An Impact of Active ADSL Signal on Twisted Pair Transmission Properties

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Abstract — **This paper analyses qualitative and quantitative impact of large number twisted pairs transmitting ADSL signal, on one specific pair in the same cable. Change of pair capability to establish ADSL signal in respect to number of near active ADSL signals is observed. Downlink transmission rate is chosen as parameter of observed pair quality. At the beginning of this paper, simplified mathematical model of treated case is presented. After that, one pair during exploitation is analysed.**

Keywords — **asymmetrical digital subscriber line, crosstalk, downlink, transmission line, transmission rate, twisted pair, twisted pair couple, uplink.**

I. Introduction

WITH appearance of Digital Subscriber Line (DSL) on world telecommunication market, provision of broadband services using ordinary twisted pairs as transmission medium between subscriber's terminal equipment and switching node, became possible.

Logical question which was imposed by the inauguration of the DSL service is: what parameters symmetrical twisted pair needs to be, in order to ensure specific service quality, for example, downlink transmission rate. It is obvious that these parameters need to be much more rigid then in the case of Plain Old Telephone Service (POTS), mainly because DSL requests wider frequency band than POTS.

Importance of some twisted pair primary parameters and their influence on broadband signal characteristics is analysed in [1] and [2]. Influence of twisted pair fault location on ADSL transmission rate is described in [3]. In [4], influence between two near ADSL signals is analysed. Insulation resistance impact on ADSL signal, using relatively short pair, is treated in [5] as well as possibility of establishment ADSL signal over relatively long pair [6].

In this paper, we shall observe impact of active ADSL signals on specific pair in the same cable. Downlink transmission rate is chosen as output parameter of observed twisted pair. First, we shall measure parameters of chosen twisted pair, in absence of any ADSL signals through other pairs, and we shall establish transmission rate. After that, we shall be establishing ADSL signals through neighbour pairs progressively and observing an impact of that activity on transmission rate. We shall be performing this activity until we establish all ADSL signals in the cable.

We made the experiments by using cable TK 00-V 50×4×0.4 (paper insulated cable with lead sheath and with star quads as stranding elements), 1000 m long, and cable TK 59-45 100×2×0.4 (foamed polyethylene insulated cable with laminated aluminium-polyethylene sheath and with pairs as stranding elements), 2500 m long. Used cables interconnect two main distribution frames. ADSL signals 384/4096 kbps only is transmitted through these cables.

After short introduction of transmission line theory, appropriate theoretical analysis of chosen system is done, in order to compare it with practical measurement results obtained on observed real objects.

II. General Mathematical Description Of Analysed Object

Symmetrical twisted pair is usually observed as transmission line with distributed parameters. Although strict analysis of this object requires electromagnetic field theory using, in this paper we shall apply much simpler electrical circuit theory. According to practice, it can be concluded that electrical circuit theory can be applied in transmission line theory, with acceptable precision.

Electrical circuit theory is much simpler than electromagnetic filed theory, because it uses electrical voltage and current as relevant quantities of analysed system, instead of electric and magnetic field. According to that, to solve transmission line means found functions of voltage and current distribution, for all dots in the space, in any moment.

As the basis of this analysis, transmission line elementary cell Δx_k is used, making Δx_k as short as the cell parameters are concentrated. It is shown in figure 1.

We assumed that transmission line primary parameters like resistance $R_k^{'}$, inductivity $L_k^{'}$, conductivity $G_k^{'}$ and capacity $C_k^{'}$ per unit length unit in k^{th} cell, are constants (frequency independent).

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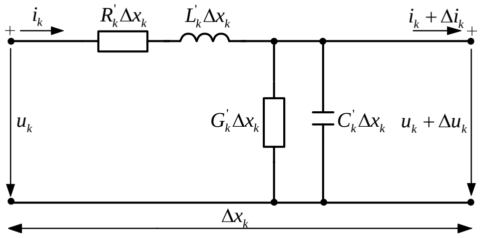

Figure 1: Transmission line elementary cell

According to previous assumption, transmission line is composed of elementary cells shown on figure 1, connected in cascade configuration, figure 2.

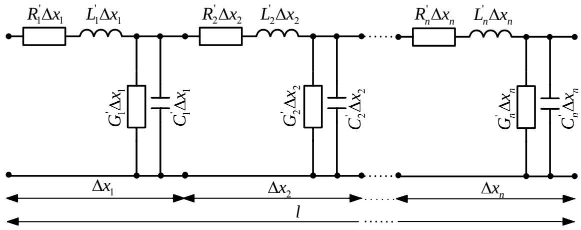

Figure 2: Transmission line of length l

For arbitrary elementary cell, shown on figure 1, functions of voltage and current distribution for all dots and in any time can be found by using modified telegraph equations [7]:

$$
\begin{aligned}
-\frac{\Delta u_k(t)}{\Delta x_k} &= R_k' i_k(t) + L_k' \frac{\Delta i_k(t)}{\Delta t} \\
-\frac{\Delta i_k(t)}{\Delta x_k} &= G_k' u_k(t) + C_k' \frac{\Delta u_k(t)}{\Delta t}
\end{aligned}
\qquad (1)
$$

where $u_k = u_k(t)$ and $i_k = i_k(t)$ are functions of voltage and current distribution. Equations (1) are valid for k^{th} cell. Functions of voltage and current distribution in system (1) are time-dependent functions only, because, according to assumption, one-cell parameters are concentrated.

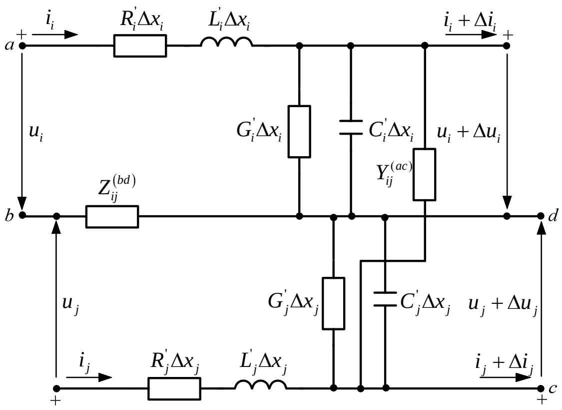

Figure 3: Two cell coupling model

Elementary cell model (figure 1) and transmission line model (figure 2) can be applied also for analysis of copper twisted pairs and coupling between wires stored in different circuits. If we analyse one twisted pair, than *a* wire and *b* wire of twisted pair correspond to normal and opposite direction wire in model. If we analyse one quad, then our model can be applied also for *b* and *c* wire analysis or any other wires combination. But usually we want to analyse couple between one pair, as a whole, on another one. In that case, it is necessary to expand presented two-wire model with four-wire one. We shall observe the system of two twisted pairs, presented using model in figure 2. We shall note the wires of pair 1 and they will be *a* and *b*. We shall note the wires of pair 2 and they will be *c* and *d*. Generally, any cell of pair 1 has an impact on every cell of pair 2, through galvanic, capacitive and inductive couples, and vice versa.

Example of couple between i^{th} (pair 1) and j^{th} (pair 2) cell is shown in figure 3. Wires *b* and *d* are series coupled through common impedance $Z_{ij}^{(bd)}$ and wires *a* and *c* are shunt coupled through common admittance $Y_{ij}^{(ac)}$.

Common impedance and admittance from figure 3 can be any nature. For example, if series couple is composed of galvanic and inductive components, and shunt couple is composed of galvanic and capacitive components, we can write equations for i^{th} cell, as

$$
\begin{aligned}
-\frac{\Delta u_i(t)}{\Delta x_i} &= \left(R_i' + \frac{\mathrm{Re}\{\underline{Z}_{ij}^{(bd)}\}}{\Delta x_j}\right)\cdot i_i(t) + \left(L_i' + \frac{\mathrm{Im}\{\underline{Z}_{ij}^{(bd)}\}}{\omega\cdot\Delta x_j}\right)\cdot\frac{\Delta i_i(t)}{\Delta t} \\
-\frac{\Delta i_i(t)}{\Delta x_i} &= \left(G_i' + \frac{\mathrm{Re}\{\underline{Y}_{ij}^{(ac)}\}}{\Delta x_j}\right)\cdot u_i(t) + \left(C_i' + \frac{\mathrm{Im}\{\underline{Y}_{ij}^{(ac)}\}}{\omega\cdot\Delta x_j}\right)\cdot\frac{\Delta u_i(t)}{\Delta t}
\end{aligned}
\qquad (2)
$$

Of course, series and shunt couples generally exist between all wires of our system composed of two pairs, and those couples can be any nature. Equations (2) in that case can be rewritten to any practical case.

III. Chosen Practical Case Analysis

We shall consider two adjacent pairs in low-pass subscriber cable, in the spectrum allocated to ADSL technology.

Series couples between them are produced mainly because of wire or insulation pair continual physical damages. Continual physical damages are almost impossible in practice, so we shall neglect series couples between cells shown in figure 3.

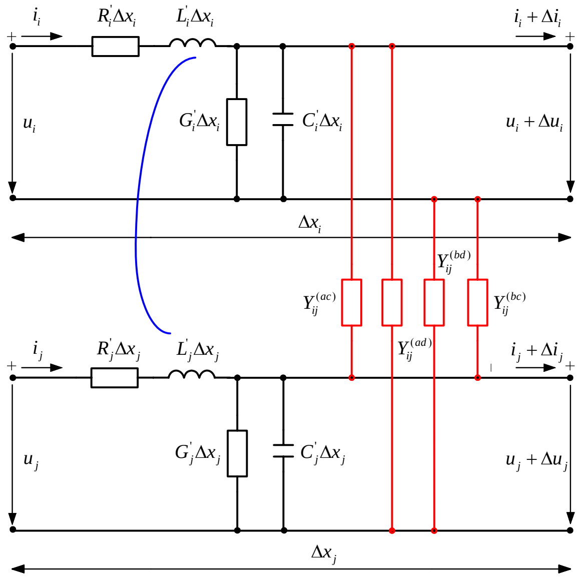

Figure 4: Simplified two-cell coupling model

Shunt couples, on the other hand, are produced because of disturbed symmetry, twist step unequal over the cable, and different physical damages. Shunt couples are usually present, they appear in practise between all lines and they can not be neglected.

It follows that, in the case of real pairs instead of model shown in figure 3, we can analyze simplified model (figure 4). Admittances of couple in the figure 4 are capacitive. Intensity and phase angle of these admittances depend on manufacturing characteristics of cable, exploiting conditions and class of damage, if it exists.

Generally, wires *a*, *b*, *c* and *d* of system from figure 4 have different voltage. Because of that coupling admittances are not connected in parallel configuration and total admittance is not higher then sum of partial ones. Analysis of this kind of system is quite complex. Because of that, in this paper we assumed admittances connected in parallel configuration, composed of galvanic and capacitive elements, connected in parallel configuration.

Then total coupling admittance on pair 1 is

$$\underline{Y}_{ij} = \left(G_{ij}^{(ac)} + G_{ij}^{(ad)} + G_{ij}^{(bc)} + G_{ij}^{(bd)}\right)\frac{\Delta x_i}{\Delta x_j} + + j\omega\left(C_{ij}^{(ac)} + C_{ij}^{(ad)} + C_{ij}^{(bc)} + C_{ij}^{(bd)}\right)\frac{\Delta x_i}{\Delta x_j} \quad (3)$$

where we neglected mutual inductivities (3).

Conductance G_{ij} is related with insulation quality between analysed wires. They can be neglected in the case of cable without damage. Any two wires and insulation between them can be presented as capacitor, so capacity C_{ij} can not be ignored.

We can write, according to these assumptions,

$$-\frac{\Delta u_i(t)}{\Delta x_i} = R_i^{'} i_i(t) + L_i^{'}\frac{\Delta i_i(t)}{\Delta t}$$
$$-\frac{\Delta i_i(t)}{\Delta x_i} = G_i^{'} u_i(t) + \left(C_i^{'} + \frac{\sum_{k,l} C_{ij}^{(k,l)}}{\omega\cdot\Delta x_j}\right)\cdot\frac{\Delta u_i(t)}{\Delta t} \quad (4)$$

for i^{th} cell of pair 1. Similar equations can be also written for j^{th} cell of pair 2. Capacity sum in second equation is preformed for all wires combinations, except these who are related to the same pair.

IV. Measurement Results

The most important measurement results are shown in tables below.

TABLE 1: MEASURED PARAMETERS FOR CABLE TK 00-V

active pairs	SNR [dB]		I-Noise [mVp]		W-Noise [dBm]		Uplink rate [kbps]	Downlink rate [kbps]
	near	far	near	far	near	far		
0	66,7	63,6	0	0	-77,3	-76,1	1357	10433
1	64,0	58,9	11	12	-43,2	-42,8	1015	9759
2	53,9	53,4	11	16	-43,0	-42,4	1006	9759
3	53,6	52,9	11	12	-42,8	-42,3	1018	9737
4	53,5	52,7	12	13	-42,7	-41,8	1009	9371
5	53,5	52,5	11	13	-42,7	-41,8	1015	9362
6	53,3	50,5	11	17	-42,6	-40,0	1000	9293
7	53,5	50,5	13	17	-42,4	-39,7	1012	9014
8	52,7	49,4	13	22	-41,9	-38,2	984	8520
9	52,5	48,9	15	22	-41,8	-38,1	997	8505
10	52,5	48,9	15	24	-41,7	-38,1	990	8439
12	51,8	47,8	15	29	-40,9	-36,8	1003	7992
14	51,2	46,7	17	30	-40,3	-36,0	1000	7726
16	51,1	46,7	17	27	-40,2	-36,0	997	7663
18	51,1	46,7	17	31	-40,2	-35,9	994	7632
20	51,1	46,5	16	29	-40,2	-35,7	1003	7632
25	51,1	46,6	16	28	-40,2	-35,8	990	7623
30	51,1	46,5	16	28	-40,2	-35,7	1003	7617
35	51,0	46,5	18	29	-40,2	-35,7	1006	7613
40	51,0	46,4	16	28	-40,2	-35,7	1000	7601
45	51,0	46,5	17	28	-40,2	-35,7	1006	7598
50	51,0	46,5	16	29	-40,2	-35,7	997	7598
60	51,0	46,6	16	29	-40,2	-35,7	1000	7592
70	51,0	46,5	16	29	-40,2	-35,7	997	7592
80	51,0	46,5	15	29	-40,2	-35,7	994	7579
90	50,9	46,5	18	28	-40,1	-35,7	987	7567
100	50,9	46,5	17	29	-40,1	-35,7	1003	7523

TABLE 2: MEASURED PARAMETERS FOR CABLE TK 59-45

active pairs	SNR [dB]		I-Noise [mVp]		W-Noise [dBm]		Uplink rate [kbps]	Downlink rate [kbps]
	near	far	near	far	near	far		
0	64,9	68,8	0	0	-77,4	-81,9	1202	8579
1	54,4	69,5	6	0	-56,9	-77,3	1186	8452
2	46,9	67,1	6	0	-55,2	-77,2	1186	8439
3	43,7	60,8	5	6	-50,1	-67,0	1202	3453
4	38,4	53,6	9	1	-45,9	-61,5	1192	2667
5	32,1	52,4	18	1	-39,9	-60,3	1180	2624
6	31,9	52,2	18	1	-39,7	-60,2	1777	2583
7	31,9	52,0	18	1	-39,4	-59,9	1149	2130
8	33,7	57,7	15	0	-41,2	-65,7	1164	2077
9	31,3	51,7	20	1	-38,9	-59,6	1124	1913
10	31,0	51,7	20	1	-38,8	-59,6	1105	1903
12	31,9	53,8	18	0	-39,5	-61,6	1093	1900
14	33,0	54,9	16	0	-40,4	-62,4	1189	1782
16	30,0	44,2	23	3	-38,0	-52,1	1068	1580
18	29,6	44,2	23	3	-37,5	-52,1	1043	1509
20	28,9	43,8	27	3	-37,3	-51,7	1074	1475
25	29,5	44,2	27	3	-37,5	-52,1	1074	1462
30	29,4	43,8	25	3	-37,3	-51,7	1074	1444
35	29,6	44,0	24	3	-37,4	-51,9	1056	1425
40	29,5	43,8	26	4	-37,3	-51,7	1046	1419
45	28,8	44,0	24	3	-37,4	-52,0	1074	1366
50	28,8	43,6	26	4	-36,7	-51,6	1046	1223
60	29,0	43,6	25	11	-36,7	-51,6	1049	1220
70	28,9	43,6	26	3	-36,6	-51,5	1056	1192
80	28,9	43,6	26	20	-36,7	-51,6	1053	1174
90	28,9	43,6	27	4	-36,7	-51,6	1034	1174
100	28,8	43,6	27	9	-36,7	-51,7	1046	1171

Measurements on both 100-pair cables, which are mentioned in the introduction of this text, are made in the same way. Pair from the middle of the cable is chosen (it is the first pair). Its characteristics were measured when the other 99 pairs had been gone off. After that, second pair was switched on, and characteristics of first pair were measured, then third, repeating process of measurement. The procedure of measurement performed on first pair was performed until all pairs were switched on.

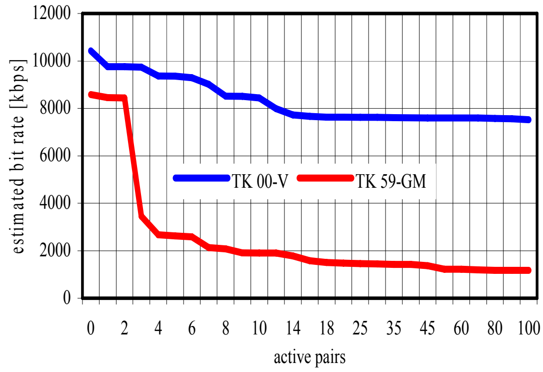

Figure 5: Measure downlink transmission rates

Except measurements shown in the tables above, attenuation and characteristic impedance on some ADSL frequencies, together with insulation resistance and loop resistance, were measured. Attenuation and characteristic impedance did not change their values in respect to the number of switched adjacent ADSL signals. Loop resistance has expected value for both cables. Insulation resistance for both cables was satisfying (10 GΩ at least for TK 00-V and 5 GΩ at least for TK 59-45 cables).

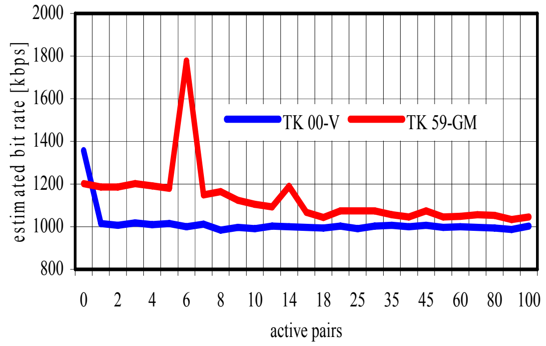

Figure 6: Uplink transmission rates

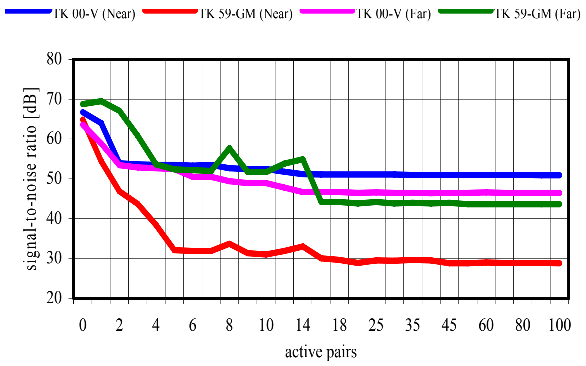

Figure 7: Signal to noise ratio

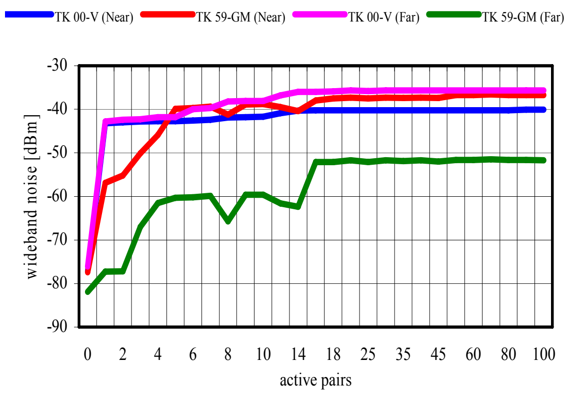

Figure 8: Wideband noise level

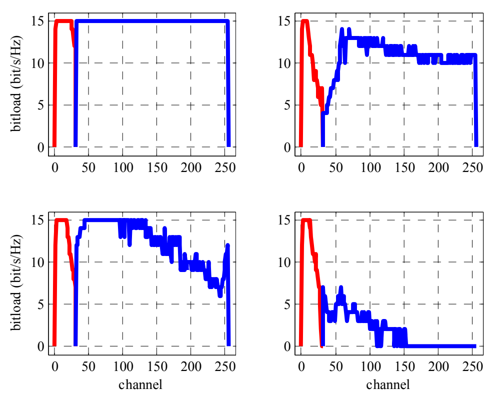

Figure 9: Spectral characteristics of ADSL signal

In figures 5-8, results from tables 1 and 2 are presented graphically. It can be seen that after switching some pairs, "stationary condition" is established, and increase of active signals number in the cable of do not have significant effect on parameters of analysed fixed pair.

In figure 9, spectral characteristics for boundary cases are presented, in order to allow comparison. Two top figures are related to TK 00-V, and other two to TK 59-45. Left figures are describing case without active pairs, and the right ones are describing case with all active pairs.

V. Conclusion

According to presented results, we can conclude that there is a difference between achieved transmission rates on subscriber pairs in dependence on number of near active ADSL signals. By increasing that number, transmission rate on analysed pair decrease.

After switching approximately 10 to 15 pairs in the cable, "stabile state" is established. Further increase of switched pair number does not affect significantly on achieved bit rate. According to that, it can be concluded that wideband services using ADLS technology can be provided also using huge capacity cables, for few Mbps transition rates. The impact of adjacent ADSL signals in percentage is expresser for longer cables.

By analysis of spectral characteristics of observed pair in the cable, we can see that increase of number of active adjacent ADSL signals has the same impact on the whole spectrum which is used. This can be easily explained using the fact that all ADSL signals occupied the same band, so they physically affect observed pair as some kind of wideband noise. Impact of mutually near signals can be extra reduced with spectral redistribution (adjacent signals use different bands).

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