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TECHNICAL REPORT

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

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES FOR DIGITAL COMMUNICATIONS –

Part 1-3: Electrical transmission parameters for modelling cable assemblies using symmetrical pair/quad cables

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IEC/TR 61156-1-3, which is a technical report, has been prepared by subcommittee 46C: Wires and symmetric cables, of IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
46C/924/DTR	46C/932/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

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

A list of all the parts in the IEC 61156 series, published under the general title *Multicore and symmetrical pair/quad cables for digital communications*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES FOR DIGITAL COMMUNICATIONS –

Part 1-3: Electrical transmission parameters for modelling cable assemblies using symmetrical pair/quad cables

1 Scope

This technical report is a supplement to IEC 61156-1 Edition 3 (2007): Multicore and symmetrical pair/quad cables for digital communications – Part 1: Generic specification.

This technical report covers the following topics following this standard:

– the near-end crosstalk test methods and length correction procedures of 6.3.5;

– the far-end crosstalk test methods and length correction procedures of 6.3.6;

– the concatenation of measured cable segments, even if they are of different design.

The final objective of this technical report is to describe the mathematics involved to model the concatenation of cable sections of different length, not based upon measurements but based upon the specification limits of the cables involved. This is required as a base foundation of the complete channel modelling, involving also the connectivity covered by IEC SC48B towards channels, as required and requested by ISO/IEC JTC1/SC25 WG3 for incorporation into ISO/IEC 11801:2002 [1] [1].

This TR is informative and contains observations and recommendations applicable to using the length correction formulas for either measurements or modelling of balanced cables.

2 Normative references

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

IEC 60050-726, *International Electrotechnical Vocabulary – Part 726: Transmission lines and waveguides*

IEC 61156-1:2007, *Multicore and symmetrical pair/quad cables for digital communications – Part 1: Generic specification*

IEC/TR 61156-1-2, *Multicore and symmetrical pair/quad cables for digital communications – Part 1-2: Electrical transmission characteristics and test methods of symmetrical pair/quad cables*

IEC 61156-5, *Multicore and symmetrical pair/quad cables for digital communications – Part 5: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz – Horizontal floor wiring – Sectional specification*

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1 The figures in square brackets refer to the Bibliography.

IEC 61156-6, *Multicore and symmetrical pair/quad cables for digital communications – Part 6: Symmetrical pair/quad cables with transmission characteristics up to 1 000 MHz – Work area wiring – Sectional specification*

IEC/TR 62152, *Transmission properties of cascaded two-ports or quadripols – Background of terms and definitions*

3 Terms, definitions, symbols, units and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-726, IEC/TR 61156-1-2, and IEC/TR 62152 apply.

3.2 Symbols, units and abbreviated terms

For the purposes of this document, the following symbols, units and abbreviated terms apply.

Transmission line equation electrical symbols and related terms and symbols:

R	pair resistance (Ω/m)
L	pair inductance (H/m)
G	pair conductance (S/m)
C	pair capacitance (F/m)
α	attenuation coefficient (Np/m, or dB as indicated)
β	phase coefficient (rad/m)
γ	propagation coefficient (Np/m, rad/m)
x	length coordinate (m)
Z_{o}	complex characteristic impedance, or mean characteristic impedance if the pair is homogeneous or free of structure (also used to represent a function fitted result) (Ω)
l	length, variable (m)
M	length, reference, disturbing (m)
Λ	length, reference, disturbed (m)
j	imaginary denominator
ω	radian frequency (rad/s)
f	frequency (Hz)
I	current, coupled
I_{diff}	current in the differential-mode circuit (I)
I_{com}	current in the common-mode circuit (I)
U_{diff}	voltage in the differential-mode circuit (V)
U_{com}	voltage in the common-mode circuit (V)
1, 2	index to designate the pair 1 and pair 2, respectively
N, F	index to designate the near end and far end, respectively
TU	transverse unbalance
LU	longitudinal unbalance
K	coupling coefficient
K_N	near end cross-talk coupling coefficient
K_F	far end cross-talk coupling coefficient

k_1, k_2, k_3	attenuation coefficients for the twisted pair
$FEXT$	far-end crosstalk loss (dB)
$NEXT$	near-end crosstalk loss (dB)
$EL\ FEXT$	equal-level far-end crosstalk loss (dB)
$ACR\text{-}F$	attenuation-to-crosstalk-ratio far-end loss (dB)
Δ	length correction coefficient
S	S parameter matrix
S_{11}	S parameter
T	T parameter matrix
T_{11}	T parameter
ab	index to designate the incident port and reflected port, of multiport parameter

4 Traditional length correction formulae

4.1 Introduction

The traditional length correction formulae were intended for measurements on long manufactured lengths to be corrected to the specified nominal length; i.e. for cables complying to IEC 61156-5 and IEC 61156-6, as outlined in IEC 61156-1. Therein the length corrections apply to measurements made on longer lengths than 100 m, to be corrected to the 100 m specification. Moreover, these formulae were normally used in the cable industry for quality assurance purposes.

The formulae are intended for measurements of crosstalk within cables with length uncorrelated crosstalk coupling characteristics. Thus they do not readily adapt to the limit lines for crosstalk loss, which are the upper-bounds for the characteristic length correlated crosstalk coupling, i.e. a homogeneous coupling along a cable that is at the limit line at every frequency, at the specified length.

4.2 Length correction formulae in IEC 61156-1

The formulae are

$$FEXT_{\ell} = FEXT_{M} - 10 \cdot \log_{10}\left(\frac{\ell}{M}\right) - \alpha_{M} + \alpha_{\ell} \tag{1}$$

and

$$NEXT_{\ell} = NEXT_{M} - 10 \cdot \log_{10}\left(\frac{1 - 10^{-\frac{4\alpha_{\ell}}{20}}}{1 - 10^{-\frac{4\alpha_{M}}{20}}}\right) \tag{2}$$

where

ℓ	is the actual cable conversion length;
M	is the reference cable specification length;
α	is the attenuation for the indexed length in dB.

Normally, we measure FEXT and derive from it, using the corresponding attenuation, either the EL FEXT or more pertinent to data grade cables the ACR-F.

For these last two values, we have then the following length corrections:

$$EL\,FEXT_{\ell} = EL\,FEXT_{M} - 10 \cdot \log_{10}\left(\frac{\ell}{M}\right) \tag{3}$$

and

$$ACR-F_{\ell} = ACR-F_{\Lambda} - 10 \cdot \log_{10}\left(\frac{\ell}{\Lambda}\right) \tag{4}$$

Here a distinction between the length M and Λ is made to indicate the difference between disturbing and disturbed pair attenuation, respectively.

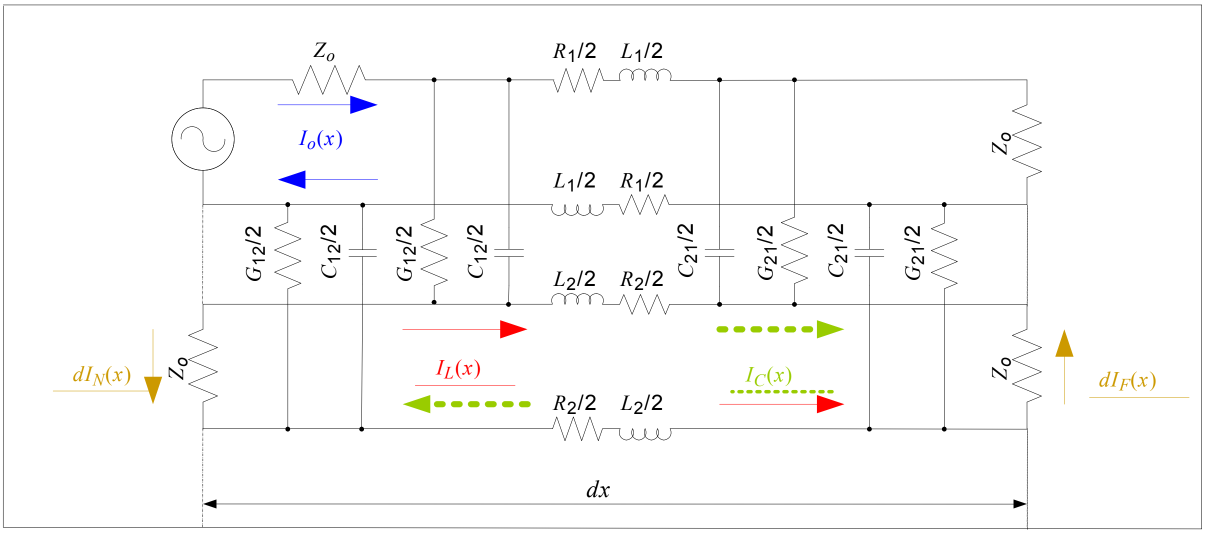
The measurement magnitude values or the complex values of the actual cable may be used to compute the crosstalk parameter when applying the traditional length correction formula, though these formulae refer only to magnitude values.

4.3 The development of the traditional cross-talk length correction formulae NEXT and EL FEXT [3]

First only in-put to out-put and the out-put to out-put cross-talk coupling are considered. These correspond to the near-end cross-talk and the equal level far-end cross-talk. These are called in the cable industry generally NEXT (IO–NEXT though this denomination is in the present case irrelevant) and EL FEXT (or OO–FEXT). These two terms are treated first, before going over to the in-put to out-put FEXT (IO–FEXT).

NOTE It should be noted that the following derivation was first published by the members of the technical staff of the Bell telephone laboratories [6].

If we consider the coupling between two infinitesimal short circuits, we have to take first the unbalances of the primary parameters of both circuits 1 and 2 into account. This inherently implies the assumption that the primary parameters as prime responsible factor for the crosstalk coupling are statistically distributed over the length of the cable.



IEC 631/11

Key

$I_C(x)$	current induced at the length x due to capacitive coupling
$I_o(x)$	current going into the infinitesimal length of the line dx at the length x
$I_L(x)$	current induced at the length x due to inductive coupling
$dI_N(x)$	current increment flowing through the near end termination of the infinitesimal length element
$dI_F(x)$	current increment flowing through the far end termination of the infinitesimal length element
Z_o	impedance of the termination of the length element. It is assumed here to be identical for all source and load impedances, and corresponds additionally to the characteristic impedance of the pairs

Figure 1 – Coupling between two circuits due to unbalances of the primary parameters

We get then according to Figure 1 for the corresponding crosstalk values of interest between two infinitesimally short circuits.

As a result of the above, it is implied that the integration direction of the infinitesimal current or voltage increments is reversed in direction.

Besides the mathematically easier treatment, this has also an historical background. Thus the telephone linesmen could not determine the IO-FEXT, but they could easily measure the OO-FEXT on the poles.

For the transverse and the longitudinal unbalances of the primary parameters, we get following the indications in Figure 1:

$$TU = (G_{21} + j \cdot \omega \cdot C_{21}) - (G_{12} + j \cdot \omega \cdot C_{12}) \quad (5)$$

$$LU = (R_2 + j \cdot \omega \cdot L_2) - (R_1 + j \cdot \omega \cdot L_1) \quad (6)$$

where

TU is the transverse unbalance between the pairs of the corresponding primary parameters G and C;

LU is the longitudinal unbalance between the pairs of the corresponding primary parameters R and L;

1,2 are indices indicating pair 1 and 2;

G is the conductance unbalance between the pairs;

C is the capacitance unbalance between the pairs;

R is the mutual resistance unbalance of the pairs;

L is the mutual inductance unbalance of the pairs;

j is the complex operator;

ω is the circular frequency.

We neglect the conductance unbalance between the pairs which we can – at least for modern data grade cables – assume to be zero. This is the result of the use of insulating materials with a very low tanδ, like PE or FEP. In fact, the resulting conductance unbalance is generally so small that it would be extremely hard to determine it at all.

We then get

$$G_{12} = G_{21} \approx 0 \tag{7}$$

$$TU = j \cdot \omega \cdot C_{21} - j \cdot \omega \cdot C_{12} = j \cdot \omega \cdot \left(C_{21} - C_{12} \right) \tag{8}$$

$$LU = (R_2 - R_1) + j \cdot \omega \cdot (L_2 - L_1) \tag{9}$$

We can furthermore assume that both infinitesimal elements of Figure 1 are on each side terminated in Z_o, which is also the characteristic impedance of the pairs considered. In other words, we consider only the case of perfectly matched pairs. The impedance of the capacitance unbalances is as a result much higher than the characteristic impedance, such that we may neglect the latter one to calculate the current going through each termination. In this case – due to the fact of matched impedances – we have then for the infinitesimal element the transverse and the longitudinal unbalances of the primary parameters of the pairs considered:

We then get

$$2 \cdot I_C(x) = -j \cdot \omega \cdot \frac{C_{12} - C_{21}}{2} \cdot \frac{Z_o \cdot I_o(x)}{2} \tag{10}$$

and

$$I_L(x) = -\frac{R_2 - R_1}{2 \cdot Z_o} - j \cdot \omega \cdot \frac{L_1 - L_2}{2 \cdot Z_o} \tag{11}$$

or with

$$C = C_{12} - C_{21} \tag{12}$$

$$R = R_2 - R_1 \tag{13}$$

$$L = L_1 - L_2 \tag{14}$$

we get

$$I_C(x) = -j \cdot \omega \cdot \frac{C \cdot Z_o \cdot I_o(x)}{8} \tag{15}$$