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THE ANALYSIS OF NEGATIVE INFLUENCES IN THE ENVIRONMENT OF HOMOGENEOUS SYMMETRIC LINES AT THE SIGNAL TRANSMISSION BY MEANS OF THE ADSL TECHNOLOGY

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For successful understanding of the signal transmission on metallic homogeneous symmetric lines, it is necessary exactly to recognize essential negative influences in the real environment of local subscriber loops. This article discusses in detail frequency characteristics of linear negative influences on transmitted signal, near-end and far-end crosstalks and the impulse noise. Also, the analysis of these negative influences at the signal transmission is presented. The results of this analysis are based on the computer simulation of the ADSL transmission system.

K e y w o r d s: propagation loss, transmission function of the channel, transmission functions of the NEXT and FEXT crosstalks, model of the ADSL transmission system

1 INTRODUCTION

In present days, an interest in broadband service provisioning — such as multimedia services, distance learning or teleworking — is increasing. However, high-speed connections to the Internet are also desirable. Acceptation and realization of these demands need to provide a data stream with a sufficient transmission capacity to end customers. For solving a bottleneck problem in the access network, there are many new wired or wireless technologies. Utilization of already existing metallic telephone lines in cooperation with new high-capacity optical cables is a competitive alternative to other access technologies. A family of xDSL ("x" Digital Subscriber Line) technologies allows a cost-effective utilization of common metallic lines at the high-speed data transport. Since a majority of interactive services are asymmetrical according to the character of downstream and upstream signal rates, great attention is dedicated to the ADSL (Asymmetric DSL) technology. This is the reason why we focused on this specific type of xDSL technologies.

This paper concerns the analysis of negative influences at the signal transmission in the environment of metallic homogeneous lines by means of ADSL technologies and is focused on concrete characteristics of these negative environmental influences. Also a model is presented that allows to analyze performances of ADSL modems utilizing modified modulation and coding techniques. Description of the model construction is made for the ADSL transmission system with regard to the main negative influences of the transmission environment.

Lately, telecommunication access networks were nearly exclusively built up by bundles of metallic homogeneous lines. A majority of local subscriber loops are used as underground cable bundles, but sometimes they occur as aerial cables. A preferred material used in the core of wires is copper but also we can meet wires with an aluminium core. Common local subscriber loops were used at the call signal transmission in the frequency band from 300 Hz up to 3400 Hz. The local subscriber loop starts on the main distribution frame (MDF) in the local central office (CO) marked as the line termination unit (LTU). Then, it passes as a part of multipair cables to the cross-connect point (CCP) where it is divided into smaller bundles of local subscriber loops or to the subscriber distribution point (SDP) where subscriber shunts are directly created. The local subscriber loop is terminated at the subscriber location in the network termination unit (NTU). The structure of typical subscriber lines presented in Fig. 1 is introduced in [1].

The access cable bundle contains some joint sections of local subscriber loops that may have unequal core diameters, numbers of neighbouring pairs and types of insulation. The length of local subscriber shunts is in the range of hundreds meters up to a few kilometres. It is very difficult and pretentious to find characteristics and features of all line types used today in the access network. Therefore, it is necessary to determine the main environmental characteristics of lines with standard parameters that exactly represent their features from the viewpoint of signal transmission.

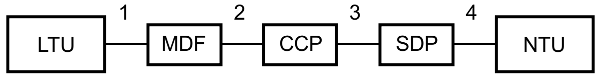

Fig. 1. A structure of typical local subscriber loops 1 — central office cable, 2 — main cable bundle, 3 — distribution cable, 4 — installation cable

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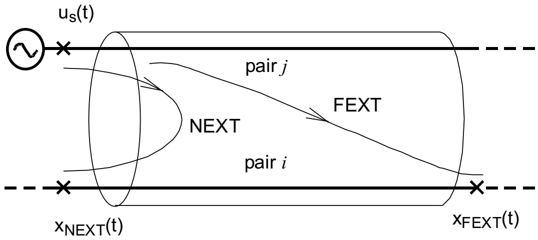

Fig. 2. Types of crosstalks

2 THEORETICAL PART

2.1 Principal negative influences on transmitted signals

Propagation loss and distortions of the module and phase characteristics as well as the group delay characteristic in a frequency band of interest are nearly proportional to the physical and construction parameters such as the line length, core diameter of the wire, mismatch of impedances in cross-connecting points of sections [2].

We first discuss the propagation loss L_{dB} in a perfectly terminated line. If R, L, G and C are the primary constants of a line and $\omega = 2\pi f$, where f is the frequency, then

$$\gamma(\omega) = \alpha(\omega) + j\beta(\omega) = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{1}$$

and

$$Z(\omega) = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}} \tag{2}$$

where $\gamma(\omega)$ denotes the propagation constant of the line, $\alpha(\omega)$ is the specific constant of the attenuation, $\beta(\omega)$ is the specific constant of the phase-shift and $\mathcal{Z}(\omega)$ is the characteristic impedance of a line. For a perfectly terminated line with length l, the transfer function $\mathcal{H}(l, f)$ of metallic homogeneous symmetric lines is given by

$$H(l, f) = e^{-l\gamma(f)} = e^{-l\alpha(f)} \cdot e^{-jl\beta(f)} \tag{3}$$

and the propagation loss L_{dB} is given at the distance l and the frequency f as

$$L_{dB}(l, f) = -20\log_{10}|\mathcal{H}(l, f)| = \frac{20}{\ln 10} l\alpha(f) \approx 8.686 l\alpha(f) = a_{line}(l, f)\,[dB]\,. \tag{4}$$

We must place emphasis on the interchangeable use of the words the attenuation of the line $a_{line}(l, f)$ and the propagation loss $L_{dB}(l, f)$ to designate the quantity in (4) only for the case of a perfectly terminated line. We can see the linear dependence of the propagation loss L_{dB} on the line length l. The loss is also an increasing function of the frequency f as should be apparent from the expression for the propagation constant $\gamma(\omega)$ in (1). The loss of a signal power is also influenced by other important parameters — the core diameter and the construction material of the core [2].

For lower frequency regions, for which is valid $\omega L \ll R$ and G can be neglected, the propagation constant expressed in (1) can be simplified to

$$\gamma(\omega) = \alpha(\omega) + j\beta(\omega) \approx \sqrt{\frac{\omega RC}{2}}\Big[1 - \frac{\omega L}{2R}\Big] + j\sqrt{\frac{\omega RC}{2}}\Big[1 + \frac{\omega L}{2R}\Big] \quad f < 20\,\text{kHz} \tag{5}$$

For frequencies less than 20 kHz, both the real and imaginary parts $\alpha(\omega)$ and $\beta(\omega)$ are approximately proportional to $\sqrt{f}$. At higher frequencies, the frequency dependences of the primary line parameters R and L (except for C) become noticeable and the propagation constant in (1) can be approximated by

$$\gamma(\omega) = \alpha(\omega) + j\beta(\omega) \approx \frac{R(\omega)}{2}\sqrt{\frac{C}{L(\omega)}} + j\omega\sqrt{CL(\omega)}\,, \quad f > 150\,\text{kHz} \tag{6}$$

In this case, the imaginary part β is approximately a linear function of frequency. Major variations for the real part α are due to the frequency dependence of R, which becomes proportional to $\sqrt{f}$ because of the skin effect for large frequencies. Therefore, it is necessary to take into account the increased signal attenuation in the area of high frequencies.

The phase τ_ϕ and envelope τ_e delays of a loop can be expressed as

$$\tau_\phi(\omega) = \sqrt{\frac{\beta(\omega)}{\omega}} \qquad \tau_e(\omega) = \sqrt{\frac{\mathrm{d}\beta(\omega)}{\mathrm{d}\omega}} \tag{7}$$

where $\beta(\omega)$ is the imaginary part of the propagation constant. The group envelope delay τ_e and the phase delay τ_ϕ are at higher frequencies approximately constant, equal, frequency-independent and acquire a value of about $\tau_e \approx \tau_\phi = 5.4\,\mu$s/km [2].

2.2 Near-end and Far-end crosstalks

The word "crosstalk" generally refers to the interference that enters a communication channel through some coupling paths. Figure 2 presents a kind of generation and propagation of two crosstalk types in a multipair cable.

At the input of pair j, the information signal $u_s(t)$ is generated. This signal, when propagating through a line, can generate two types of crosstalk signals arising in pair i. The crosstalk signal $x_{NEXT}(t)$ is called a near-end crosstalk NEXT. The crosstalk signal $x_{FEXT}(t)$ is called a far-end crosstalk FEXT. From a data communication point of view, the NEXT crosstalk is generally more damaging than the FEXT crosstalk because the NEXT does not necessarily propagate through a line length and thus does not experience a propagation loss of the signal.

If either single or multiple interferers generate a crosstalk signal, we can define a gain of the NEXT crosstalk path according to [2], [3] using the following relation

$$|\mathcal{H}_{NEXT}(l,f)|^2 = \frac{\pi^2 f^2 k_{NEXT}}{\alpha(f)}\left[1-e^{-4\alpha(f)l}\right] \approx K_{NEXT}\cdot f^{3/2} \quad (8)$$

where variables are given as $K_{NEXT} = 0.882\cdot 10^{-14} N_d^{0.6}$, N_d is the number of disturbing pairs disturbers), f is the frequency in Hz. An approximation on the right in (8) is valid when the line length l is large and for frequency regions where the real part $\alpha(\omega)$ of the propagation constant is proportional to $\sqrt{f}$. We can also derive the gain of the FEXT crosstalk path according to [2], [3] in a similar manner using the following relation

$$|\mathcal{H}_{FEXT}(l,f)|^2 = 4\pi^2 f^2 k_{FEXT} l e^{-2\alpha(f)l} \approx K_{FEXT}\cdot l\cdot 3280\,.\,f^2\,.\,|\,H(l,\,f)\,|^{\,2} \quad (9)$$

where variables are given as $K_{FEXT} = 3.083\times 10^{-20}$, l is the line length in km, f is the frequency in Hz and $\mathcal{H}(l,f)$ expresses the transfer function of a metallic homogeneous symmetric line.

2.3 Impulse noise

In unshielded twisted pairs, various equipment and environmental disturbances such as signalling circuits, transmission and switching gear, electrostatic discharges, lightning surges and so forth can generate impulse noise. The impulse noise has some reasonably well-defined characteristics. The features of the typical impulse noise can be summarized using [2] as follows:

- it occurs about 1–5 times per minute (on an average 4 times per minute),
- it has peak values in the range 2–33 mV,
- it has most of its energy concentrated below 40 kHz,
- it has time duration in the range 30–150 μs.

Of course, the mentioned features do not characterize all possible impulse noise signals.

2.4 Other negative influences

In addition to the influences described previously, there are some other well known negative influences on xDSL digital transmission systems using metallic homogeneous lines such as changes of the core diameter, mismatched impedances and other noise types (thermal noise, background noise, radiofrequency interference). These influences are small in comparison with the mentioned main negative influences and can be neglected in our analysis.

3 EXPERIMENTAL PART

3.1 The environment of simulation and the basic scheme of the model

For considering of the signal transmission on metallic homogeneous lines by means of xDSL technologies, it is necessary comprehensively to know the characteristics of negative environmental influences and features of applied modulation and coding techniques. It is difficult to realize exact analytical description of complex systems such as xDSL technologie in the real environment of local access networks. Also, due to dynamical nature of some processes, it is not suitable. For analyzing the modulation and coding techniques used by xDSL technologies, a suitable and flexible enough tool are computer simulations and modelling schemes of real environmental conditions at signal transmission.

For our modelling of the transmission path we used the software program *Matlab v*5.3 together with the dynamic system simulation environment *Simulink* 3.0. *Matlab* is a powerful collection of tools for algorithm development, computation and visualization. It provides more control and flexibility compared with a traditional high-level programming language and is based on fields and matrixes equipped with many functions for program-run controlling and data structures processing. From additional libraries, *Signal Processing Toolbox* 4.2 and *Communication Toolbox* 1.4, functions for signal processing, were utilized [4].

The proposed and realized modelling scheme represents the transmission of high-speed data signals in the downstream or upstream direction by means of the ADSL technology utilizing metallic homogeneous lines. This model can be divided into three main parts — transmitter, environment of the transmission channel, and receiver. The transmitter for digital communication systems may include blocks of source coding, data compression, error-control coding, digital modulation and multiple accesses. The transmitter is primarily responsible for transmitted data protection and for the modulation of the signal into the form which can be transported through the line. I addition to the propagation loss, the signal transmission environment in the local subscriber loop is characterized also by negative influence of crosstalk noises from neighbouring pairs and by activities of the impulse noise. Because these negative influences expressively interfere into the communication and represent its main limiting factors, they constitute a critical part of the model and, therefore, it is necessary exactly to recognize and express their characteristics by correct parameters. The receiver is conceptually inverse in comparison with the transmitter. Its main functions are demodulation and correction of corrupted information bits. Before demodulation, the received signal is amplified to compensate for the propagation loss arisen in the transmission line. Basic functional blocks realized in our simulation model are shown in Fig. 3.

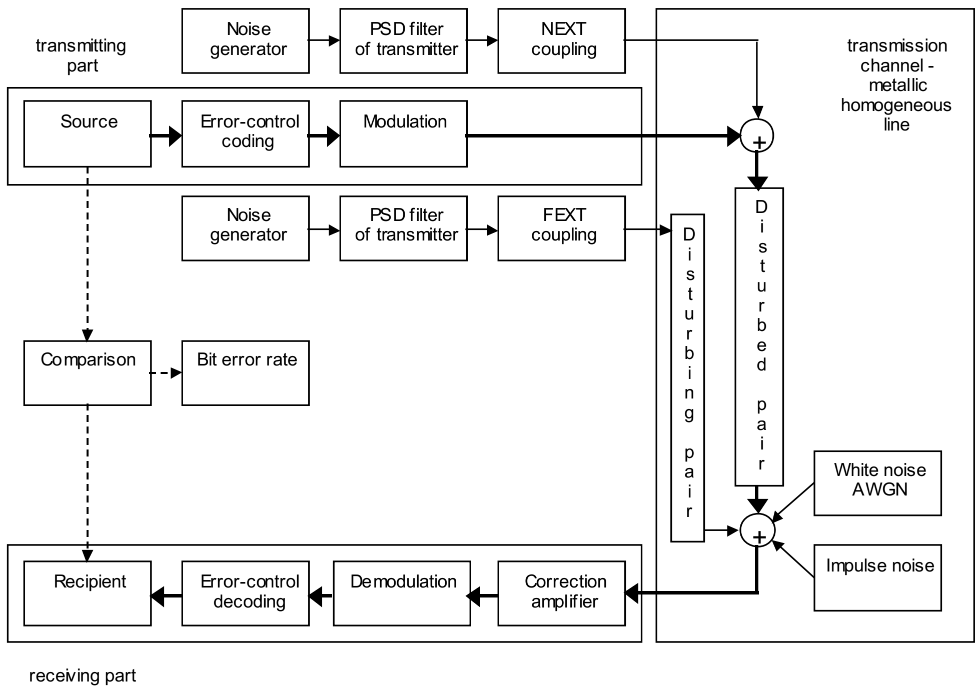

Fig. 3. The block scheme of the simulation model

3.2 The transmitting part of the model

The transmitted message carried to the receiving part is generated as a random binary chain with a given length. This message is also saved for the comparison with the received message because of the calculation of the bit error rate.

Because of using forward error correction techniques, the generated message is encoded and is extended with control characters. Optional parameters for the FEC block are the kind of used codes (Reed-Solomon, Bose-Chaudhuri-Hocquenghem ...), its redundancy and the codeword length for block codes. For preventing cell losses at the transmission of unidirectional video data signals through an ATM network and for providing a high quality of service, it is asked for the protection with an interleaving technique. The interleaving scheme uses a two-dimensional memory array. The incoming cell-data are written columnwise into the memory. The outcoming data are read in blocks row by row. The optional parameter for interleaving is its depth. Determination of appropriate methods for the data protection and its parameters is one of application opportunities of our model [5], [6].

The encoded message is converted from the bit sequence entering the modulation block into k-bit symbols ($k = \log_2 M$) due to M-ary digital modulations. Optional parameters for this block are the type of modulation, the number of modulation states, the symbol rate, the input signal power, the carrier frequency and the sampling frequency. Due to good sensitivity to the impulse noise and crosstalks [6], [7], the 16-QAM (Quadrature Amplitude Modulation) modulation is the basic modulation in our proposed model.

3.3 The receiving part of the model

The input into the receiver is the signal discarded and attenuated by the transmission. For correct demodulation, the received signal must be recovered as soon as possible into the original form of the transmitted signal. In the correction amplifier, the compensation for the propagation loss is executed. As the transmission characteristics of each metallic homogeneous line in the local subscriber loop are different, it is necessary to know the frequency characteristics of the particular transmission channel. The receiver can get this information by measuring the received signal levels during the startup initialization sequence in the precise frequency spacing.

The amplified and corrected signal acquired in this way is suitable for processing of the demodulation. The acquired symbols are transformed into the form of binary messages. In the error-control decoding block, possible errors are detected and corrected. The corrected message is shifted to the information sink. In the final part of the modelling, we compared the original message from the source and the resulting message in the recipient. The output of this comparison is the number of erroneous transmitted bits expressed in the form of the bit error rate and can be used in our next analysis.

3.4 The transmission line

From relations (5) and (6) it results that the propagation loss is directly proportional to $\sqrt{f}$ for both low and high frequencies. In the transition region, the loss function increases with frequency somewhat slower and

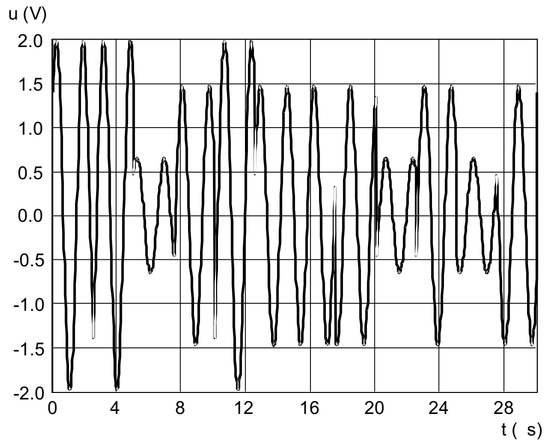

Fig. 4a. The time representation of the modulated signal

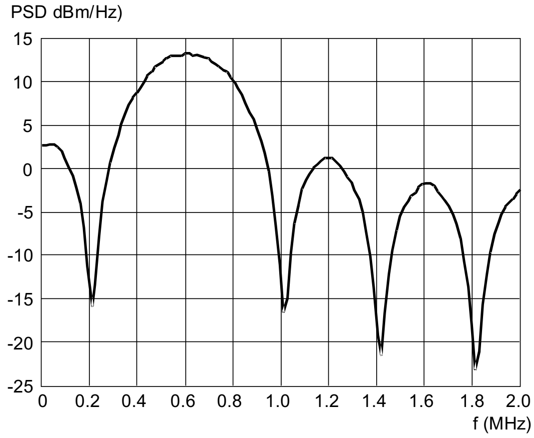

Fig. 4b. The frequency characteristic of the modulated signal

is approximately proportional to $f^{1/4}$. The transition region is a function of the core diameter [2].

For modelling, the frequency dependence of the propagation loss is sufficiently perceived by the representation of the transmission function that we derived using relations (5) and (6)

$$\mathcal{H}(l,f) = e^{-l\xi\sqrt{f}}\,, \tag{10}$$

where l is the line length and f is the frequency. We specified the constant ξ incident to a homogeneous line so that the transmission function representation by (10) simulated the transmission function representation calculated by primary constants of the model line. For typical metallic lines with core diameter 0.4 mm (26 AWG) and Cu core material, we calculated the value $\xi = 3^{-6}$.

3.4.1 Near-end and Far-end crosstalks

Because crosstalk signals from the POTS service in disturbing pairs do not have significant influences on the ADSL signal in the disturbed pair, we supposed both disturbing and disturbed signals to have the same power spectral densities $PSD_1(f) = PSD_2(f)$. This situation occurs when in the neighbouring pairs are also ADSL signals — we can talk about the self-NEXT crosstalk and the self-FEXT crosstalk.

For local subscriber loops we assigned the power spectral density of NEXT and FEXT crosstalks using relations (8) and (9) as follows

$$PSD_{NEXT}(f) = PSD(f)\ |\mathcal{H}_{NEXT}(l,f)|^2\,, \tag{11}$$

$$|\mathcal{H}_{NEXT}(l,f)|^2 \approx K_{NEXT}\, f^{3/2}, \tag{12}$$

$$PSD_{FEXT}(f) = PSD(f)\ |\mathcal{H}_{FEXT}(l,f)|^2\,, \tag{13}$$

$$|\mathcal{H}_{FEXT}(l,f)|^2 \approx K_{FEXT}\cdot l\cdot 3280 f^2\ |\mathcal{H}(l,f)|^2\,, \tag{14}$$

where variables K_{NEXT} and K_{FEXT} are functions of disturbed pairs.

Equations (10)–(13) allow very good approximation of practically observed kind of multiple interferer crosstalks. Before starting the simulation, we determined the values of variables K_{NEXT} and K_{FEXT} in our simulation model as a function of the number of disturbing pairs N_d for typical 50-pairs cable as:

$$K_{NEXT} = K_{NEXT-49}\frac{N_d^{0.6}}{10}\,, \tag{15}$$

$$K_{FEXT} = K_{FEXT-49}\frac{N_d^{0.6}}{10}\,. \tag{16}$$

The value of the $K_{NEXT-49}$ constant is given as 8.8×10^{-14}, the value of the $K_{FEXT-49}$ constant is empirically estimated as $8\times 10^{-20}/3280$ [1], [3].

3.4.2 Impulse noise

Due to the important effect of this negative influence, we took into account also this type of noise. The most common and the most damaging type of impulse noise seems to occur when a disturbed pair shares a common cable sheath with the switched disturbing pairs — that is usual in the local access network. Sharp voltage changes can occur on analogue pairs because of the opening and closing of relays. These voltage changes, when coupled into neighbouring pairs through the NEXT and FEXT coupling path, create spurious, impulsive-like voltages with amplitudes that can be quite significant [2].

4 RESULTS OF THE ANALYSIS

Before transmitting of the signal into the transmission line, we arranged the amplitude of the modulated signal to required transmitted signal powers. Values of the signal power level range between 9 and 19 dBm. In the realized model, we set a default basic value of the input signal level to 14 dBm corresponding to the transmitted signal power 25 mW. In Figs. 4a, 4b there are shown a time representation and frequency characteristic of the power spectral density for the modulated signal with basic parameters —

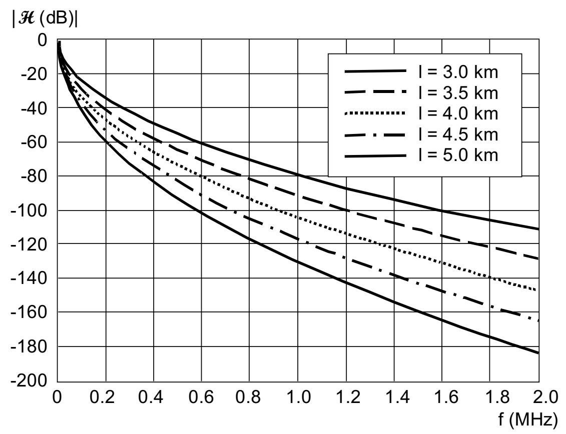

Fig. 5a. Frequency characteristics of the transmission function module for various line lengths

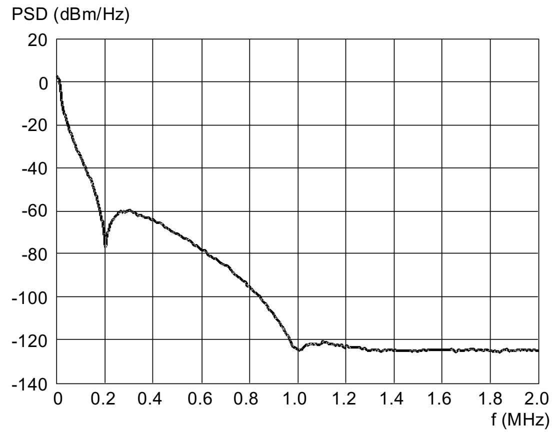

Fig. 5b. The frequency characteristic of the transmitted signal through the transmission line

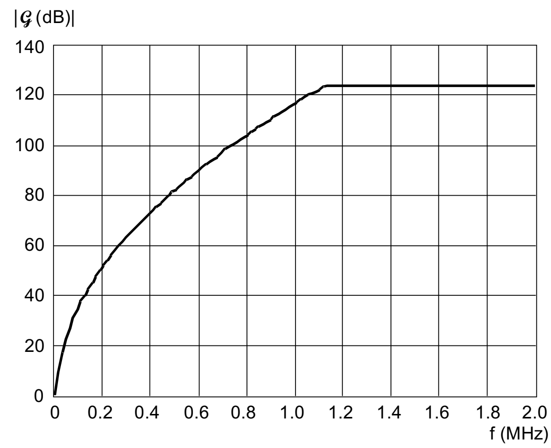

Fig. 6a. The frequency characteristic of the gain function module at the receiver

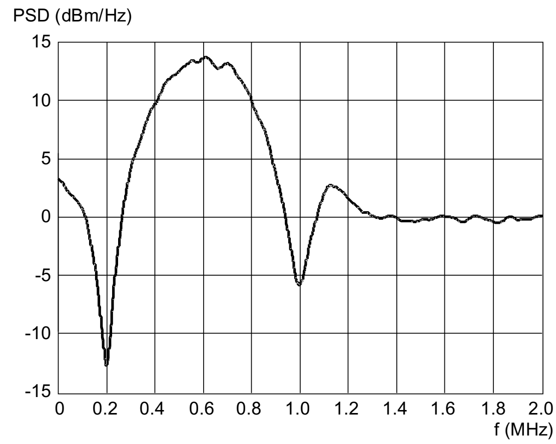

Fig. 6b. The frequency characteristic of the PSD of the regenerated signal

the bit rate 1.544 Mbit/s, the modulation 16-QAM, the baud rate 400 kBd/s, the input signal power 14 dBm.

Before starting of the simulation, we calculated the transmission function of the line for given parameters (l, ξ). The values of this function are sampled in equal proportioned frequency intervals in the range from 0 Hz up to the half of the sampling frequency $(f_{samp}/2)$. The number of samples is optional. For signal processing, it is desirable to choose the number of samples equal to 2^N, where N is an integer number. Using sampled values, the impulse characteristic of the transmission line $h(t)$ is calculated using the inverse Fourier transform with the same number of samples (from practical viewpoint, the number of 512 samples is adequate). This sampled impulse characteristic is used as coefficients for the digital filter. Simulation of the signal transmission through the line itself is executed by digital filtering of the sampled modulated signal using the proposed filter. In Figs. 5a, 5b there are shown frequency characteristics of the transmission function module for the transmission line ($\phi = 0.4$ mm, Cu) for various line lengths and a frequency characteristic of the power spectral density for the transmitted signal through the line.

The influence of the transmission channel that we can derive from its transmission function is expressed above all in the attenuation of the transmitted signal. Signal attenuation is more damaged for areas of higher frequency components of power spectral density characteristics. This influence is more expensive for longer line lengths. However, we find out that the influence is decreased with increasing the core diameter of wires. This results from the change of values for the primary constant of the line, concretely R and L. As mentioned above in paragraph 2.1, at higher frequencies (above 150kHz) the imaginary part of propagation constant is approximately linear function and this characteristic is sufficient for the simulations purposes. We focus on specific features of the phase frequency characteristic in our next research."

In our model, we supposed the knowledge of frequency characteristics of the transmission function for used lo-

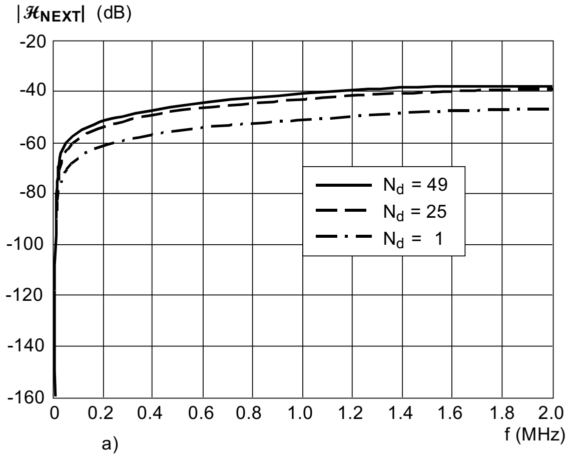

Fig. 7a. Frequency characteristics of the NEXT crosstalk transmission function module for various numbers of disturbers

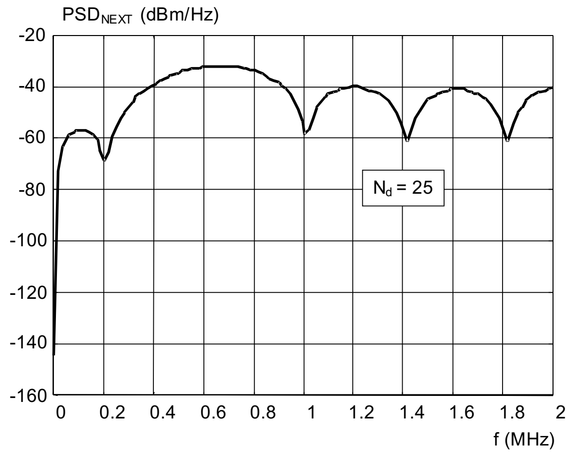

Fig. 7b. The frequency characteristic of the NEXT noise signal for 25 disturbers

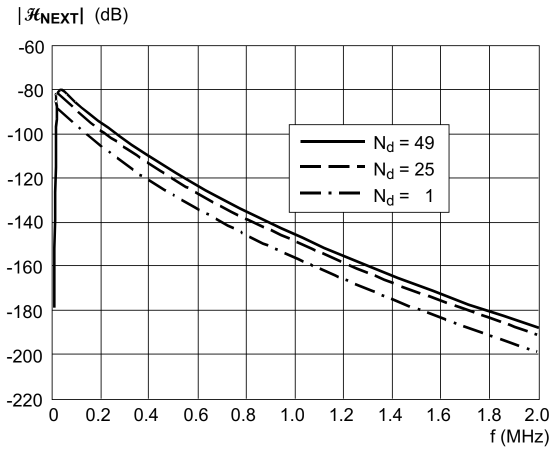

Fig. 8a. Frequency characteristics of the FEXT crosstalk transmission function module for various numbers of disturbers

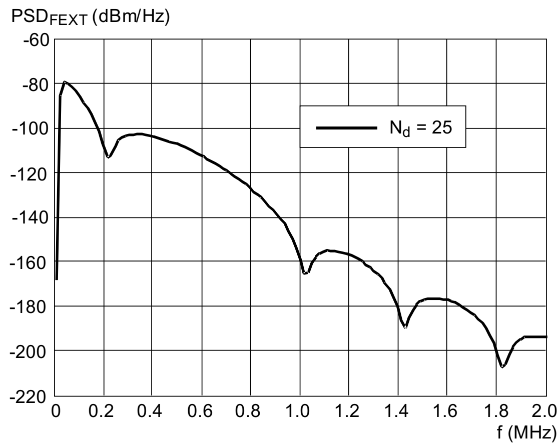

Fig. 8b. The frequency characteristic of the FEXT noise signal for 25 disturbers

cal subscriber loop (with the precision 1 dB). The number of frequencies and therefore also the frequency spacing are optional parameters. Using the approximation of values acquired in this way, the receiver can approximate transmission characteristics of metallic homogeneous lines. These characteristics can be used as the opposite value for amplifying of the received signal. Moreover, the maximum of the gain characteristic of the correction amplifier is limited by the background noise level to prediction of wasted amplifying of high frequency components of the signal. For exact compensating of the propagation loss, these frequencies should use substantial gains. In Figs. 6a, 6b there are presented the frequency characteristic of the gain function module and the frequency characteristic of the power spectral density of regenerated signal.

We created the NEXT crosstalk noise signal by forming of the white noise spectrum (constant $PSD(f) = 0\,\mathrm{dB/Hz}$) that is generated by a random number generator. First, we calculated a frequency characteristic of the $\mathcal{H}_{NEXT}(l, f)$ crosstalk transmission function module using (11). Its parameters are the number of disturbing pairs and the appropriate value of the variable K_{NEXT}. In Fig. 7a, the NEXT crosstalk transmission function module for various numbers of disturbers is presented. Next, this function of the NEXT crosstalk path multiplies the power spectral density of the transmitted signal.

This PSD function is acquired by calculation from a signal consisting of a sufficiently high count of random symbols produced by a chosen type of modulation. In this manner, we obtained a spectral characteristic of the NEXT crosstalk signal $PSD_{NEXT}(f)$ (Fig. 7b) in accordance with (10). This characteristic is used for calculating the impulse characteristic and its samples created coefficients of digital filters. For modelling of the NEXT negative influence, the NEXT crosstalk noise signal acquired by filtering is added to the transmitted signal entering the transmission line.

The influence of the NEXT crosstalk transmission function is determined by the power spectral density of the NEXT crosstalk signal and by the NEXT crosstalk path. This influence is accentuated at higher frequency components of the transmitted signal. It is necessary to take into account the NEXT crosstalk at signals of symmetric services and applications, and at very high bit rates of information signals because they occupy higher frequency bandwidths of metallic homogeneous lines. As we can see in Fig. 7a, the crosstalk coupling for the line with the core diameter 0.4 mm for 49 disturbing pairs is approximately about 10 dB larger than the crosstalk coupling for only single disturbing pair.

The FEXT crosstalk signal is created in a similar manner as the NEXT crosstalk signal (its spectrum is presented in Fig. 8b). Because this type of a crosstalk must be propagated through a disturbing line, we included into calculating the FEXT crosstalk transmission function module (Fig. 8a) also the transmission function of the line $\mathcal{H}(l, f)$ using (9) with given parameters (the line length 4.6 km). The FEXT crosstalk signal is added to the transmitted information signal attenuated at a transmission through the metallic homogeneous line.

The influence of the FEXT crosstalk transmission function is characterized by the power spectral density of the FEXT crosstalk signal and by the FEXT crosstalk path. This FEXT crosstalk path is depend on the line length, on the frequency of signal and on the transmission function of the transmission line because of propagating of crosstalk signals through the disturbing pair. For longer line lengths, the influence of the FEXT crosstalk can be neglected. On the other side, this influence is accentuated at higher frequency components of the transmitted signal. Therefore, it is necessary to take into account the FEXT crosstalk for the new VDSL technology transmitting signals of asymmetric services and applications at very high bit rates of information signals and on very short distances because they occupy higher frequency bandwidths of metallic homogeneous lines.

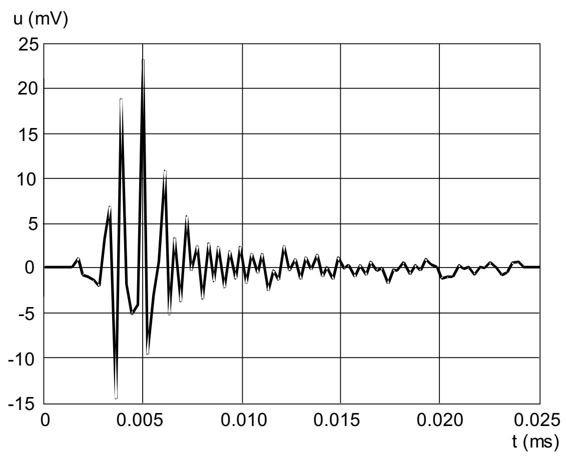

Fig. 9. The time representation of typical model impulse noise

A time representation of impulses can be acquired by measurement in the access network [7] and typical representations considered for testing are introduced in an appropriate standard [8]. At every impulse, the value is chosen randomly from the range between 2–33 mV that is the most likely case. The density of impulse occurrences is optional (common 4 times per minute). From the viewpoint of the simulation time, there are relative long time periods between impulse occurrences, therefore we chose more frequent occurrences and arranged the consequence of their effects. In Fig. 9 is shown the time representation of one of the generated impulse patterns used in the simulation model created on the basis of the work [7].

In the simulation model, we represented a background noise and thermal noise using the additive white Gaussian noise (AWGN). Its parameter is a level of the power spectral density. The level of the PSD for the AWGN noise is determined empirically and is moved in the range from -150 dBm/Hz in the favourable noise environment to -110 dBm/Hz in the increased expressive noise environment. Due to the additive character of the AWGN noise, we realized its effects by adding to the transmitted signal. The received signal constellation of modulation states (the modulation 16-QAM, the baud rate 400 kBd/s, the input signal power 14 dBm) after transmitting on the line with given parameters ($\phi = 0.4$ mm, $l = 4.6$ km, $N_d = 10$ disturbers) in the environment of the AWGN noise with the level -125 dBm/Hz is demonstrated in Fig. 10.

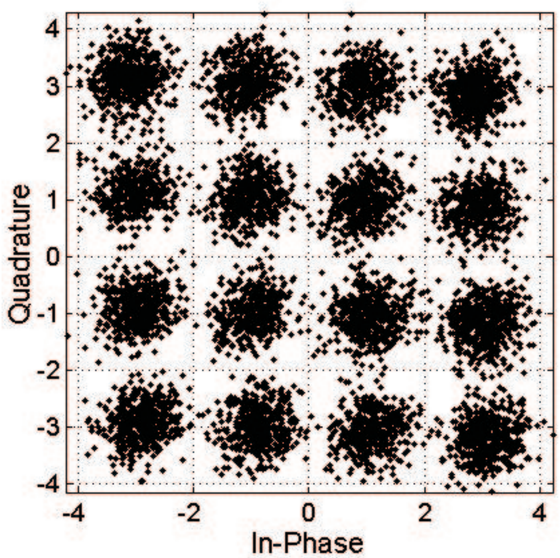

Fig. 10. The state constellation of the modulated signal with the AWGN noise

5 CONCLUSIONS

This paper analyzes basic features of the real transmission environment of metallic homogeneous lines and presents possibilities for modelling and simulating the information signal transport in this environment by means of ADSL technology.

The basic block scheme of the proposed model for the ADSL transmission path is composed of 3 parts that are closely specified. We focused on the determination and analysis of concrete characteristic features for substantial negative influences of internal and external environments and on the representation of frequency dependences of transmitted information signals. For realizing of individual model blocks, we concentrated on the choice of appropriate parameters so that these blocks could be adjusted and modified for future demands.

The attenuation determined by the channel transmission function is more damaged for areas of higher frequency components of power spectral density characteristics for transmitted signals. This attenuation is more expensive for longer line lengths. However, we can partly limit this negative influence with increasing the core diameter of wires. The influence of the NEXT crosstalk signal is accentuated at higher frequency components of the transmitted signal. The influence of the FEXT crosstalk signal depends on the line length, on the frequency of signal and on the transmission function of the transmission line because of propagating of crosstalk signals through the disturbing pair. For long enough line lengths, the influence of the FEXT crosstalk can be neglected. On the other side, this influence is again accentuated at higher frequency components of the transmitted signal. Therefore, for the new VDSL technology that transmit information signals of asymmetric and symmetric services at very high bit rates of information signals and on very short distances, it is necessary to take into account of the NEXT and FEXT crosstalks at signals occupying higher frequency bandwidths of metallic homogeneous lines. Due to the damaging effect of the impulse noise, we must take into account also this type of negative environmental influence. The most common type of the impulse noise seems to occur in the local access network, when a disturbed pair shares a common cable sheath with switched disturbing pairs.

Appendix — abbreviations

ADSL – Asymmetric DSL
NEXT – Near End Crosstalk
AWGN – Additive White Gaussian Noise
NTU – Network Termination Unit
CCP – Cross-Connect Point
POTS – Plain Old Telephone Service
CO – Central Office
PSD – Power Spectral Density
FEC – Forward Error Correction
QAM – Quadrature Amplitude Modulation
FEXT – Far End Crosstalk
SDP – Subscriber Distribution Point
LTU – Line Termination Unit
VDSL – Very high bit rate DSL
MDF – Main Distribution Frame
xDSL – "x" Digital Subscriber Line

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