2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Method for measuring background noise levels conducted over low voltage power lines

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Abstract

This paper describes a measurement methodology for background noise conducted over low voltage power lines in the 0.15 MHz – 30 MHz frequency range. A block diagram of a background noise voltage measuring system with supporting components is provided, along with a description of the measurement methodology used. Example measurement results are presented. The paper also describes relationships, which can be used for assessing environment disruption levels on a given power line.

1. Introduction

Data transmission technologies utilizing low voltage power lines to transmit information within buildings are continuously rising in popularity. These data transmission systems are referred to as Power Line Communications (PLC) solutions. Low voltage circuits are convenient data transmission pathways for indoor premises within a building. To make use of these circuits, one needs to install dedicated powerline modems, which need to be plugged directly into a electrical wall socket. Energy suppliers use power lines for a similar purpose, i.e. to collect metering information from compatible energy meters. Therefore, background noise levels on low voltage power lines are an important concern to anyone deploying Power Line Communications technologies. Measurements of background noise levels conducted over voltage power lines within frequency ranges up to 500 kHz can be found in available literature [2, 3, 4, 5]. To assess whether a given power line circuit is able to support PLC with broadband speeds (up to several Mbit/s), information on background noise levels in a wider frequency range, up to 30 MHz, is required. However, information provided in current literature [1] on background noise measurement in that frequency range is outdated. The last paper on this subject was published in 1999, and focuses solely on urban areas. This article describes a method for measuring background noise levels conducted over low voltage power lines, and an example schematic of the measurement system.

Levels of conducted background noise depend on natural (thermal) noise and any interference generated either intentionally or intentionally by people. There are few quantitative descriptions of conducted background noise in available literature. As presented in available literature [1], one can state that background noise levels conducted via low voltage power lines, as measured in 1999 for a single location within the territory of the United States, subjected to representative disturbances from electrical and electronic devices in frequency ranges of (1÷20) MHz and (20÷60) MHz equal 40 dB and 30 dB respectively above the thermal noise levels defined by the following relationship:

$$P_{ter,b} = k \cdot T_0 \cdot b \qquad (1)$$

where:

- k – Boltzmann constant, equal to $1.38 \cdot 10^{-23}$ J/K,
- T_0 – temperature of 290 K,
- b – equivalent bandwidth of a reference selective system in [Hz].

Upon conversion to logarithmic units and substituting fixed values, such as the Boltzmann constant, and the ambient temperature T_0=290 K, the relationship (1) becomes easier to use.

$$P_{ter,b}[dBm] = -174 + 10\log b \qquad (2)$$

See Fig. 1 for example values of thermal noise levels $P_{ter,b}$ and conducted background noise levels $P_{n,b}$ as published in existing literature [1].

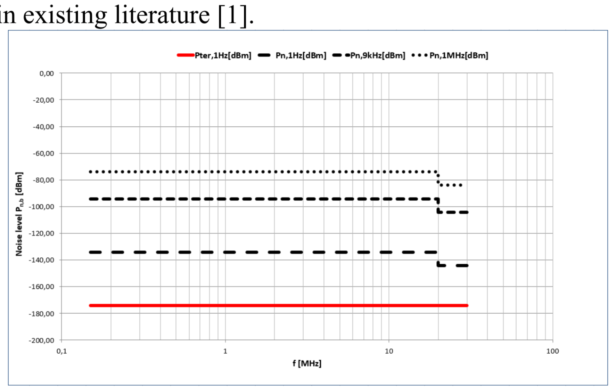

Figure 1. Example values of thermal noise levels $P_{ter,b}$ and conducted background noise levels $P_{n,b}$ for a frequency range of 150 kHz – 30 MHz, as presented in existing literature [1]

In many application, it would more convenient to use the value of conducted background noise voltage $U_{n,b}$ in the b band defined by the pre-detection circuit of a monitoring receiver connected to the monitored low voltage power line. To convert the conducted background noise levels

$P_{n,b}$ to their respective conducted background noise voltages $U_{n,b}$ in the b band, relating to monitored low voltage power lines, one needs to use the Johnson-Nyquist noise relationships, which define the mean square value of thermal noise voltage:

$$u_{ter,b}^2 = 4 \cdot k \cdot T_o \cdot R \cdot b\,, \qquad (3)$$

where R – load resistance in [Ω].
When converted to logarithmic units, the relationship (3) takes the following form:

$$U_{ter,b}[dB\mu V] = 20\,log\frac{\sqrt{4 \cdot k \cdot T_o \cdot R \cdot b}}{0.000001} \qquad (4)$$

This relationship allows to calculate the mean square value of thermal noise voltage in a frequency range of 150 kHz to 30 MHz. This relationship is represented by a red line on Fig. 2. Similarly to the conducted background noise level $P_{n,b}$ presented in the literature [1], for background noise voltage levels conducted $P_{n,b}$ in low voltage power lines, as measured in the year 1999 in a single location within the territory of the United States, subjected to representative disturbances from electrical and electronic devices in frequency ranges of (1 - 20) MHz and (20 – 60) MHz, the value of conducted background noise level $U_{n,b}$ in low voltage power lines is measured as being 40 dB and 30 dB respectively over the value of thermal noise defined by the relationship (4) for a given filter band of the monitoring receiver b. Taking the above into account, conducted background noise levels $U_{n,b}$ in low voltage power lines for various frequency ranges in urban areas may be described using relationships presented in Table 1.

Table 1. Transmitted background noise levels $U_{n,b}$ in low voltage power lines for each frequency range, measured in an urban area

$U_{n,b}$[dBμV]	Frequency range
$U_{n,b}[dB\mu V] = U_{ter,b} + 40$	(0.15÷20) MHz
$U_{n,b}[dB\mu V] = U_{ter,b} + 30$	(20÷30) MHz

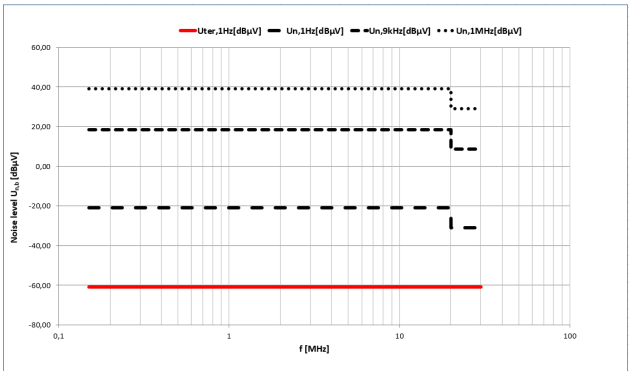

Figure 2. Mean root values of thermal noise voltage levels $U_{ter,b}$ and conducted background noise $U_{n,b}$ for a frequency range of 150 kHz – 30 MHz

See Fig. 2 for example values of $U_{n,b}$ for filters with bandwidths of b=1 Hz, b=9 kHz and b=1 MHz. The measured value $U_{n,b}$ for low voltage power lines, provided in Table 1, may be used as a measure for assessing environment disruption levels on a given power line.

Unfortunately, the method of assessing conducted noise levels on any given power line on the basis of $U_{n,b}$ relationships presented in Table 1 has a number of faults, as the aforementioned relationships are based on measurement values, which were performed:

- a relatively long time ago (in 1999),
- only for an urbanized area.
- using a measurement system, which only records mean values, which in many instances aren't that practical to use in power line assessment.

2. Example implementation of a measurement system

This section of the paper describes an example implementation of the measurement system used to measure the conducted noise levels $U_{n,b}$ in low voltage power lines.

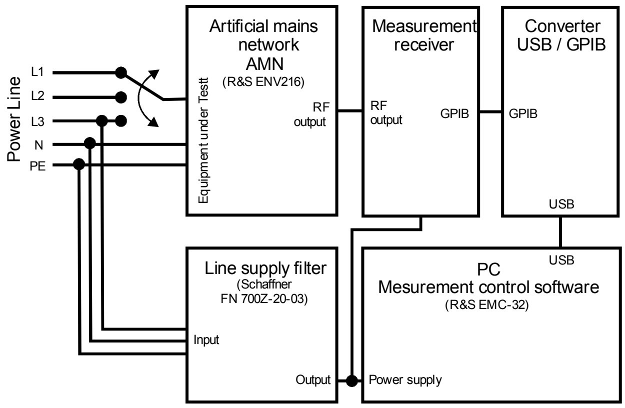

Figure 3. Block diagram of a measurement system designed to measure conducted thermal noise voltage levels $U_{ter,b}$ and conducted background noise $U_{n,b}$ for a frequency range of 150 kHz – 30 MHz

Figure 4. Illustration of a measurement system designed to measure conducted noise

See Fig. 3 for a block diagram of an example measurement system used to measure the conducted noise levels $U_{n,b}$ in low voltage power lines. The measurement system consists of:

- Rohde&Schwarz ESIB26 test receiver operating in a range of 9 kHz – 22 GHz.
- Rohde&Schwarz ENV216 V-network Artificial Means Network (AMN) operating in a range of 150 kHz - 30 MHz.
- A Schaffner FN 700Z 20 3 AC 230V 50Hz powerline filter, which minimizes disturbance conducted by the components of the measurement system (the test receiver and the personal computer). This is achieved by filtering conducted interference signals generated by these components out from the measurement of conducted background noise $U_{n,b}$ in low voltage power lines.
- A personal computer with EMC 32 measurement control software, set up with a remote control system via USB and GPIB interfaces,
- Agilent 82357A USB/GPIB remote control interface adapter.

This measurement system, designed to measure conducted background noise $U_{n,b}$ in low voltage power lines, is built from components typical for a conducted disturbance measurement system, which was defined in the standards document [6]. The document contains a description of a procedure for measuring conducted disturbance levels generated by information technology equipment (ITE) on a power port. Basic components of the system include the Artificial Mean Network device (AMN) and a test receiver connected to the AMN's measurement output with a coaxial cable. The design of the conducted background noise voltage level $U_{n,b}$ measurement system for low voltage power lines presented herein is similar to the design of the conducted disturbance measurement system as defined in the standards document [6], but with one key difference – the location of low voltage connection to the AMN. This is because in this document, the authors are investigating a low voltage powerline circuit, which is connected to the AMN's input, whereas in the design described in document [6] the AMN's input connected to the power port of the studied ITE.

Correction factors $K_{AMN}(f)$ should be measured for the AMN being used, to allow for recalculation of noise voltages induced on the studied power line to the voltage present on the measurement output of the AMN. In order to recalculate the signal level, sent from the AMN's measurement output through a coaxial cable, to the input level of the measurement receiver on the other end, one needs to specify the transfer function $A(f)$ of the used coaxial cable for each measurement frequency. The correction factor and the transfer function of the signal line are used by the EMC32 measurement software to calculate conducted environment noise levels $U_{n,b}$ in the investigated low voltage power line.

The measurement receiver detects and measures radio frequency signals. The system is equipped with a GPIB interface, which enables remote control of the device via a PC with EMC 32 measurement control software installed.

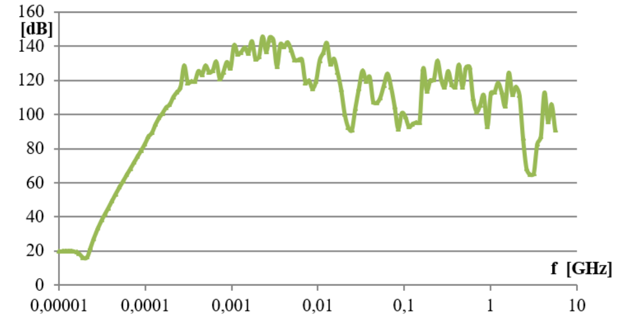

Figure 5. FN 700Z-20-03 filter attenuation in the frequency range of 150 kHz – 30 MHz

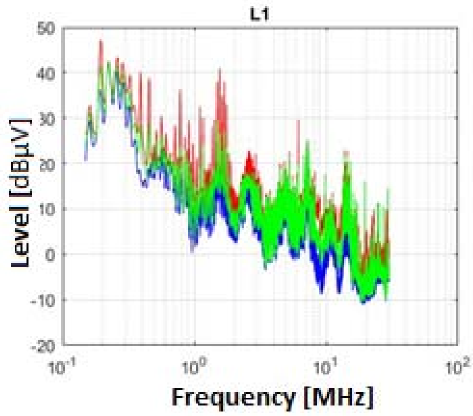

Figure 6. Maximum (red), minimum (blue) and average (green) values for the conducted background noise level $U_{n,b}$ measured in the 150 kHz – 30 MHz frequency range on each low voltage power line L_1

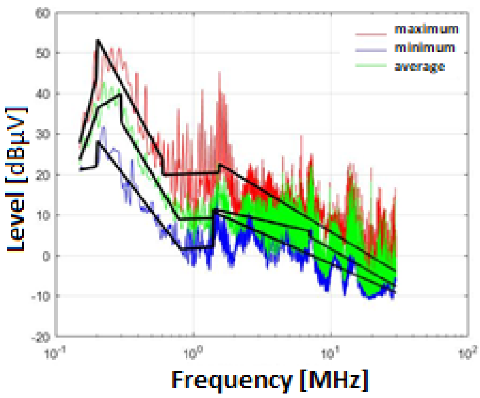

Figure 7. Maximum (red), minimum (blue) and average (green) values along with approximation functions for the conducted background noise level $U_{n,b}$ measured in the 150 kHz – 30 MHz frequency range on all low voltage power lines: L_1, L_2, L_3 and N

The powerline filter has an important function in the measurement system, as it minimizes disturbance conducted from the components of the measurement system (the test receiver and the personal computer), filtering out any conducted interference signals generated by these components from the measurement of conducted background noise level $U_{n,b}$ in low voltage power lines. For this purpose, in the described measurement system, a filter with the transfer function characteristics presented on Fig. 5 and an attenuation of over 100 dB was used, allowing to effectively attenuate any conducted disruptions generated by the test system and the personal computer used as a part of the measurement system.

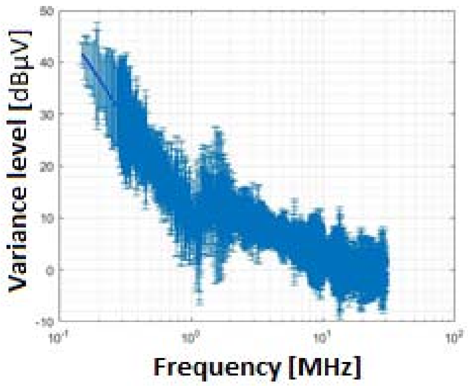

Figure 8. Distribution of values measured in the frequency range from 150 kHz to 30 MHz on all low voltage power supply lines: L_1, L_2, L_3 and N

5. Example measurement results

See Figs. 6 to 8 for measurement results of conducted environmental noise levels $U_{n,b}$ on low voltage power lines performed on the premises of the Military University of Technology in Poland, between 6 AM and 6 PM, in order to verify the measurement system.

The collected measurement results of average values of the conducted background noise level $U_{n,b}$ measured in the 150 MHz – 30 MHz frequency range on all low voltage power lines are as follows: L_1, L_2, L_3 and N for the Military University of Technology campus. These results allow for the following conclusions:

- the results exhibit a significant variance of 20 dB in noise levels between minimum and maximum noise values,
- the highest level of noise conducted in the power line circuit was measured in the frequency range of 150 kHz – 20 MHz,
- the level of noise in the power line circuit is much lower in the frequency range of 20 kHz – 30 MHz.

See Fig. 7 for maximum, minimum and average values along with approximation functions for the conducted background noise level $U_{n,b}$ measured in the 150 kHz - 30 MHz frequency range on all low voltage power lines L_1, L_2, L_3 and N. On the figure above, black straight lines were used to approximate minimum, maximum and average values for the voltage levels of background noise conducted in each frequency subrange from 150 kHz to 30 MHz. The analytical form for the approximating functions is described using the relationship (5):

$$U_{n,9kHz} = a_1 \cdot log\, f + a_2\,, \qquad (5)$$

where:

$U_{n,9kHz}$ – environment noise voltage levels conducted in the 9 kHz band, expressed in [dBμV],
f - signal frequency [Hz],
a_1, a_2 - factors dependent on frequency subrange.

5. Summary

Using measurements obtained through the methodology and the measurement system described above, it is possible work out approximating functions for minimum voltage levels of conducted environment noise $U_{n,9kHz}$ for various frequency ranges and locations in the low voltage powerline network, in a frequency range of 150 kHz - 30 MHz for any b band.
Measurements made using the above-described method can also be used to create filters, the parameters of which would be coherent with the relationship (5) and factor values a_1 and a_2 for specified frequency ranges and location types. Such filters could be used to separate devices connected to the internal circuit from any disturbances present in power distribution networks. This would allow to fragment the networks in various locations. By doing so, it would be possible to support multiple home networks based on the PLC standard on a single circuit, and would enable energy providers to collect metering information from smarting metering systems via the power line network.

7. References

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