Modeling of Telecommunication Cables for Gigabit DSL Application

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Abstract. *The first part of our paper brings the description and analysis of method used for modeling of metallic cables' parameters according to the modified KPN model. Moreover we were able to perform measurements and estimations for real metallic cables with various transmission characteristics and constructional arrangement, for which we derived the necessary parameters of a new modeling method. Following part contains the comparison of measured characteristics with their models according to the modified KPN model. Finally, we discussed obtained results.*

Keywords

G-FAST, gigabit digital subscriber line, modeling, telecommunication cables, xDSL.

1. Introduction

Today, the existing metallic lines are still being widely used due to the slower development of passive optical networks in many countries. The continuously increasing demands for higher transmission speeds lead to exploit the potentials of metallic lines, which were not considered before. Until recently, the VDSL2 (Very High Speed Digital Subscriber Line) technology, which is standardized for frequencies up to 30 MHz and transfer speeds up to 100 Mbit$\cdot$s^{-1}, has been considered as the fastest solution in data transmissions over metallic lines [1]. Many experiments tried to increase transmission performance of DSL (Digital Subscriber Line) technology; however, the main limitation is a crosstalk, especially far-end crosstalk (FEXT) [2]. The newly standardized G-fast system, which is currently being developed, will be based on vectored discrete multitone modulation (DMT) to eliminate FEXT and its frequency band will be extended up to 212 MHz.

These enhancements will enable reaching gigabit transmission speed. For that purpose, it is necessary to modify existing models and parameters of lines for such high frequencies or design completely new modeling methods. The current version of the G-FAST draft uses a new method of modeling that is not based on calculations of the primary parameters, but instead of it uses the modeling of longitudinal impedance Z_s and transverse admittance Y_p of a homogenous line. This type of modeling is conceptually based on the method specified in the recommendation ETSI TS 101 270-1, the number of parameters was reduced to 10 and additionally, several modifications were made. Furthermore, the draft also contains specific values of these parameters for four basic types of metallic lines frequently used in access networks.

The combined network architecture with the twisted pairs and the optical fibers, called FTTB or FTTC (Fiber to the Building, Fiber to the Curb), should be considered, because the broadband transmission can be used only for short lines. The designation “Fiber Distribution Point” (FTTdp) was introduced for these situations [6].

2. Theory

Instead of using standard primary parameters (R, L, C and G), the models presented within newly developed G-FAST draft are based on estimations of longitudinal impedance Z_s and transverse admittance Y_p of a homogenous line [4]. An empirical model, which is discussed below, can be used for modeling frequency characteristics up to 300 MHz. The model can be obtained by Eq. (1), Eq. (2), Eq. (3), Eq. (4), Eq. (5), Eq. (6) and Eq. (7) [4] and is conceptually based on the modified equations presented as KPN model [5]. Resistivity is considered as complex value in this model. It is a main difference from other reference models.

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

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

$$L_{s\infty} = \frac{1}{\eta_{VF} \cdot c_0} \cdot Z_{0\infty}, \tag{3}$$

$$C_{p0} = \frac{1}{\eta_{VF} \cdot c_0} \cdot \frac{1}{Z_{0\infty}}, \tag{4}$$

$$q_s = \frac{1}{q_H^2 \cdot q_L}, \tag{5}$$

$$\omega_s = q_H^2 \cdot \omega_{s0} = q_H^2 \cdot \left(\frac{4\pi \cdot R_{s0}}{\mu_0}\right), \tag{6}$$

$$\omega_d = 2\pi \cdot f_d, \tag{7}$$

where $c_0 = 3{\cdot}10^8$ m·s^{-1} and $\mu_0 = 4\pi{\cdot}10^{-7}$ H·m^{-1}. This model can be usually simplify by $q_c = 0$ and $f_d = 1$. After this simplification, the transverse admittance Y_p is showed in Eq. (8).

$$Y_p = j2 \cdot \pi \cdot f \cdot C_{p0} \cdot (1 + j \cdot f)^{-2\cdot\phi/\pi}. \tag{8}$$

The estimation of characteristic impedance $Z_{0\infty}$ of a line is also necessary for appropriate application of presented models, as well as the velocity of propagation η_{VF}, which can be obtained by using TDR (Time-Domain Reflectometer) method or direct calculations from the phase characteristics.

The formulas for the series impedance Z_s Eq. (11) and parallel admittance Y_p Eq. (12) can be derived from the equations for the secondary parameters Eq. (9), Eq. (10) of symmetrical lines.

$$\gamma = \sqrt{Z_s \cdot Y_p}, \tag{9}$$

$$Z_C = \sqrt{\frac{Z_s}{Y_p}}, \tag{10}$$

$$Z_s = \sqrt{\gamma \cdot Z_c}, \tag{11}$$

$$Y_p = \frac{\gamma}{Z_c}. \tag{12}$$

Parameters ϕ, q_H, q_L, q_x, q_y, R_{s0}, $Z_{0\infty}$, η_{VF} for reference model are obtained by measurements and approximation of characteristics.

Finally, attenuation factor α is a real part of γ as shown in Eq. (13).

$$\gamma = \alpha + j\beta. \tag{13}$$

2.1. The Method of Measuring the Transmission Parameters

The measurement workspace in the Department of Telecommunication Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague had to be upgraded and optimized for measurement of gigabit digital subscriber lines. Figure 1 illustrates the basic schematic of measurements. The measurements were performed by network analyzer Rohde&Schwarz ZVRE (spectral analyzer with vector signal analyzer option) with balun transformers North Hills. The Automated Measuring Workplace (AMW) [3] was also used during our experiments.

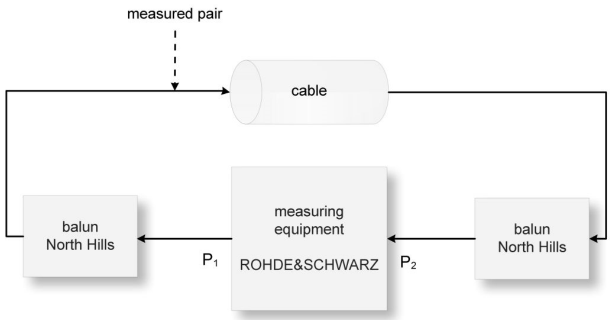

Fig. 1: The schematic illustration of measurements.

The measurements were performed for cable TCEP-KPFLE in the frequency band from 5 MHz up to 300 MHz due to the equipment limitations. The rest of the cables, measured by AMW, the frequency band was set from 100 kHz to 250 MHz.

3. The Results of Performed Measurements and Models

The measurements were performed for four typical communication cables:

- TCEPKPFLE $75 \times 4 \times 0,4$ (one sub-group (8 randomly selected symmetrical pairs)),
- SYKFY $4 \times 2 \times 0,5$,
- UTP CAT5e (Unshielded Twisted Pair),
- UTP CAT6.

3.1. The Results of Measurements

The results of measuring and modeling of attenuation factor and characteristic impedance are given in following figures.

1) TCEPKPFLE $75 \times 4 \times 0,4$

The cable has star-quad construction with polyethylene insulation and is standard for use in telecommunication. The measuring and modeling of attenuation factor and characteristic impedance are shown in Fig. 2 and Fig. 3.

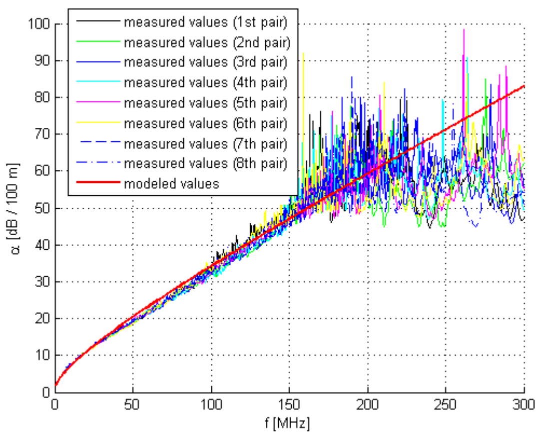

Fig. 2: Attenuation factor α TCEPKPFLE $75 \times 4 \times 0,4$ and model.

2) SYKFY $4 \times 2 \times 0,5$

This type of interior cable with four symmetrical pairs with PVC insulation corresponds to CAT3 (Category 3) for the frequency band up to a few MHz. Its frequency characteristics are presented in Fig. 4 and Fig. 5.

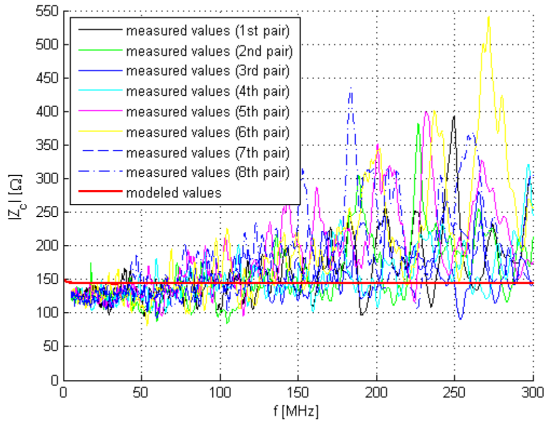

Fig. 3: Module of characteristic impedance Z_c TCEPKPFLE $75 \times 4 \times 0,4$.

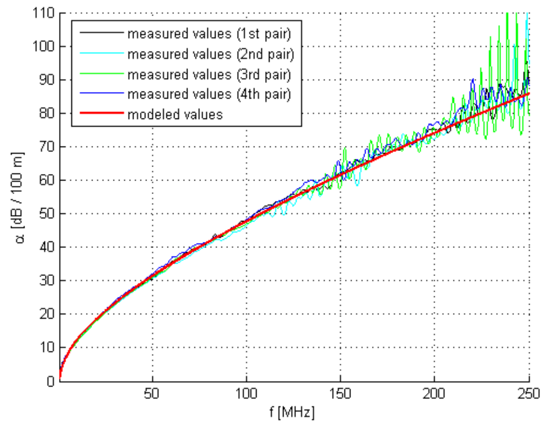

Fig. 4: Attenuation factor α SYKFY $4 \times 2 \times 0,5$ and model.

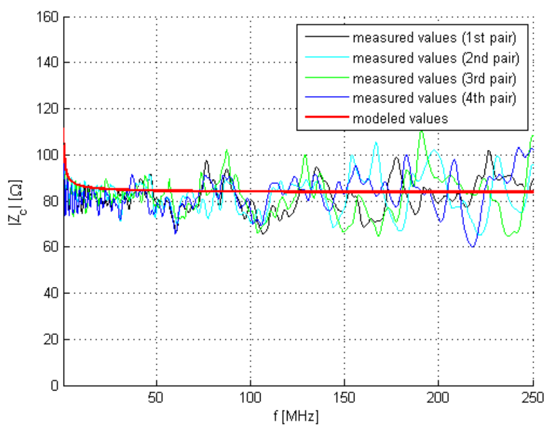

Fig. 5: Module of characteristic impedance Z_c SYKFY $4 \times 2 \times 0,5$.

3) UTP CAT5e

The CAT5e is a category of cables primary used for local area networks with parameters guaranteed up to

100 MHz. The measuring and modeling of attenuation factor and characteristic impedance are shown in Fig. 6 and Fig. 7.

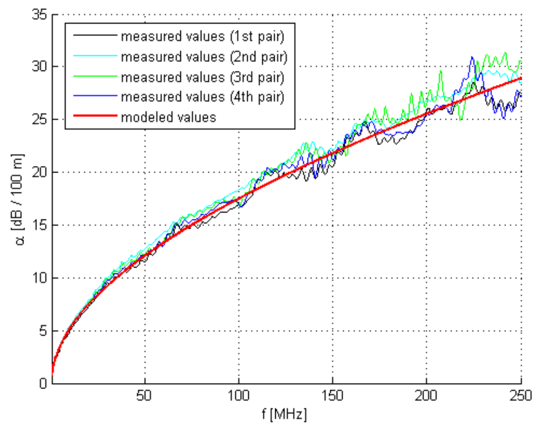

Fig. 6: Attenuation factor α UTP CAT5e and model.

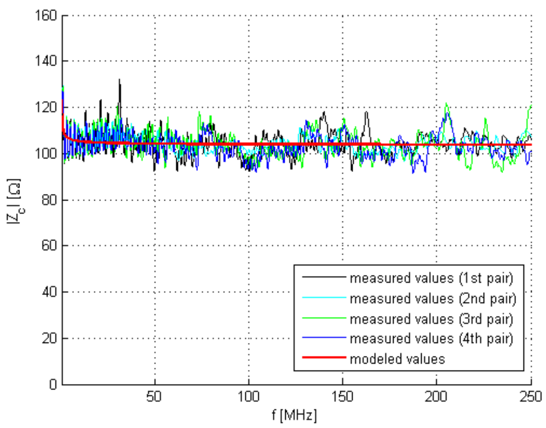

Fig. 7: Module of characteristic impedance Z_c UTP CAT5e.

4) UTP CAT6

The CAT6 is a category of cables with the same type of construction as CAT5e, furthermore, in this category the parameters are guaranteed up to 250 MHz. Its frequency characteristics are presented in Fig. 8 and Fig. 9.

3.2. Parameters of the Reference Model

The measured values were processed in program Matlab and optimized parameters were estimated. The parameters obtained for reference model (above) are presented in Tab. 1 and Tab. 2.

Output parameters of the reference model are presented in Tab. 3. The velocity of propagation η_{VF} was

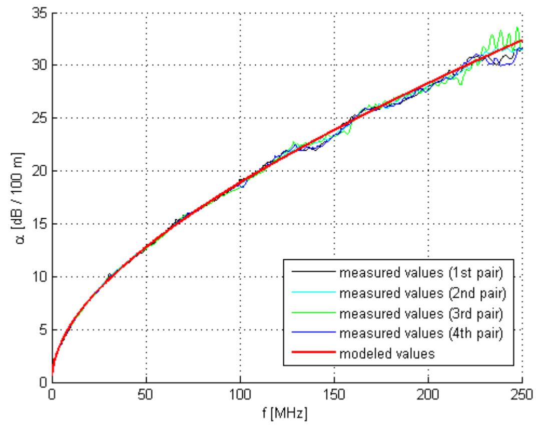

Fig. 8: Attenuation factor α UTP CAT6 and model.

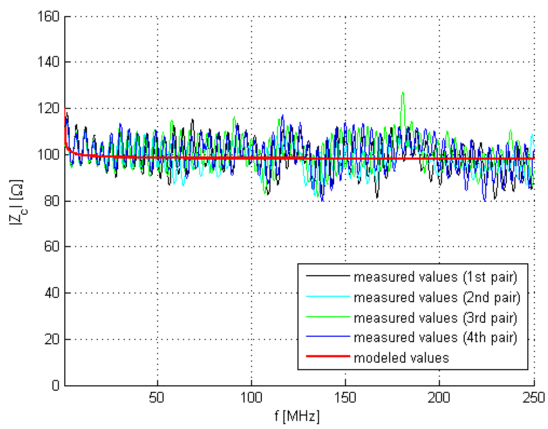

Fig. 9: Module of characteristic impedance Z_c UTP CAT6.

Tab. 1: q-parameters of the reference model.

Cable type	q_H	q_L	q_X	q_Y
TCEPKPFLE $75 \times 4 \times 0,4$	0,902	2,15	0,5	0,723
SYKFY $4 \times 2 \times 0,5$	0,501	2,75	0,2	1,492
UTP CAT5e	0,880	2,15	1,6	0,820
UTP CAT6	0,835	2,40	1,4	1,800

Tab. 2: Others parameters of the reference model.

Cable type	ϕ	$R_{S0}[\Omega{\cdot}\mathrm{m}^{-1}]$	$Z_{0\infty}[\Omega]$
TCEPKPFLE $75 \times 4 \times 0,4$	1,530e-2	0,2800	131
SYKFY $4 \times 2 \times 0,5$	9,992e-3	0,1900	78
UTP CAT5e	1,100e-3	0,1659	97
UTP CAT6	2,200e-3	0,16100	102

Tab. 3: Output parameters of the reference model.

Cable type	$C_{p0}[\mathrm{F}{\cdot}\mathrm{m}^{-1}]$	$L_{S\infty}[\mathrm{H}{\cdot}\mathrm{m}^{-1}]$	η_{VF}
TCEPKPFLE $75 \times 4 \times 0,4$	3,877334e-11	6,653892e-07	0,6562575
SYKFY $4 \times 2 \times 0,5$	5,667929e-11	3,448368e-07	0,7539799
UTP CAT5e	4,405455e-11	4,145093e-07	0,7800388
UTP CAT6	4,655176e-11	4,843245e-07	0,7020087

calculated by using derivation of measured phase characteristic.

4. Conclusion

According to our results, the TCEPKPFLE cable can be used up to the frequency of 150 MHz (Fig. 2). The propagation of a signal at higher frequencies is performed by crosstalk and couplings between symmetrical pairs, which cannot be used for reliable transmissions. On the other hand, the frequency characteristics of SYKFY, UTP CAT5e and UTP CAT6 cables have the estimated shapes in the whole frequency band that is why the G-FAST models could be successfully applied. In conclusion, we can say that proposed reference model, which is presented in G-FAST draft of recommendation [4], can be used for modeling of metallic cables up to 300 MHz. The modeled parameters will be used for estimation of gigabit digital subscriber lines data rates in the on-line program "xDSL simulator" [7].

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About Authors

Marek NEVOSAD was born in Prague, Czech Republic. He received his M.Sc. degree in electrical engineering from Czech Technical University in Prague in 2004. His research interests include telecommunication transmission systems and software development. He also participates in numerous international projects focused on new methods in education as a software developer.

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