Investigation of Short Twisted Pair Insulation Resistance Impact on ADSL Signal

Alen Begović, Narcis Behlilović

Abstract — **this paper analyses qualitative and quantitative impact of common copper-based symmetrical twisted pair insulation resistance on some ADSL signal properties. The case of relatively short pair (up to 200 meters) is considered. Mathematical model of the treated case is introduced and analysed in the beginning. After that, introduced model is simulated on the same input values as well as in the case of the mathematical analysis. In the end, one twisted pair in the exploitation conditions is analysed and comparison of results got by mathematical analysis, computational stimulation and measurement in the real conditions is done. Measured results, in the lower and higher part of the used downlink band, are especially analysed.**

Key words — **asymmetrical digital subscriber line, bit rate, downlink, insulation resistance, transmission line, transmission line fault, twisted pair and uplink.**

I. INTRODUCTION

WITH the coming of the Digital Subscriber Line (DSL) on the telecommunication market in the world, offering of wideband service by using common copper-based twisted pair as transport medium between the subscriber terminal equipment and the packet switching node is enabled. Digital Subscriber Line enables using of wideband services to many subscribers-these services are not privilege of only small number of powerful companies.

Before the coming of the DSL it was thought that the future of the copper-based cables in the telecommunication access networks was at least questionable. However, economic unjustifiable of already built access networks abandonment and the coming of the digital subscriber line ensured existence of the copper-based access networks on the telecommunication market for a long time.

Logical question which was imposed by the inauguration of the DSL service is: which parameters does twisted pair need to have to ensure some specific quality of such service offering e.g. bit rate in downlink? It is obviously that those parameters have to be much stricter than the parameters in the case of the Plain Old Telephone Service (POTS). DSL uses much wider frequency band than the POTS.

For the telecommunication service providers, which offer DSL service, it is important to know these "new" parameters, because on the basis of them they can evaluate weather and how much it is worth to invest in the old copper-based access network maintaining, or it is better to build a new access infrastructure.

Significance of some basic twisted pair parameters and their impact on the wideband signal properties is analysed in [1] and [2]. The impact of the location of the twisted pair fault on the ADSL signal bit rate is described in [3] while in [4] is analysed impact of one ADSL signal on the other spatially close ADSL signal. By the evaluation of possibilities for installation of DSL over some pair, it is important to define band limit of that pair [5].

Twisted pair parameters which are necessary for clean installation of DSL over it have to be better than the parameters for the case of POTS or some similar service installation. It shows the fact that most relevant producers of copper-based cables offer special kinds of cables, which are dedicated to DSL service offering commercially on the market for some time. It can be read in [6] and [7].

The offering of the DSL brought to a need for the different access networks on the basis of low-pass copper-based cables [8]. Wideband access to telecommunication network is treated in some newer basic books from the region of telecommunications area [9], [10].

In this paper, the intensity of copper-based subscriber line fault impact on the ADSL signal downlink bit rate will be analysed. As the kind of the fault, it is observed the galvanic connection of the two wires of subscriber line, which is illustrated in practice as the insulation resistance decrease. Because of that, fault intensity is the insulation resistance value (it means the lower the insulation resistance, the higher the fault). In the experiment, there is the fixed fault place, where we vary its intensity.

This experiment was done on the new low-pass copper-based subscriber cable with the polyethylene sheath and the foamed polyethylene insulation, where the length of the treated pair is 140 meters, and where the fault is located on the length of 70 meters, so at mid-share. Short cable is used in the experiment to emphasize the impact of the insulation resistance in reference to the other parameters of the twisted pair as much as possible.

After giving the short list of the basic transmission line theory in the beginning of the paper, suitable theoretical analysis of the chosen line is done to compare the same one with the results of the relevant practical measurements on the observed real objects.

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II. GENERAL MATHEMATICAL DESCRIPTION OF THE ANALYSED OBJECT

It is usual to observe the twisted pair as the transmission line with the distributed parameters. Although the strict analysis of such object requests the use of the electromagnetic wave theory, we are going to use much simpler electrical circuit theory here. The practice showed that with enough precision, electrical circuit theory can be used in the transmission line analysis.

Electrical circuit theory is considerably simpler than the electromagnetic field theory, because instead of the electrical and magnetic field as relevant coordinate of the analysed system it uses electrical voltage and current. In this respect, transmission line solving includes implicitly finding the functions of the current and voltage distribution for every dot of the place and in any moment.

Transmission line elementary cell whose length is Δx is used as the starting basis of the transmission line analysis, where Δx is short enough to consider such transmission line cell parameters concentrated as it is shown on the figure 1.

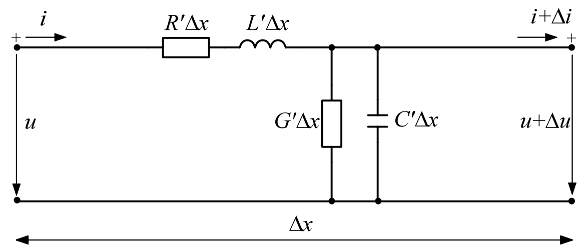

Figure 1: Transmission line elementary cell whose length is Δx

Primary parameters of the transmission line, resistance R', inductance L', conductance G', and capacitance C' per unit length are considered to be constants. On these assumptions, transmission line consists of the elementary transmission lines from the figure 1 which are connected in the shape of cascade, figure 2.

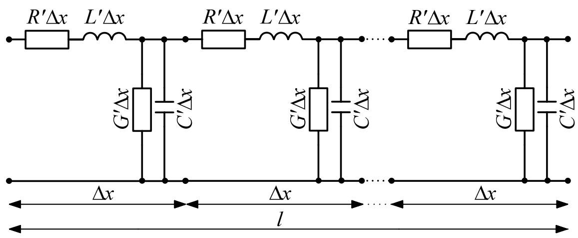

Figure 2: Transmission line whose length is l

For the arbitrary elementary cell from the figure 1, we can find the functions of the voltage and current distribution, in every dot of the space and in every moment, from the telegrapher's equations [11]:

$$
\begin{aligned}
-\frac{\partial u(x,t)}{\partial x} &= R' i(x,t) + L' \frac{\partial i(x,t)}{\partial t} \\
-\frac{\partial i(x,t)}{\partial x} &= G' u(x,t) + C' \frac{\partial u(x,t)}{\partial t}
\end{aligned}
\qquad (1)
$$

where $u=u(x,t)$ and $i=i(x,t)$ are wanted functions of the voltage and current distribution. The equations system (1), in the general case, is not possible to solve in the closed form. Because of that, the simpler cases are considered in the theoretical analysis, which the system (1) can be solved for in the closed form.

III. ANALYSIS OF THE CHOSEN PRACTICAL CASE

Transmission line model has some definite specific qualities from the aspect of the DSL. As it is explained in [1], we have to treat the subscriber line, where DSL service is installed, as the unbalanced loss transmission line. We are going to do some simplifications here because of the known fact that the analysis of such transmission line in the closed form is very complicated.

We are going to observe the idealised transmission line where only resistance per unit length is different from zero, while the other three primary parameters are zeros. We are going to assume that the transmission line beginning is connected to the ideal voltage source U_1, and its ending to the resistance R_p, figure 3.

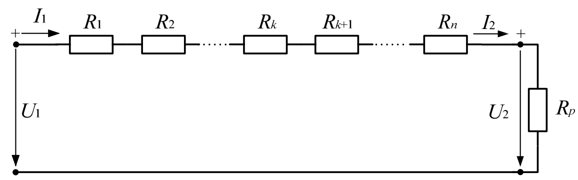

Figure 3: Idealized transmission line

Electrical power on the resistance R_p is in accordance with Kirchhoff's laws [12]:

$$P_1 = \frac{R_p}{\left(\sum_{i=1}^{n} R_i + R_p\right)^2} \cdot U_1^2 \qquad (2)$$

Now, we are going to connect the resistance R_C in the circuit from the figure, in the same way as it is shown on the figure 4. We are going to analyse changes of the power P_2 on the transmission line ending.

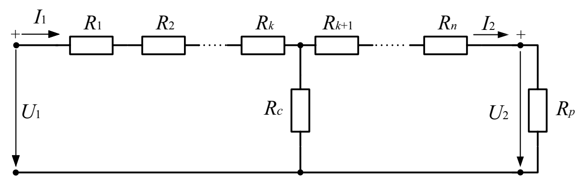

Figure 4: Idealized fault transmission line

The power on the resistance R_p is, in this case, given by the equation

$$P_2 = \frac{R_p}{\left(\left(\sum_{i=k+1}^{n} R_i + R_p\right) \cdot \frac{\sum_{i=1}^{k} R_i}{R_C} + \sum_{i=1}^{n} R_i + R_p\right)^2} \cdot U_1^2 \qquad (3)$$

If we denote the total resistance left of R_C, with R_A and the total resistance right of R_C, with R_B, we shall get a model shown on the figure 4,

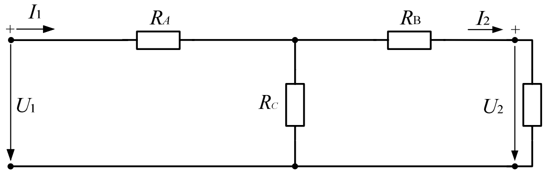

Figure 5: Simplified idealized transmission line with the fault

while the equation (3) becomes

$$P_2 = \frac{R_p}{\left((R_B + R_p)\cdot \frac{R_A}{R_C} + R_A + R_B + R_p \right)^2} \cdot U_1^2 \qquad (4)$$

Let us suppose now, because of simpler numerical analysis, that the fault is placed in mid-transmission line. In that case is $R_A = R_B$ and equation (4) can be written as

$$P_2 = \frac{R_p}{\left((R + R_p)\cdot \frac{R}{R_C} + 2R + R_p \right)^2} \cdot U_1^2 \qquad (5)$$

where we denoted common value of the total resistance which is left and right of the fault place with R.

We shall assume now that we want to make model a pair whose length is 200 meters, and whose diameter is 0.4 mm. Then the resistance per unit length is toward 300Ω/km and the total resistance of such pair is 60Ω. It follows that the resistance in the equation (5) is R=30Ω. If we know that the resistance of one standard ADSL modem which is order kΩ, we can neglect R because R_p is much bigger than R. So it follows

$$P_2 = \frac{U_1^2}{R_p \cdot \left(1 + \frac{R}{R_C} \right)^2} \qquad (6)$$

If we include the simplifications for the power on the ending of the pair without fault presence in equation (2) and substitute it into equation (6), we can write

$$\frac{P_1}{P_2} \cong \left(1 + \frac{R}{R_C} \right)^2 \qquad (7)$$

We can see the lower fault resistance R_C (so, as high fault as possible), decrease the power on the resistance R_p in reference to the case without the fault ($R_C \rightarrow +\infty$). In the same way, we observe that the power on the resistance R_p depends only on it if the resistance R is much lower than the resistance R_C. For the short pairs, that condition is always satisfied and it suggests immediately that the insulation resistance has not a significant impact on the terminal equipment power.

The first reason for this is assumption that there is the ideal voltage source in our model. In the real conditions, every voltage source has some internal resistance and it means that the power on the source side significantly depends on R_C and R_p resistances. Because of that, it is better to observe P_2/P_1 ratio, where P_1 and P_2 are power on the healthy and fault pair ending, respectively.

The second reason for an imperfection of the analyzed model is complete neglecting of the reactive elements. Existence of these elements in the real conditions is especially marked on the higher frequencies.

The third, and perhaps the most important reason for the imperfection of the model, is neglecting of the electrical connection existence between the wires and the cable sheath. These connections are very important in practice and they have an important impact on the ADSL signal properties.

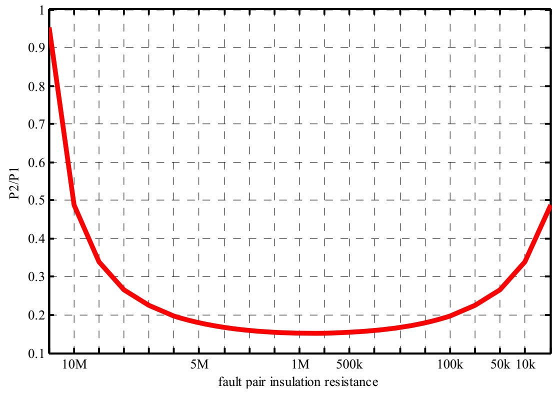

Figure 6: Dependence of the P_2/P_1 ratio on the R_C in the theoretical case

Figure 6 shows the P_2/P_1 ratio for the different faults. We can conclude that the quotient of the power on the fault pair ending and the power on the healthy pair decreases with the decrease of the fault resistance R_C, approximately according to a hyperbolic function.

It needs to be mentioned that the curve from the figure 6 is a bit different. This is primarily because, as we have noticed before, we can not construct an ideal voltage source. Because of that, the voltage in the beginning of the transmission line is not a constant.

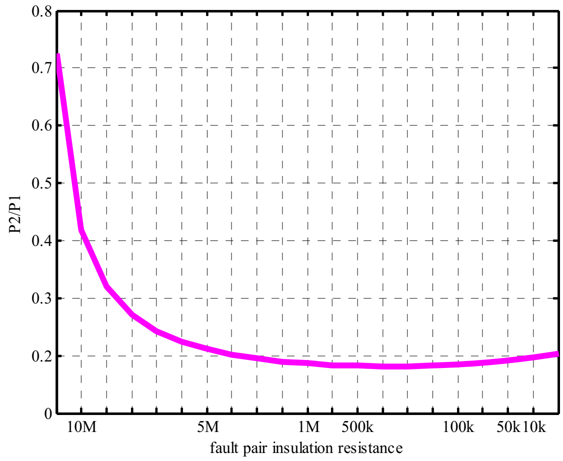

Figure 7: Dependence of the P_2/P_1 ratio on the R_C in the simulation case

Figure 7 shows the results of laboratory simulation. We can see that the shape of the curves from the last two figures are similar, except on the right part of the graph, which is in accordance with the discussion which is done in this chapter.

IV. RELEVANT RESULTS OF MEASUREMENT ON THE CHOSEN OBJECT

As the object for the practical experiment, symmetrical copper-based twisted pair whose length is 140 m on the access point whose distance is 70 m from the beginning, respectively from the ending of the pair, is used.

TABLE 1: MEASURED BIT RATES

insulation resistance	bit rate[kb/s]	insulation resistance	bit rate[kb/s]
∞	10433	500 kΩ	8306
6 MΩ	9226	400 kΩ	8203
3 MΩ	9137	300 kΩ	7997
1.5 MΩ	9025	250 kΩ	7792
750 kΩ	8622	200 kΩ	7043

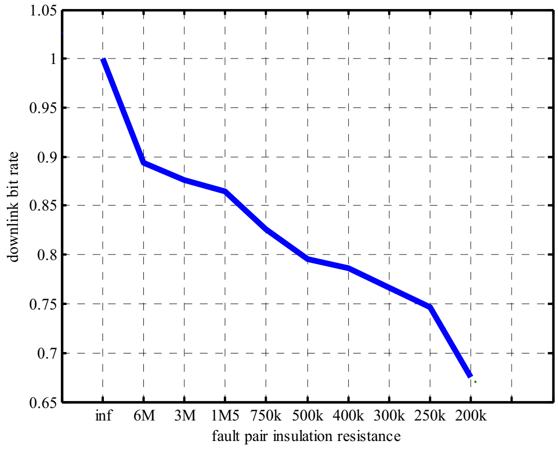

Figure 8: Dependence of the achieved bit rate on the pair fault intensity

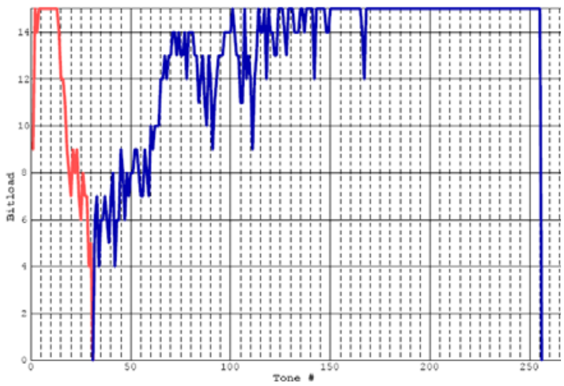

Figure 9: Spectrum of ADSL signal

The transmission line terminations are connected to DSL testers (master and slave). Those instruments are set to simulate the standard DSLAM (master) and ADSL over POTS modem (slave). On the access point in the mid-pair, a galvanic fault is shunted.

Results of measurement are shown in the table 1, and the suitable graph is shown on the figure 8. The case, when there is not a fault on the line, is marked with ∞ in the first column. Because of the example, spectral characteristic of the ADSL signal, for the case of the lowest fault, is shown on the figure 8.

V. CONCLUSION

Based on the results of the theoretical analysis of laboratory simulations and practical experiment, we can directly conclude that there is a significant difference of achieved bit rates on the subscriber pairs, depending on the insulation resistance on those pairs. As that resistance is lower, it damages the ADSL signal.

By the analysis of the characteristics of such damaged signal, we can see that the decrease of the insulation resistance has the most effect on uplink and the downer part of downlink. In the middle part of downlink, the impact of the insulation resistance is negligible, while it practically does not exist on the upper part of downlink. It happens because the capacity resistance decreases and shunts the insulation resistance more and more on the higher frequencies. This fact can be used for the DSL establishment on the longer pairs (several kilometres). On the long pairs, majority of the length is concentrated in the lower part of downlink as opposed to the shorter pairs where the power is concentrated in the whole downlink band. It follows that by the insulation resistance raising even on the old cables (they are on average longer than the young ones), we can offer the ADSL service which has good performances.

REFERENCES

[1] A. Begović, N. Behlilović, A.Sarajlić: „Analysis of effect of some parameters of symmetrical-copper-twisted-pair on quality of ADSL service", ELMAR, Zadar, Croatia, June 2006,

[2] A. A. Rahman: „Research of Capability of Existing Network for Broadband Applications; Simulation with x-DSL Technology on Indonesian Condition", ISPAN 2004,

[3] A. Begović, N. Behlilović: „Research of Impact of Location of Transmission Line Fault on the Quality of ADSL Service", TELFOR, Belgrade, Serbia, November 2006,

[4] A. Begović, N. Behlilović: „ Research of Symmetrical Copper Based Twisted Pair near Active ADSL Service Parameters Properties", ELMAR, Zadar, Croatia, September 2007,

[5] Đ. Kopitović, V. Šćepanović: „Real active frequency of symmetrical pairs in LF networks", TELFOR, Belgrade, November 2006,

[6] Z. Bojić, L. Genčić: „ADSL cable", TELFOR, Belgrade, November 2006,

[7] Đ. Kopitović, V. Šćepanović: „DSL cables in Access Networks", TELFOR, Belgrade, November 2006,

[8] A. Begović, N. Behlilović: „Modern Challenges in Copper-Based Access Networks Design from the Aspect of Providing Wideband Services", MIPRO, Opatija, Croatia, May 2007,

[9] R. Freeman, L. Roger: „Fundamentals of Telecommunications", John Wiley & Sons Inc. Publication, 2nd edition, 2005,

[10] R. J. Bates: „Broadband Telecommunications Handbook", McGraw-Hill Telecom Professional, 2nd edition, 2002,

[11] M. Hajro, N. Behlilović: „Electrical Circuits I and II", manuscript for undergraduate course, Faculty of electrical engineering Sarajevo, Bosnia and Herzegovina, 2007,

[12] N. Behlilović: „Fundamentals of Electricity", manuscript for undergraduate course, Faculty of electrical engineering Sarajevo, Bosnia and Herzegovina, 2007.