Project: Copper Transmission Models for Testing above 30 MHz, SD-285

Title: Parametric two-port models for reference loops

Source:

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Date: May 2013

Distribution: Metallic Transmission

Abstract: This contribution describes a parameterised two-port cable model that is suitable for frequencies up to many hundreds of MHz. It features an accurate match with measurements, and it features a causal impulse response. This contribution also provides sets of parameter values for five different cables. It is proposed that both the model and the sets of parameter values are adopted by SD-285.

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1. Introduction

One of the goals of SD-285 is to develop models of the telephone-wire transmission environment above 30 MHz. As input to that work, this contribution provides the TNO model: a parameterised two-port cable model that is suitable to describe the transmission properties of a 100 m wire pair up to typically many hundreds of MHz[1]. In addition, sets of parameter values for five different cables are provided.

The proposed two-port models describe homogeneous sections of wire pair. They may be used as the building blocks in constructing composite reference loops. The five cables described by this contribution are:

- A BT aerial access cable
- Two KPN access cables
- A Cat5e Ethernet cable
- A piece of consumer grade in-house telephony wiring.

Both the parameterised TNO model as well as all the actual parameter values proposed in this contribution are identical to the model and values that have been provided to the ITU, and have currently been captured as part of Appendix I of the draft G.fast standard.

2. The parametric cable model

Table 1 contains the TNO model: a parametric two-port cable model to describe homogeneous cable sections for reference topologies and test loops. This cable model defines the series impedance (Z_s) and the shunt admittance (Y_p) per meter, as function of frequency. From these quantities all the other cable properties (such as attenuation, impedance, reflection, etc.) can be calculated.

Much more information on the theory and validation of this model can be found in the research report [1], which is a part of a multi-document deliverable of the Celtic 4GBB project [2]. This research report has been contributed to the ITU [3] and that ITU contribution is attached to the current contribution for the benefit of the reader.

The main benefits of this parameterised model are:

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[1] The maximum frequency of validity may be reduced for longer cables, and/or for cases where the crosstalk to other wire pairs becomes so large that its effect on the direct transfer of the wire pair can no longer be ignored.

- A good match with measurements in the frequency domain over a wide frequency interval, typically up to many hundreds of MHz for a cable of 100 meters length (see footnote 1 on page 2).
- The modelling of a realistic impulse response.

Regarding the second bullet, it should be remarked that most of the traditional cable models feature non-causal impulse responses, which make those models unsuitable for time-domain studies.

The parameterised model depends on ten parameters. Regarding these parameters, the following observations can be made:

- The parameter f_d is needed mainly for dimensional reasons, and is usually set equal to 1.
- Originally[2], the model did not feature the parameter q_c, i.e. in the original model $q_c = 0$. The free parameter q_c was added later by later by Ericsson in cooperation with Lund University to improve the match for in particular the case of the cable B05a [4].
- Simplified versions of the model can be obtained by setting $q_c = 0$ and/or by setting $q_x = 1$ and $q_y = 0$. Often, these simplified models can already provide an accurate match with measurements.

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

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

$$Y_p(jw) = jw \cdot C_{p0} \times (1 - q_c) \times \left(1 + \frac{jw}{w_d} \right)^{-2 \cdot f/p} + jw \cdot C_{p0} \times q_c$$

$L_{s\infty} = \frac{1}{h_{VF} \cdot c_0} \times Z_{0\infty}$ $C_{p0} = \frac{1}{h_{VF} \cdot c_0} \times \frac{1}{Z_{0\infty}}$ $q_s = \frac{1}{q_H^2 \cdot q_L}$ $w_s = q_H^2 \cdot w_{s0} = q_H^2 \cdot \left(\frac{4p \cdot R_{s0}}{m_0} \right)$ $w_d = 2p \cdot f_d$	$c_0 = 3 \cdot 10^8$ [m/s] $m_0 = 4\pi \cdot 10^{-7}$ [H/m].

Table 1: The proposed parametric two-port cable model.

[2] The model as described in the attachment [3] does not feature the parameter q_c yet.

3. The parameter values for five different cables

Measurements have been performed on five different cables. The transmission properties of these cables can be accurately described by the cable model introduced above[3], using the parameter values listed in Table 2. Some information on the five cables is collected in Table 3.

While these models are very good for particular examples of each cable type, some of the measurements on which these models are based exhibit significant variability (over different wire pairs) in loss characteristics at higher frequencies. These variations are much larger than those encountered at lower (ADSL and VDSL) frequencies. An important contributary factor to this variability is believed to be loss due to crosstalk (see also footnote 1). For the future we seek a unified crosstalk and loss model, but for the present we believe that the models provided in this paper are the best available.

[3] These models reflect actual measurements. Therefore, transmission properties may be better than specifications or worst-case assumptions. In particular, this holds for the attenuation of the measured cat5e cable.

Cable Type	Parameters of model
B05a (CAD55)	$Z_{0\infty}$ = 105.0694; η_{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; f = -0.2356; f_d =1
CAT5	$Z_{0\infty}$ = 98.000000; η_{VF} = 0.690464; R_{s0} = 165.900000e-3; q_L = 2.150000; q_H = 0.859450; q_x = 0.500000; q_y = 0.722636; q_c = 0; f = 0.973846e-3; f_d = 1;
T05u	$Z_{0\infty}$ = 125.636455; η_{VF} = 0.729623; R_{s0} = 180.000000e-3; q_L = 1.666050; q_H = 0.740000; q_x = 0.848761; q_y = 1.207166; q_c = 0; f = 1.762056e-3; f_d = 1
T05b	$Z_{0\infty}$ = 132.348256; η_{VF} = 0.675449; R_{s0} = 170.500000e-3; q_L = 1.789725; q_H = 0.725776; q_x = 0.799306; q_y = 1.030832; q_c = 0; f = 0.005222e-3; f_d = 1
T05h	$Z_{0\infty}$ = 98.369783; η_{VF} = 0.681182; R_{s0} = 170.800000e-3; q_L = 1.700000; q_H = 0.650000; q_x =0.777307; q_y = 1.500000; q_c = 0; f = 3.023930e-3; f_d = 1

Table 2: The parameter values for each of the five cable models.

Cable Type	Description	Source
B05a (CAD55)	Cable Aerial Drop-wire #55 (CAD55) , 0.5 mm 4-pair unshielded aerial	BT
CAT5	CAT5-enhanced cable (Cat5e), as specified in ISO/IEC 11801.	TNO
T05u	Multi-quad shielded PE cable (6 x 4 x 0.5mm) KPN Access cable, used in the Netherlands in the last copper drop (underground as well as in-building)	TNO/KPN
T05b	Multi-quad shielded in-building cable (30 x 4 x 0.5mm). Telephony cable of medium quality	TNO/KPN
T05h	Low quality unshielded cable, purchased from a consumer DIY shop, typically used for in-house telephony wiring. Cable consists of four untwisted solid conductors of 0.5 mm diameter.	TNO

Table 3: Information on the five cables.

4. Summary

This contribution describes the TNO model: a parameterised two-port cable model that is suitable to describe transmission properties for frequencies up to many hundreds of MHz. It features an accurate match with measurements, and it features a causal impulse response. Sets of parameter values are provided for five different cables. Both the model as well as all the actual parameter values proposed in this contribution are identical to the model and values that have been provided to the ITU.

While these models are very good for particular examples of each cable type, some of the measurements on which these models are based exhibit significant variability (over different wire pairs) in loss characteristics at higher frequencies. These variations are much larger than those encountered at lower (ADSL and VDSL) frequencies. An important contributary factor to this variability is believed to be loss due to crosstalk (and its variability). For the future we seek a unified crosstalk and loss model, but for the present we believe that the models provided are the best available.

The following is proposed:

- To adopt the parameterised model described in Table 1 for modelling two-port transmission in SD-285.
- To adopt the parameter values contained in Table 2 to describe the transmission properties of the five different cables discussed in this contribution.

References

[1] Rob van den Brink (TNO), *"Wideband modeling of twisted pair cables as two-ports; Part 3- TNO approach"*, Milestone M3.1C.1 / Part 2 (Interim report).

[2] 4GBB Consortium, cooperating as a project under the EUREKA CELTIC cluster. See www.4gbb.eu for further details.

[3] TNO, *"G.fast: Wideband modeling of twisted pair cables as two-ports"*, ITU-T contribution 11GS3-028, Geneva, September 2011.

[4] Ericsson AB, TNO, *"G.fast: Improved model for shunt admittance in G.fast cable model"*, ITU-T contribution 2012-05-4A-045, Geneva, May 2012.

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