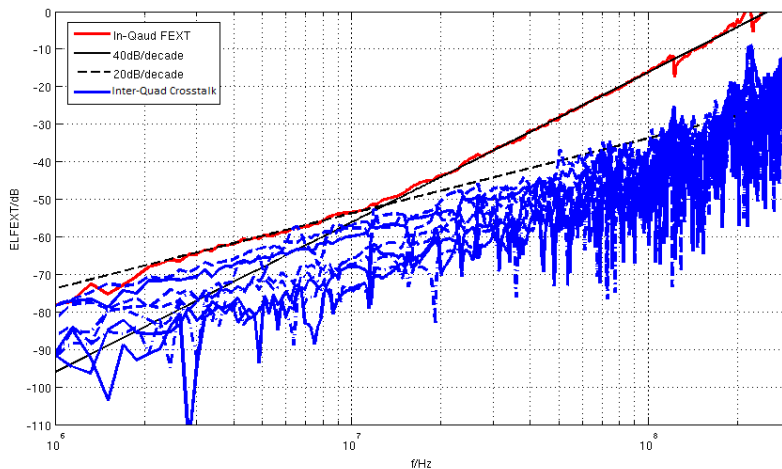


Figure 7: Detailed In-and Inter-quad crosstalk measurements of 0.5mm cable

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 0.6mm 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: 100mm
 - Quad 2: 55mm
 - Quad 3: 90mm
 - Quad 4: 80mm
 - Quad 5: 70mm

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

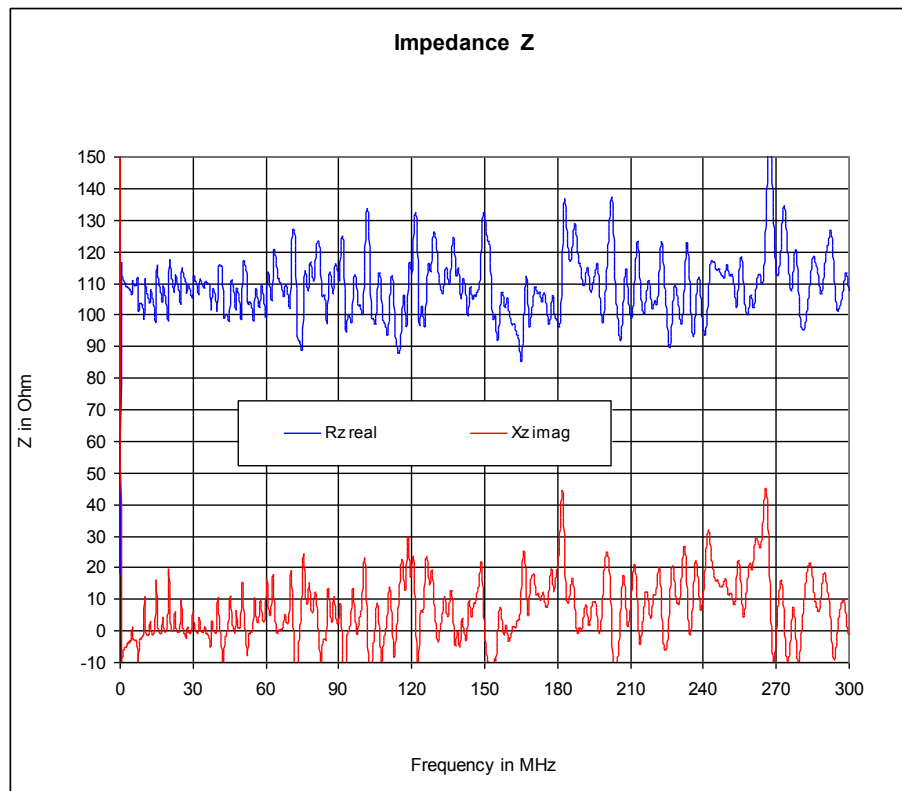


Figure 8: Characteristic Impedance of J-H(ST)H Bd 10x2x0.6 cable

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

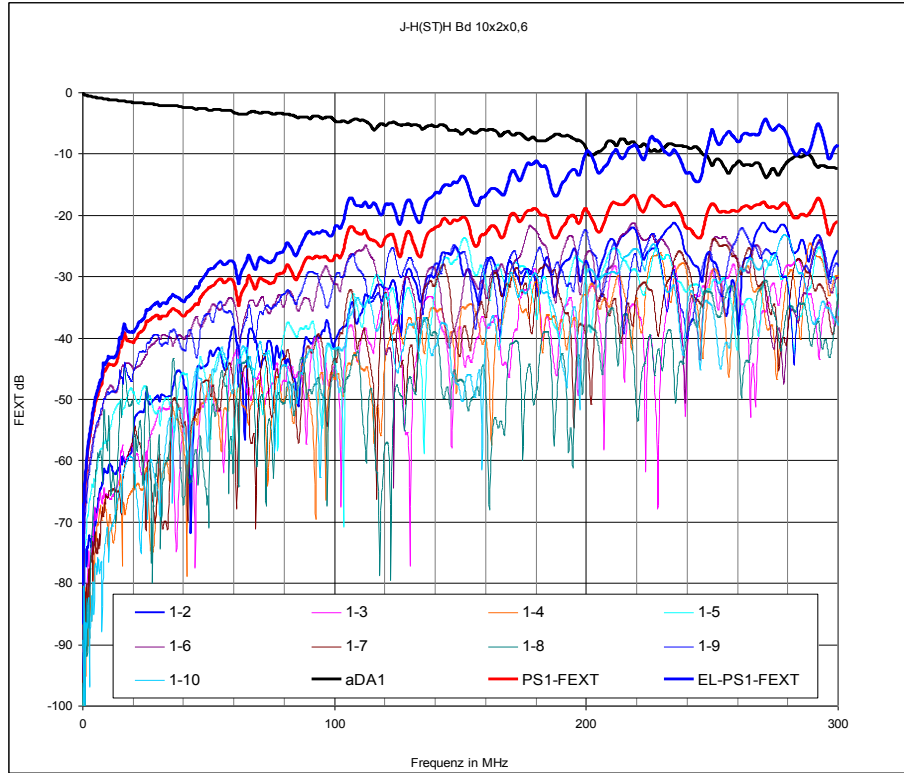


Figure 9: FEXT measurements of J-H(ST)H Bd 10x2x0.6 cable

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.

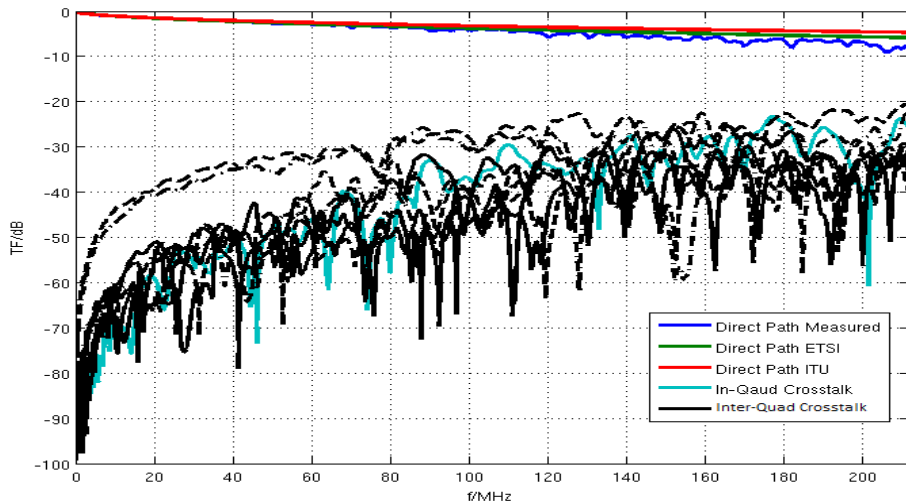


Figure 10: Measurements and single line model of J-H(ST)H Bd 10x2x0.6 cable

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.

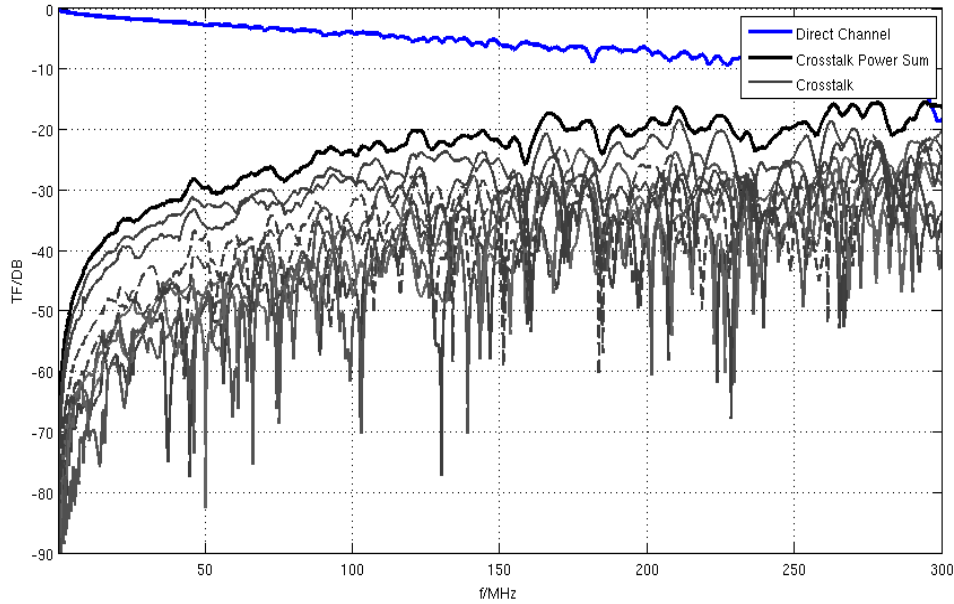


Figure 11: Another 0.6mm cable pair direct channel and crosstalk measurements

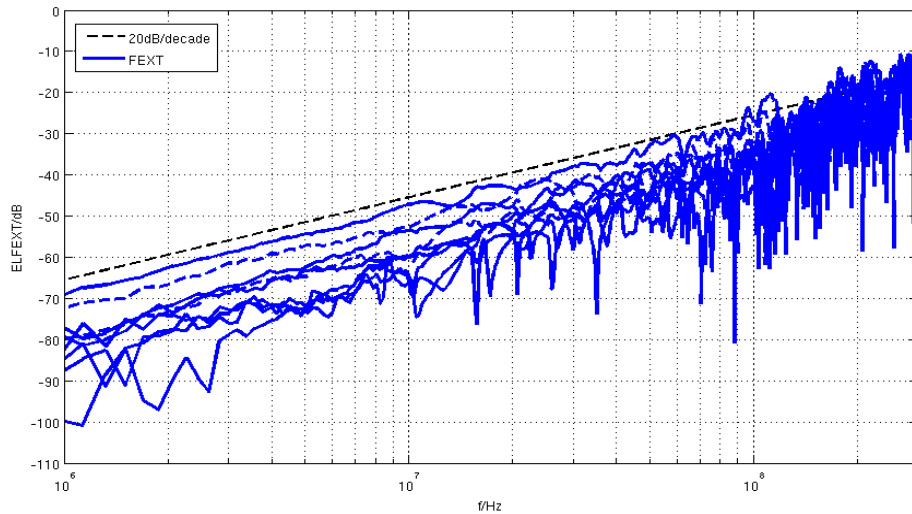


Figure 12: Detailed Inter-Quad crosstalk measurements of 0.6mm cable

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.

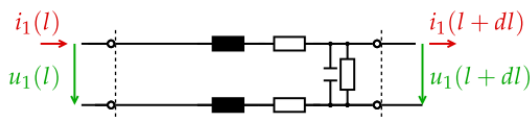


Figure 13: Single line circuit element

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

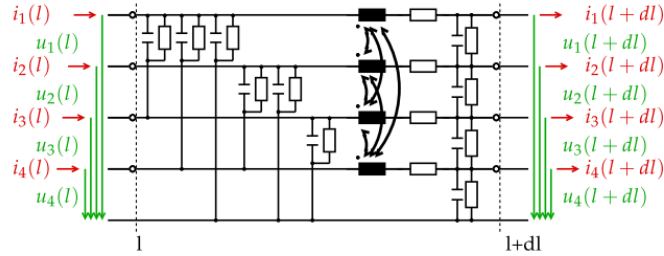


Figure 14: Multiline circuit element

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 $\frac{1}{2}$ 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 (L_{ref_pe06} and L_{ref_pe05}). The reference matrices contain the information about cable geometry and crosstalk characteristics in the spectral region of up to 300MHz. 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 (d_{ref_pe06} and d_{ref_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 0.5mm and 0.6mm 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.

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 define 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:

$$Y_c = T_l Y^{-1} T_l^{-1} Y_p$$

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.

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

herefore, \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.

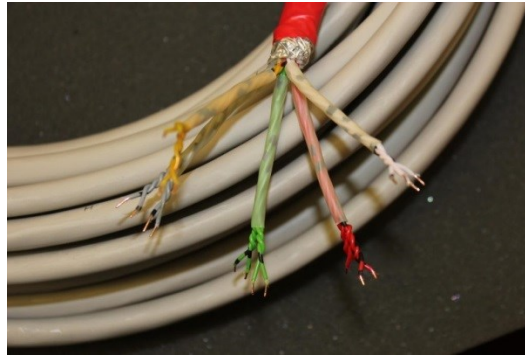


Figure 15: A Typical quad cable.

The inductance matrix is constructed from the reference geometry.

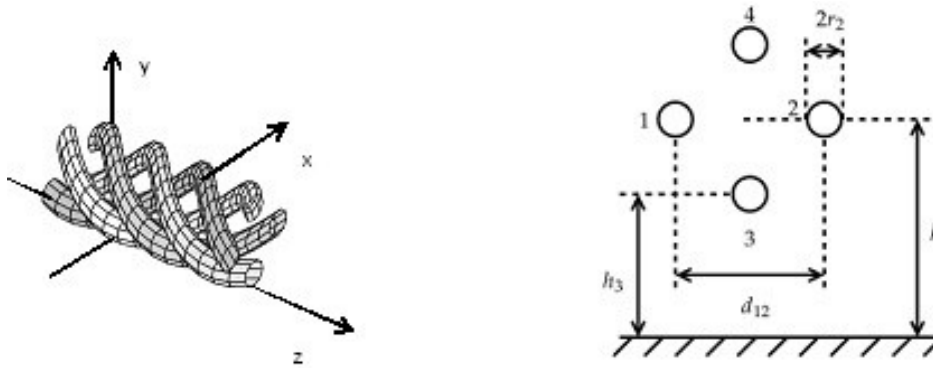


Figure 16: Quad Cable reference geometry

$$x_1 = -\cos\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2}$$

$$y_1 = -\sin\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} + h$$

$$x_2 = \cos\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2}$$

$$y_2 = \sin\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} + h$$

$$x_3 = -\sin\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2}$$

$$y_3 = -\cos\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} + h$$

$$x_4 = \sin\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2}$$

$$y_4 = \cos\left(\frac{2\pi z}{d_{twist}}\right) \times \frac{d_{ik}}{2} + h$$

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 17 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).

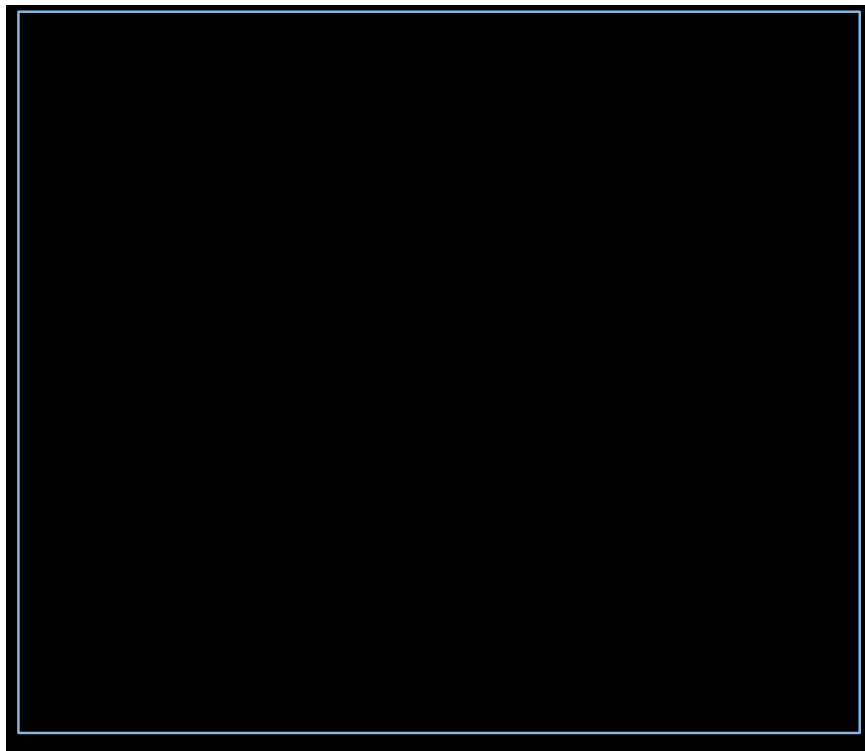


Figure 17: Reference Crosstalk Matrix Structure

As an example, Table 9 to Table 12 show the corresponding L_{ref_pe06} in-quad and inter-quad crosstalk coefficients (rounded to two decimal points) for the first cable segment (0.2220 m in d_{ref_pe06}).

Table 9 - 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 10 - 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 11 - 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 12 - 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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