Powerline Communications Channel: Modeling and Noise Monitoring

R. Abenov [1], D. Pokamestov [1], A. Geltser [1],
Ya. Kryukov [1], E. Rogozhnikov [1], A. Shibelgut [1,2]

[1] Department of telecommunications and radio engineering fundamentals, Tomsk state university of control systems and radioelectronics, Tomsk, Russia
E-mail: abenov.rr@gmail.com
[2] Department of computer measuring systems and metrology, Tomsk polytechnic university, Tomsk, Russia

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Abstract. The research of a low frequency channel of the Power Line Communications (PLC) systems was performed. A mathematical model of the channel was obtained. The model takes into account the multipath signal propagation over power lines of typical buildings. An amplitude-frequency characteristic of the channel was measured. The noise monitoring in a power network of the university academic building was fulfilled.

Keywords: PLC, multipath channel, modeling, noise measurement

INTRODUCTION

In the modern world the development of telecommunication technologies goes to direction of growth of the traffic and amount increasing of connected devices. By estimation of experts an era of the global Internet will became to 2020, when every household appliance will practically have an access to the Internet and an ability to remote control [1-3]. Therefore, a need of creation of combined networks is increasing. These combined networks have to include both wired and wireless technologies for connection to various kinds of devices. A number of standards for wired communication over power lines (power line communication – PLC) has been recently developed. This technology is above all attractive that it is possible to use the existing power line without the need to deploy an additional physical network. PLC systems can be divided into a high and a low frequency systems [4, 5]. High frequency systems operate in the range up to 100 MHz. They are used to provide PC users by access to the Internet with speed up to several hundreds of megabits per second. Low frequency PLC systems are typically used to exchange data between the sensors and for automation of industrial processes. Among the standards describing these technologies can be picked out a recently appeared European standard "G3-PLC" and an American "PRIME" [6]. In systems that work with using of these standards are applied OFDM technology on a physical level. Such systems work in the frequency range of up to 150 kHz (predominantly a range of up to 100 kHz). A correct operation of the PLC systems depends directly on the state of the transmission channel. The multipath effect, caused by a complex branched topology of network, and interferences, appeared by other connected devices, have the greatest impact on the channel [7]. In this paper these factors are studied. A mathematical model of the multipath channel which takes into account the network topology and the signal attenuation is considered. A series of measurement experiments of the frequency response of the channel and a monitoring of noises in the laboratory of academic building are performed.

MODELING

The communication channel is depicted in Fig. 1, where τ_i – time delay in i-th path, l_i – length of i-th path, ν – propagation velocity of wave in medium, k_i – attenuation along i-th path. This typology can be described as [8]:

$$H(f) = \sum_{i=0}^{N-1} k_i e^{-2\pi f \tau_i}, \quad (1)$$

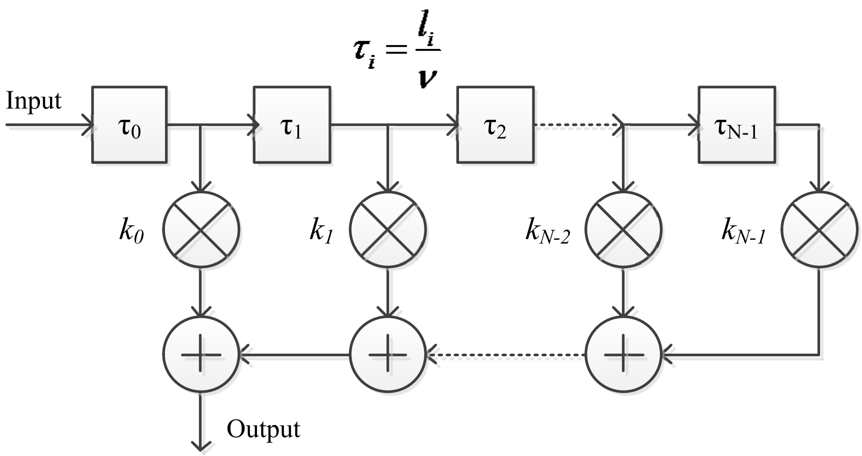

Figure 1. Multipath PLC topology

If we add a frequency-dependent attenuation of a signal along the path to (1), we have:

$$H(f) = \sum_{i=0}^{N-1} g_i e^{-\left(a_0 + a_1 f^k\right) d_i} \cdot e^{-j2\pi f \frac{d_i}{v_p}}, \quad (2)$$

where a_0 – an initial attenuation, a_1 – an attenuation increase with increase of frequency, N – total number of paths, k – coefficient of attenuation decrease, d_i – a length of the data transmission path for various path numbers (in meters), g_i – an attenuation coefficient of i-th path [9].

This approach was simulated in MATLAB and represents three models of multipath channel.

Main parameters of model:

- $a_0 = 0$ – an attenuation shift;
- $a_1 = 7.8 \cdot 10^{-10}$ – a long attenuation;
- $k = 1$ – a coefficient of attenuation decrease;
- $v_p = 1.5 \cdot 10^8$ – propagation velocity.

The propagation velocity is calculated as:

$$v_p = \frac{c}{\sqrt{\varepsilon_r}} = \frac{3 \cdot 10^8}{\sqrt{4}} = 1.5 \cdot 10^8 \text{ m/s.}$$

Fig. 2 shows the modeling results of transfer functions of these channels in the range of up to 1 MHz. The characteristic of channel 1 in the given frequency range is close to linear and has relatively low attenuation. It can be explained due to a small time delay between the direct and the reflected signals [10]. Channel 2 has a similar transfer function but the characteristic is non-linear due to a longer time delay. Channel 3 is characterized by a larger number of reflection paths and longer delays, so the given frequency range has deep fades.

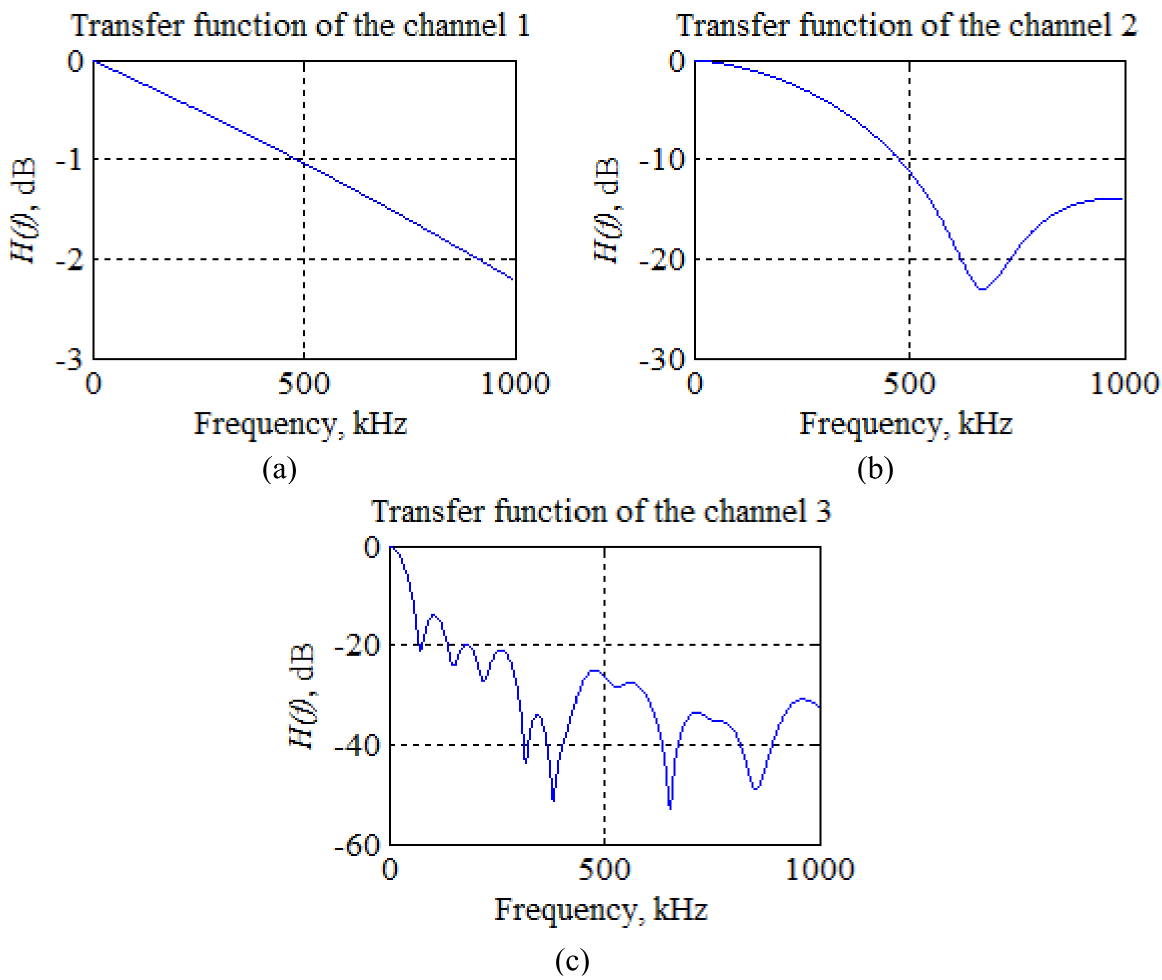

Figure 2. Frequency characteristics of paths in the range of 0–1 MHz: channel 1 (a); channel 2 (b); channel 3 (c)

NOISE MONITORING IN PLC-NETWORK

The experimental measurement of noises has been performed by a voltage converter which is presented a transformer within-series capacitor [11]. During experiment was used LeCroy WaveRunner 6100A oscilloscope. The device has been connected with the MATLAB environment to automate the registration process of the signal.

The control was carried out in MATLAB. Every five minutes an oscilloscope was keeping an input signal and transmitting it over the LAN to a computer. Then the Fourier transformation was performed and the result was stored in the computer memory as a matrix form. Further the influence of the voltage converter is eliminated by dividing the Fourier transform on a pre-measured amplitude-frequency characteristic of the voltage converter. The registration of the signal was continued during 24 hours, from 7:35 p.m. till 7:45 p.m. of next day. According to the received results was built a spectrogram in the range of 10–100 kHz shown in Fig. 3. The spectrogram is represented by way of a three-dimensional picture of distribution of noise amplitudes (dBV) on the frequency-time axis.

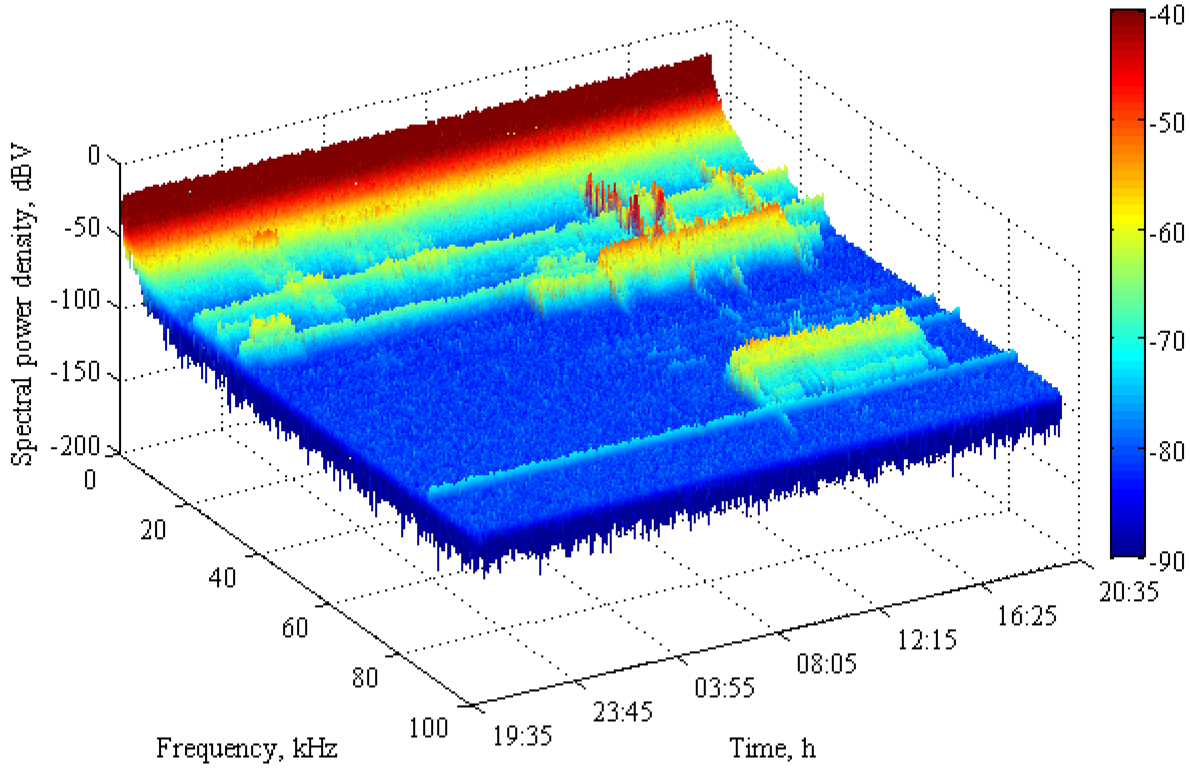

Figure 3. Spectrogram of the noise signal

The presented spectrogram enables us to evaluate the level of noises at different times of day. The measurement was performed in the laboratory of university which has about 10 working places. Every place is equipped with a computer. There are also measuring equipment (oscilloscopes, spectrum analyzers) and soldering stations in some working places. In addition, there are also a printer and a cooler of drinking water in the laboratory. At evening and night (till 9:00 a.m.) one computer, an oscilloscope and a cooler were working in the laboratory. During the day the working places were occupied by staff of the laboratory. About 12:30 p.m. students were in the laboratory with two laptops which have been also connected to the network.

This result suggests that working computers generate interferences in the frequency range of 35–45 kHz and 70–90 kHz. However, the spectrogram has broadband noises which are very different from the rest. These noises are shown in Fig. 4. Here a fragment of the frequency-time plane of the spectrogram is depicted. The spectrum of such interferences takes the band up to 50 kHz. The time of interference occurrence coincides with the connecting laptops to the network. Probably a power supply of the laptop during charging of the battery creates impulse noises in this range. The noise spectrum at different times is shown in Fig. 5. As can be seen from Fig. 5, a level of noises in non-working hours does not exceed −70 dBV. Connection of computers and measuring devices to the power line network causes the noises on a level −60…−65 dBV in above mentioned frequency range. During the maximal load the level of noises achieves a value −43…−45 dBV.

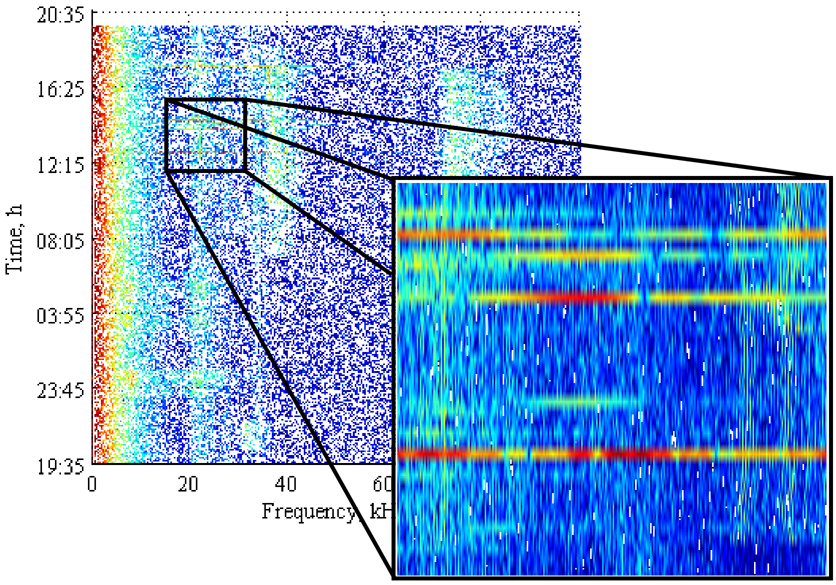

Figure 4. Short broadband interferences in spectrogram

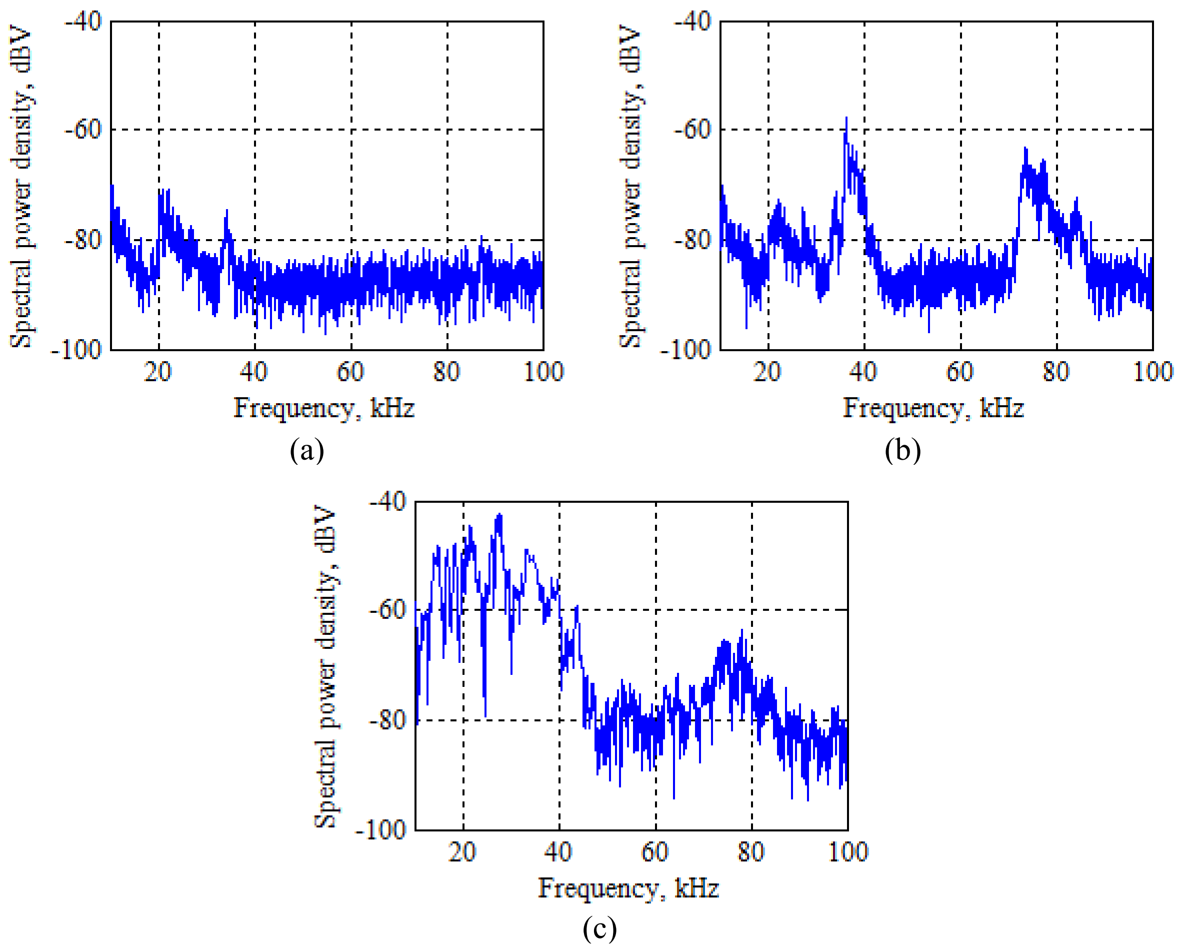

Figure 5. Spectrum of noise signal: a) night-time (04:00); b) working time (10:35); c) peak (12:45)

THE MEASUREMENT OF THE TRANSFER FUNCTION OF PLC CHANNEL

The measurement of the transfer function of PLC channel was carried out in the laboratory of university building. During the measurement were used Agilent DSO-X 2002A oscillator and LeCroy WaveRunner 6100A oscilloscope. The protection circuit was used in the operational amplifier for oscillator protection against interferences. A schematic diagram of the experimental setup is shown in Fig. 6.

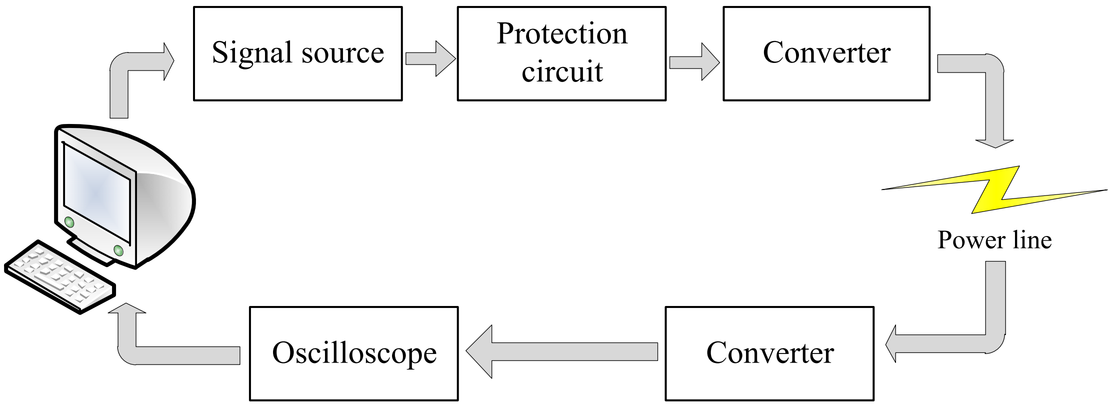

Figure 6. Schematic diagram of the experimental setup

The obtained transfer function is shown in Fig. 7. The oscillator and the oscilloscope were connected to a power supply in various parts of the laboratory. The measurements were fulfilled in two modes: non-working time and working time. Non-working time (see Fig. 7b) is characterized by a small number of devices connected to the network such as the oscillator, the oscilloscope and the PC which is used for recording and signal processing. At working time (see Fig. 7a) the devices connected to the network greatly complicate the topology of the network which will be become heterogeneous. Thus a plurality of reflecting loads are appeared in the network. It leads to multiple reflections and strong signal attenuation.

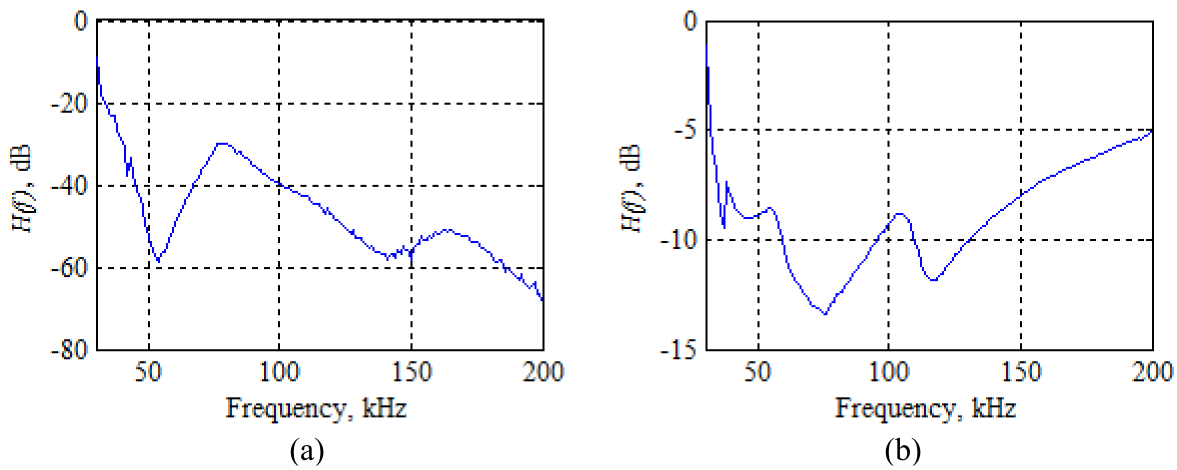

Figure 7. Transfer function of the PLC channel: a) in working hours; b) in non-working hours

CONCLUSION

PLC network deployed in a house implies that the distance between a distribution box and apartments is not more than several tens of meters. In this case according to the results we can conclude that the channel is quite stable in the range of 1 MHz. However, it should be noted that the communication channel in such networks is highly dependent on the complexity of the network organization and on the subscriber’s numbers. In certain cases the multipath effect leads to deep fade.

The obtained model allows predicting the channel state under different conditions of the multipath effect and parameters of the channel attenuation. The model can be used in engineering and deployment of real PLC networks.

The measurement results allow concluding that by modeling of the PLC networks we should take into account multipath effects in a channel as well as different appliances which generate various noises in the range of up to 1 MHz. Any devices connected to the power line can be sources of these noises. The observed noises are random in character as the number and the type of network-linked devices are constantly changed. The level and the type of noises can be also changed during the day and it depends on power line load. It should be noted that the connection of household appliances to the power line causes power line surges.

The measured transfer functions can be used in modeling of various low frequency PLC systems, for example, to quality assessment of data transmission. They can be also used to perform check of the signal processing algorithms used in these systems.

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