TECHNICAL REPORT

TR-285

Broadband Copper Cable Models

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Issue History

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1	23 February 2015	16 March 2015	Andre Holley TELUS Communications	Original
1 Corrigendum 1	9 November 2015	11 November 2015	Andre Holley, TELUS Communications	
1 Amendment 1	13 March 2017	5 May 2017	Andre Holley, TELUS Communications	
1 Corrigendum 2	21 March 2019	21 March 2019	Andre Holley TELUS Communications	Corrects length dependency.

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Executive Summary

This corrigendum corrects the text in Annex C of TR-285 Amendment 1.

This corrigendum corrects the length dependency in the definition of the ELFEXT magnitude in the reference model of the PE4D-ALT 4x10x0.6mm Quad cable and P-Pb 4x10x0.6mm Quad cable.

1 Purpose and Scope

1.1 Purpose

This corrigendum corrects the length and frequency dependency in the definition of the ELFEXT magnitude in the reference model of the PE4D-ALT 4x10x0.6mm Quad cable and P-Pb 4x10x0.6mm Quad cable.

2 References and Terminology

2.1 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 be in RFC 2119.

MUST	This word, or the term “REQUIRED”, means that the definition is an absolute requirement of the specification.
MUST 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.

3 Technical Report Impact

3.1 Energy Efficiency

TR-285 has no impact on energy efficiency.

3.2 Security

TR-285 has no impact on security.

3.3 Privacy

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

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

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

The PE4D-ALT 4x10x0.6mm 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 1. The model describes accurately magnitude and phase of the Insertion Loss.

Table 1: ITU-T Single Line Model for PE4D-ALT 10x4x0.6mm

ITU-T Model	Z_{0}□	η_{VF}	R_{s0}	q_L	q_H	q_x	q_y	q_c	□	f_d
PE4D-ALT 10x4x0.6mm	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

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

$f: Frequency\ in\ [MHz]$

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

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

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

$x: Cable\ length\ in\ [m]$

The ELFEXT phase is described by the following model.

For inductive coupling:

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

For capacitive coupling:

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

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.

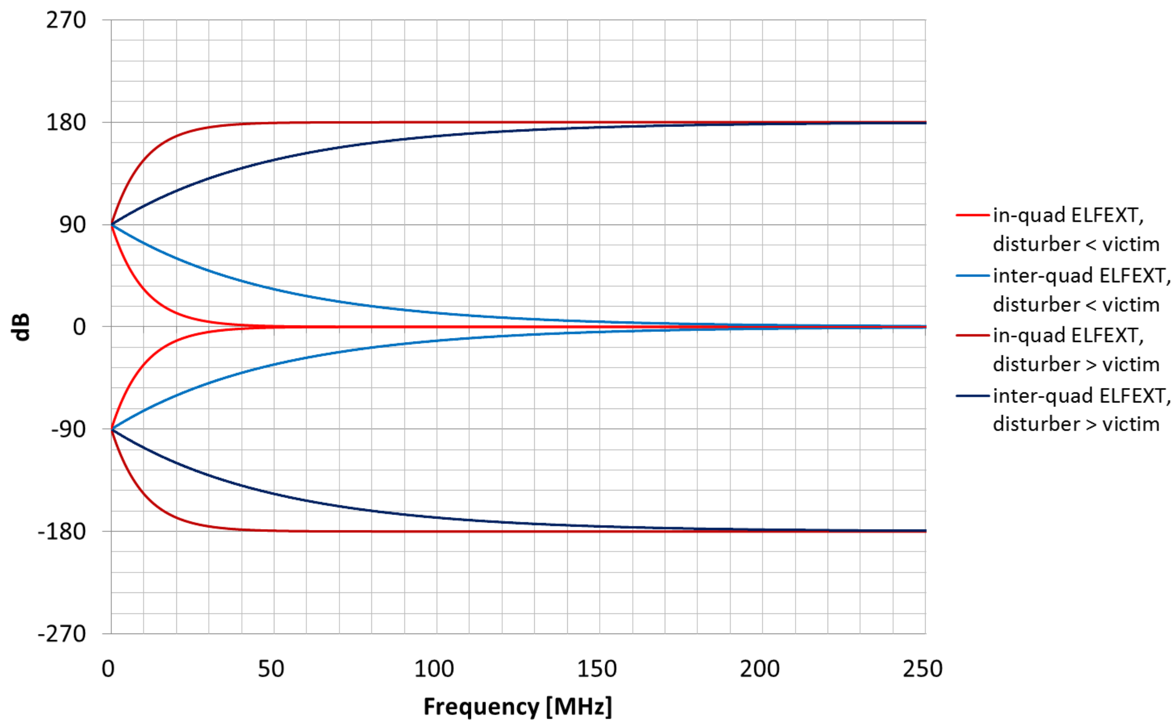

Figure 1: ELFEXT Phases for PE4D-ALT 10x40x0.6mm, 100m cable

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 4x10x0.6mm cable model all parameters are given in Table 2:

Table 2: PE4D-ALT 4x10x0.6mm Cable Parameters

	ELFEXT inter-quad pairings		ELFEXT in-quad pairings	
parameter	**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 100m:

Table 3: Calculated f_T from the parameters in Table 1

	ELFEXT inter-quad pairings		ELFEXT in-quad pairings	
parameter	**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 4x10x0.6mm PE4D cable, the statistical parameter values over all pairings of the PE4D-ALT 4x10x0.6mm 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 2 shows the model curves for 100m cable length:

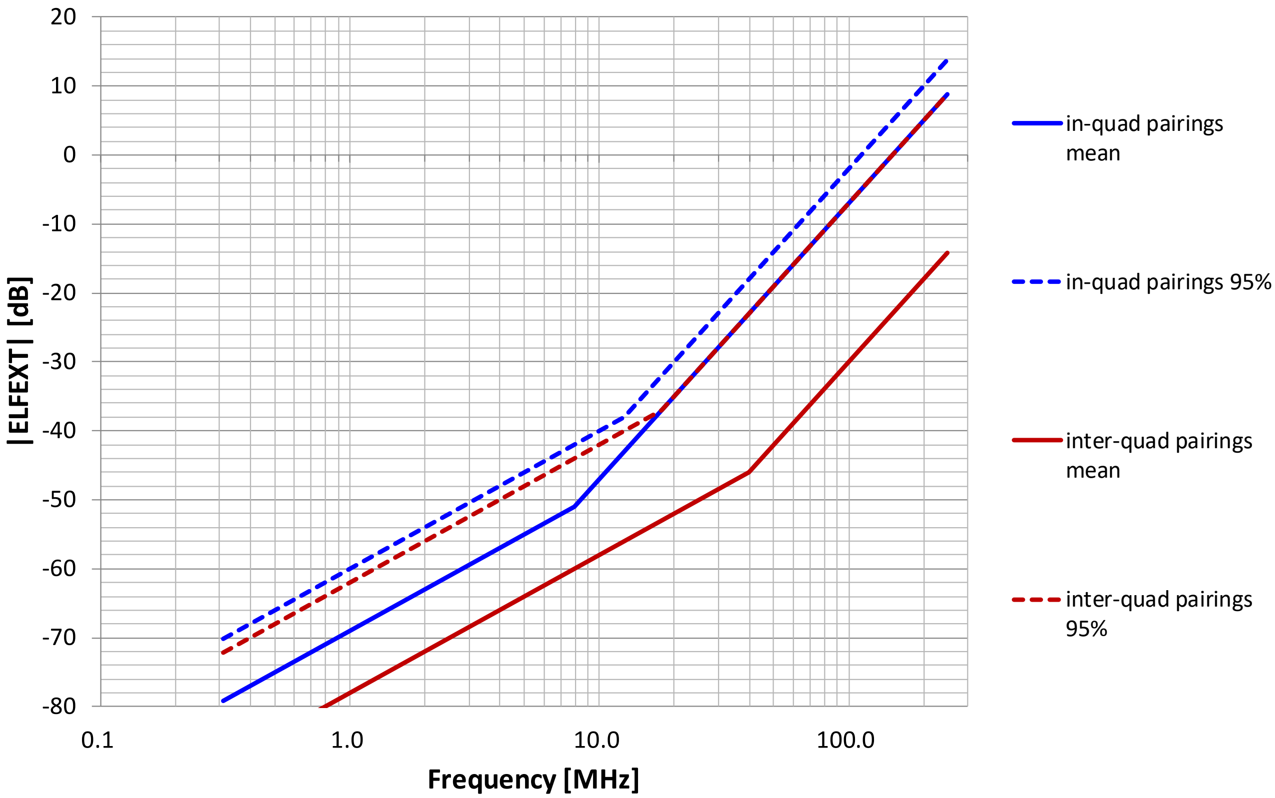

Figure 2: Statistical Dual Slope ELFEXT Model for 100m PE4D-ALT 4x10x0.6mm Cable

Figure 3 compares the mean value model curves for 50m and 100m cable length:

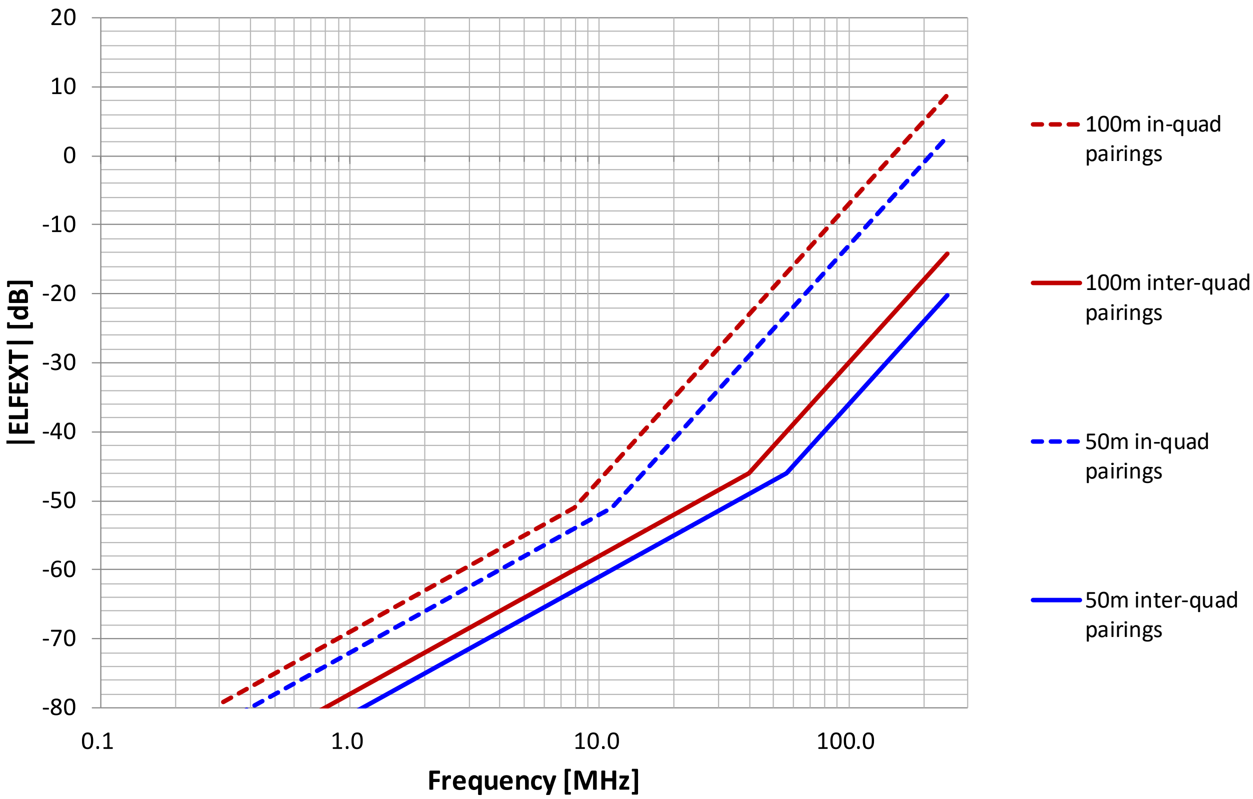

Figure 3: Statistical Dual Slope ELFEXT Model for PE4D-ALT 4x10x.06mm Cable. Mean Values for 50m and 100m

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

The P-Pb 4x10x0.6mm 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 4. The model describes accurately magnitude and phase of Insertion Loss.

Table 4: ITU-T Single Line Model for P-Pb 10x4x0.6mm 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 10x4x0.6mm	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

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

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

For capacitive coupling:

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

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.

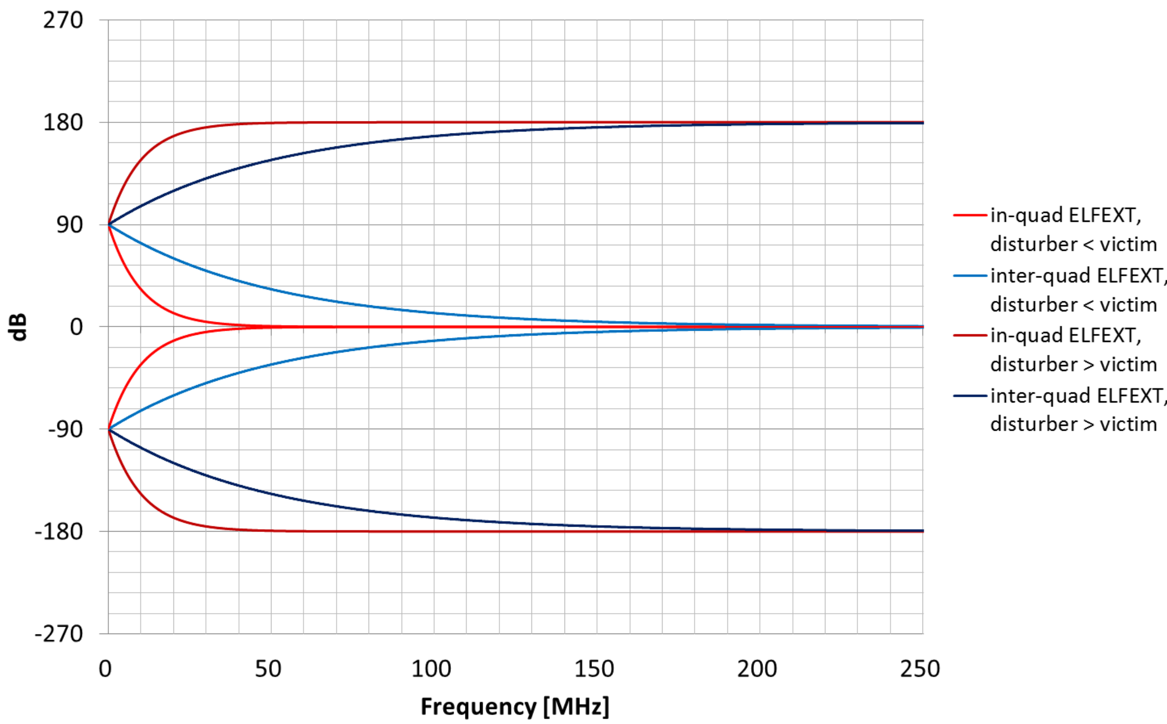

Figure 4: ELFEXT Phases for the P-Pb 1-x4x0.6mm, 100m cable

Since the number of inter-quad pairings is dominant in the P-Pb 4x10x0.6mm cable, the statistical parameter values over all pairings of the P-Pb 4x10x0.6mm 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 4x10x0.6mm cable model all parameters are given in Table 5:

Table 5: P-Pb 4x10x0.6mm Cable Parameters

	ELFEXT inter-quad pairings		ELFEXT in-quad pairings	
parameter	**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 6: Calculated f_T from the parameters in Table 5

	ELFEXT inter-quad pairings		ELFEXT in-quad pairings	
parameter	**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 5 shows the model curves for 100m cable length:

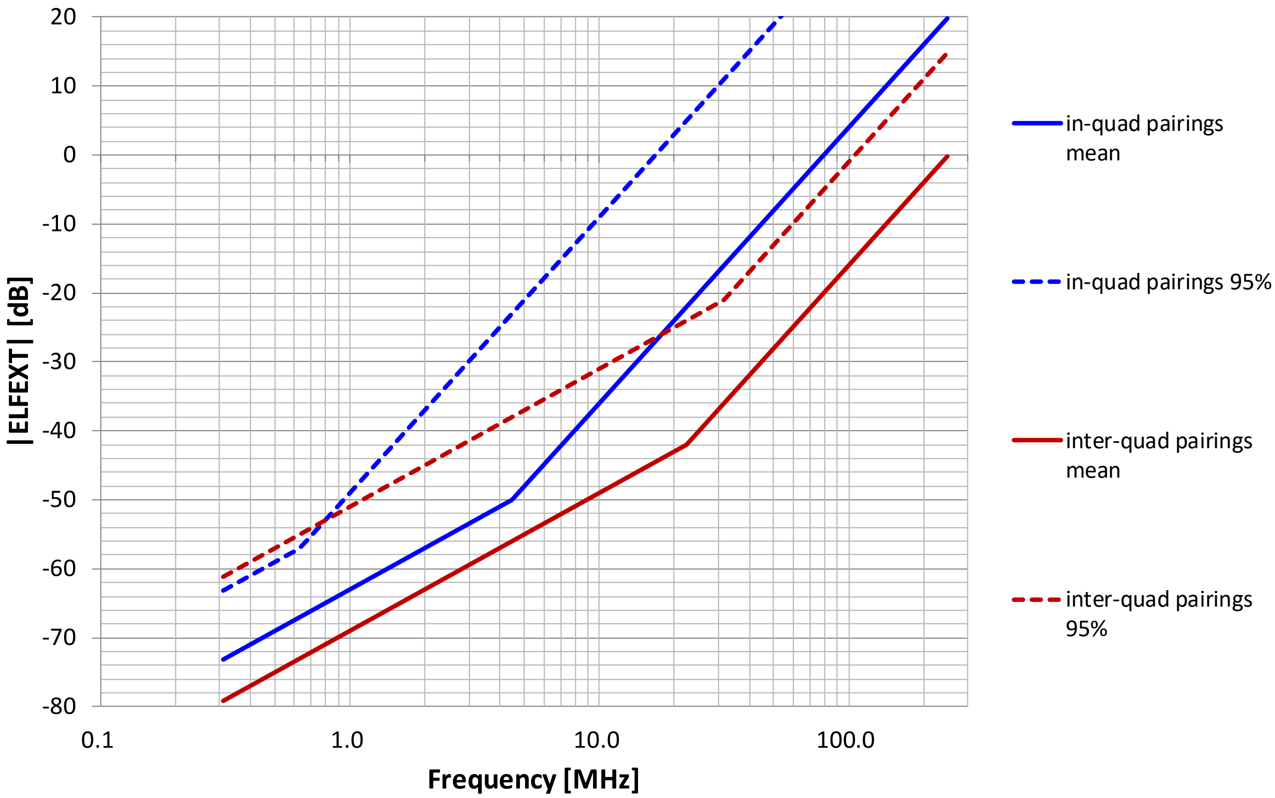

Figure 5: Statistical Dual Slope ELFEXT Model for 100m P-Pb 4x10x0.6mm Cable

Figure 6 compares the mean value model curves for 50m and 100m cable length:

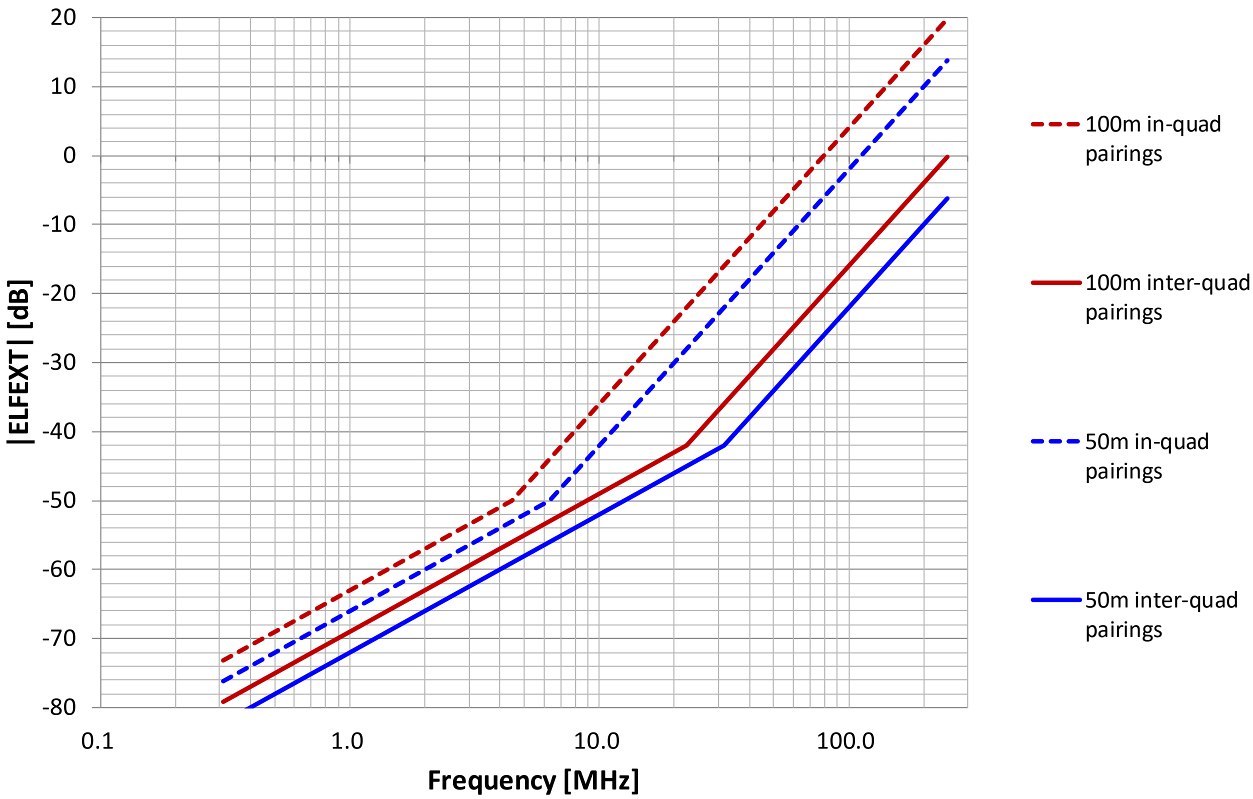

Figure 6: Statistical Dual Slope ELFEXT Model for P-Pb 4x10x0.6mm Cable

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.

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