INDOOR NETWORK NOISE IN THE BROADBAND PLC FREQUENCY RANGE

Dubravko SABOLIĆ
Vanja VARDA
HEP - Croatia
dubravko.sabolic@hep.hr

Alen BAŽANT
Faculty of Electrical Engineering and Computing, Zagreb - Croatia
alen.bazant@fer.hr

1. INTRODUCTION

Our results are based on measurements carried out in a residential house in suburban area of Zagreb town, as well as in a medium-size office building (seven stories, approx. 150 offices) in the Zagreb city center, during two moths (late August, September and early October 2003). The noise samples were collected in five whole-day (6 am – 10 pm) campaigns. Those five days were equally distributed over the two-month period. Noise was measured with the spectrum analyzer, built in the instrument Anritsu Site Master S114B, between the neutral (N) and protection (PEN) wire, so that virtually no 50 Hz voltage was present on the analyzer port. Anyways, we have provided a simple overvoltage protection for the instrument, in case a temporary network fault occurs. We have studied noise on N-PEN pair because there is a technically well grounded tendency that this wire-pair, and not the neutral-phase or phase-phase, should be utilized for PLC systems, [1]. Beside noise measurements, we also carried out simultaneous measurements of the actual office building electrical load, by periodically reading its meter. This was needed for the investigation of correlation properties between the electrical load and total noise power in the 10 to 30 MHz band. In all measurements we have recorded both noise samples from one analyzer scan (lasting about 5 seconds), thus obtaining "temporary" shots, and 5 minutes maximal values, using max-hold function of the instrument. We found 5 minutes maximums interesting because of rapid temporal fluctuations in noise power levels. Resolution bandwidth of the analyzer was 10 kHz. On all figures in this article we use noise power levels in dBm recorded by the instrument with that resolution.

2. STATISTICAL DISTRIBUTIONS

Frequency band from 10 to 30 MHz is a band in which future wide-band communication systems over indoor distribution network as transmission medium will work [1]. Linear regression (see Fig. 1.) shows slight decay with frequency, and overall average power level is around -90 dBm for one-run noise data. At frequencies bellow 20 MHz we find more pollution, coming mainly from various electronic devices. In our experiments we found that TV sets and computers are sources of intensive noise. For example, TV sets were producing especially significant disturbances in 12 to 16 MHz band. Fig. 2. gives an example of the probability function for noise power levels. Several theoretic probability functions were tried to fit the data. The best one, according to least squares calculation, was exponential cumulative distribution, $d(x) = \exp(-x/\lambda)$, where λ is expectation (λ^2 is variance), and x is $p - p_{min}$. Here p_{min} is the lowest power level recorded, and p is power level in dBm. For comparison, there is also a Rayleigh curve, which is not approximating actual distribution very well. On the other hand, see Fig. 3, we also have observed noise phenomena in the same frequency band, which is obeying to the Rayleigh distribution. This is quite obvious from the plot of the probability density function, defined as $f(x) = (1/s^2)x\exp[-x^2/(2s^2)]$. For Rayleigh distribution, expectation is $s(\pi/2)^{1/2}$, and variance is $(4-\pi)s^2/2$. By thorough observations we concluded that noise amplitudes are always distributed somewhere in between Rayleigh and exponential curves. When within frequency band in question there are some noise components that have very narrow bandwidths and that are much higher than general floor noise level, distribution is of the Rayleigh type. When we have grater number of such distinguished components, and when they have broader bandwidths, distribution is dominantly exponential. However, even when distribution is dominantly Rayleigh-like, still the highest noise power levels are distributed exponentially.

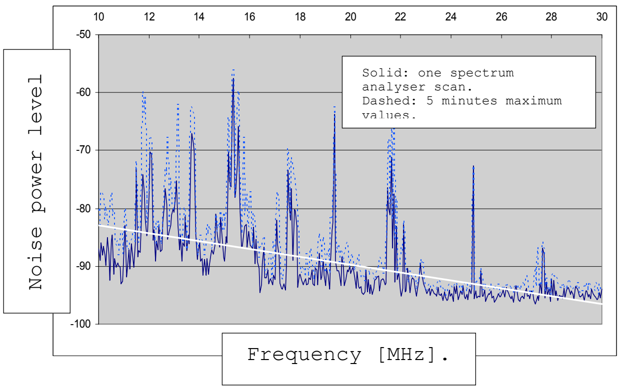

Fig.1. An example of observed noise phenomena in a PLC frequency band, from 10 to 30 MHz.

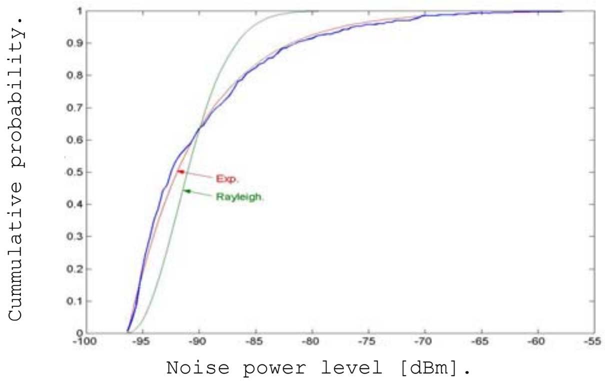

Fig.2. An example of cumulative probability of noise power levels in a frequency band from 10 to 30 MHz. Residential house, working day, noon.

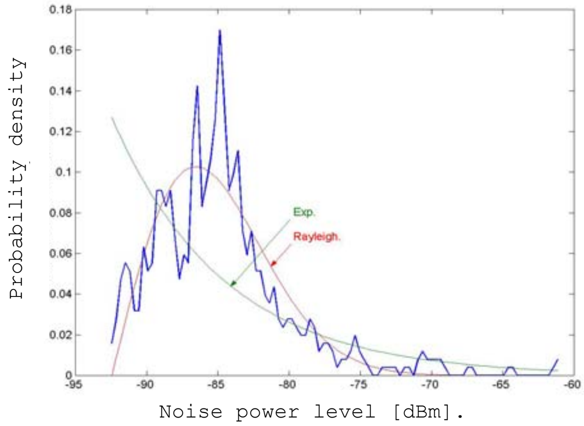

Fig. 3. Example of power level distribution density of the Rayleigh type, recorded in office building (working day, noon), for 5 minutes maximums.

We have also found that average 5 minutes levels are around 5 dB higher than averages of one-scan data. The deviations (i.e. square roots of variances) are also somewhat greater (see Figs. 5. and 6.), which can be a significant fact. It can indicate that in the total of recorded noise there might be much components which are quite time-independent, and which hold their positions on frequency axis. In other words, those components cannot be attributed to stochastic background noise, but rather to stationary interferences coming from many electronic devices. Later we shall prove this (see Chapter 5).

On Fig. 4. we show another interesting statistic. For broadband communications systems it is important that bigger portions of the total spectrum are free of interferences above certain level. Thus we derived distribution functions for widths of such frequency intervals, with respect to predefined power level thresholds. Original curves are stair cased, but in general trend they are best approximated with Cauchy-type cumulative distributions, $d(\Delta f) = (2/\pi)\text{Atan}(\Delta f/\xi)$. Here Δf is the interference free frequency interval width, and ξ is distribution parameter. There are no expectation and variance for this distribution, when defined on the $[0, \infty]$ domain (integrals are diverging). However, ξ can be regarded as a measure of deviation.

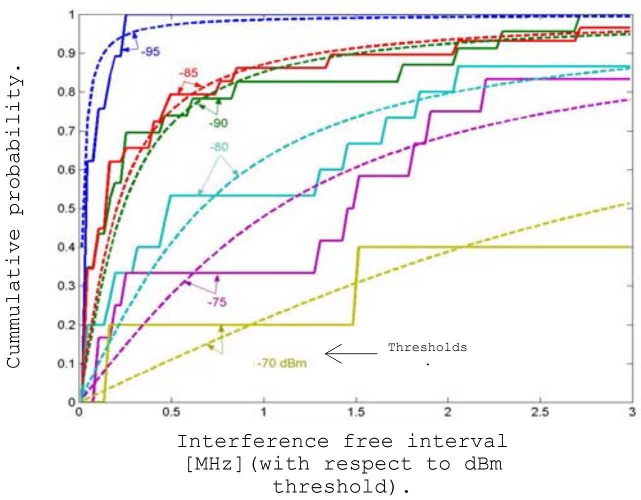

Fig. 4. Example of cumulative distributions of the band width of interference free intervals with respect to certain power level threshold. This is the probability that the frequency interval within which the noise level is lower or equal to threshold is less or equal to the abscissa value.

3. NOISE POWER VARIATIONS DURING A DAY

In this chapter we give some examples on daily variations in noise power in office building. Fig. 5 shows variations of average power levels and their standard deviations in 10 kHz sub-bands (i.e. within spectrum analyzer resolution bandwidth) for one-scan shots. On Fig. 6. there are same parameters for 5 minutes maximums. The highest noise levels are connected with periods of highest office activity, and not of highest electrical load of the network. Obviously, employers working in the office building in question were most active around 11:00 hours (just before lunch time) and around 14:00 hours (an hour before end of working time). Now we shall demonstrate a method that enables distinguishing between quasi-stationary narrowband noise components with relatively high power and floor noise. To this end, we first convert dBm values of all noise scans made during a day (or other period of interest) in regular intervals into Watt values. Then we specify a certain threshold power value which is between smallest and greatest values registrated. We compute total power (i.e. sum up all components' powers) for components weaker than threshold, P_1, and separately for those stronger than threshold, P_2. (The "component" is each of the values recorded by analyzer, for its 10 kHz resolution bandwidth.) Our task is now to find threshold, P_0, for which those two powers are equal. Then we divide P_0 with average of all components' powers engaged in calculation, P_{avg}. We get the value that describes relative contribution of strong narrowband interference components, $q = P_0/P_{avg}$. We can also calculate the decibel value, $q^* = 10\log(q)$. Now we can evaluate powers P_1 and P_2 for each noise scan, or group of noise scans formed by any desired criteria. For measurements in residential house we found q^* is 15.4 dB. In office building it was 18.8 dB, indicating significantly greater contribution of strong narrowband components. While performing simple numerical procedure for calculation of q and q^*, we found that the equilibrium between P_1 and P_2 is very sensitive to q value. Interestingly, q values are almost exactly the same for one-scan shots and for 5 minutes maximum shots of the noise phenomena.

4. CORRELATION BETWEEN NOISE POWER AND NETWORK ELECTRICAL LOAD

We have established, as expected, that noise is not correlated to the total load of larger distribution networks(e.g. on the village, town, or even regional level). It is correlated to the electrical load of local installation network in actual building. We illustrate this with an example for office building.

Fig. 7. shows normalized load and total noise power (one-scan data) in Watts, with respect to daily maximums of those two quantities. Fig. 8. shows in more details calculated correlation functions for normalized power curves of the load and noise. There are two sets of curves: for one-scan noise data (solid) and for 5 minutes maximums (dashed). For each case there are three correlation curves: for total noise power (rhomboid), for strong narrowband components (triangle), and for weak floor noise components (cross). For one-scan data, correlation function takes maximum value for zero shift between data sets of load and noise normalized powers. Narrowband noise is correlated significantly sronger to load than floor noise. Correlation function for 5 minutes maximums of strong narrowband components (see Fig. 8, dashed line, triangle) seems to be about two hours late. This is because strong narrowband interference was dropping slower than electrical load of the network.
A portion of strong narrowband components comes from electromagnetic fields of various radio emissions, which are not correlated to local building load. Additionally, it took about two hours for great majority of workers to leave the building, switching their computers off.

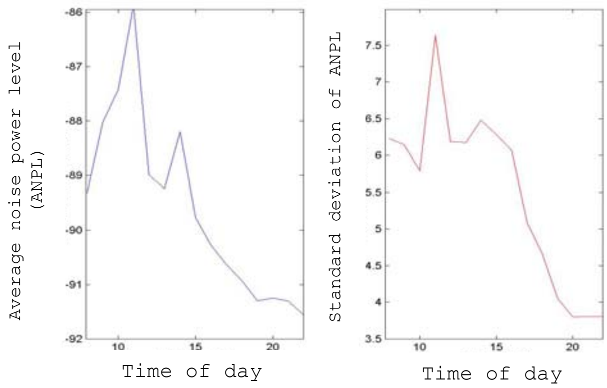

Fig. 5. Example of daily variation in average noise power level and its standard deviation. Office building, working day, one-scan data.

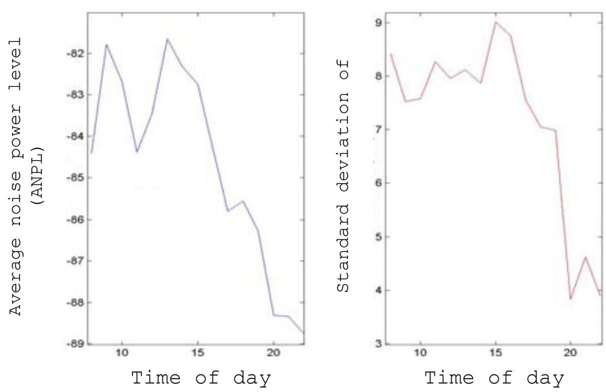

Fig. 6. Example of daily variation in average noise power level and its standard deviation. Office building, same working day as in Fig. 5, 5 minutes maximum data.

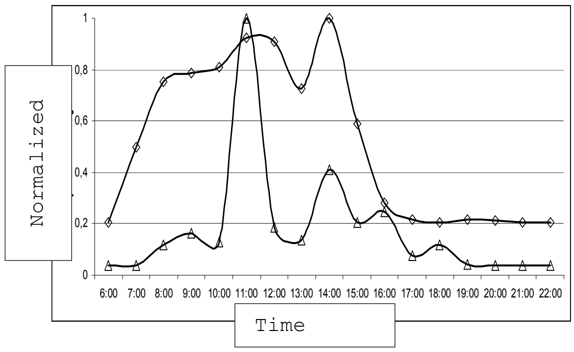

Fig. 7. Normalized electrical load and noise power in office building. Triangle: noise. Rhomboid: network electrical load. Scale is linear (*not* log).

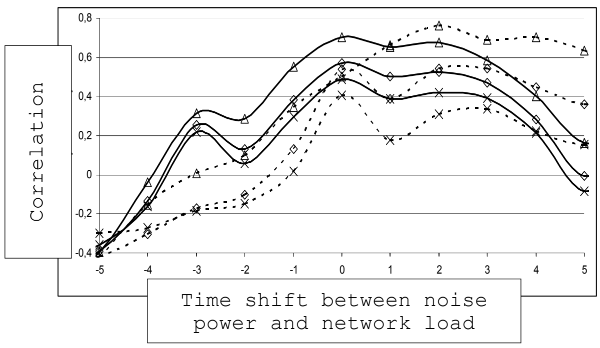

Fig. 8. Correlation functions between electrical load and noise power. Solid: one-scan data; dashed: 5 minutess maximums. Triangle: strong narrowband noise components; rhomboid: total noise; cross: floor noise (i.e. components weaker than P_0. The q^* value for both one-scan and 5 minutes maximum data is 18.8 dB.

5. CORRELATION BETWEEN NOISE SAMPLES TAKEN AT DIFFERENT TIMES AND AT DIFFERENT PLACES

Finally, let us examine some indicative correlation properties between noise samples taken at the same place, but at different times, or at (nearly) the same time, but on different network terminals. Fig. 9. gives a scattering diagram of all correlation coefficients between noise samples taken at 15 different places, during 10 minutes. We notice quite high degree of correlation. On Fig. 10. there is a diagram for samples taken at the same place, but at 15 different time instances with one hour difference. Correlations are even higher, although one might expect virtually no correlation at all, if the noise had stochastic nature. Therefore, we conducted further analyses. For the sake of shortness, we shall only state the conclusions of this investigation: There is a significant portion of interference components that do not have stochastic nature, i.e. which are coming from electronic devices connected to the network terminals in relative vicinity. PLC noise shows significant portion of stationary components, which are essentially not stochastic, i.e. which are quite stable on the frequency axis, and in time, as well.

Fig. 11. shows cross-correlation coefficients for frequency shifts of up to ±5 MHz between noise samples taken at same place, during 14 hours (15 samples, 1 hour raster). Correlations are high for zero-shift, but also for ±2.8 MHz shift, which is attributed to strong narrowband interference periodic on frequency axis with 2.8 MHz. Therefore, high cross-correlations (Figs. 9. and 10.) might come from these strong components. To rule them out, we construct "unit" noise samples, by subtracting average power level of a sample from actual value of each component within the sample, and applying signum function. In that way, we get "unit" samples with only two component values: –1 and +1. In such data string only information on frequency axis position of a component is preserved, and amplitude information is totally suppressed. Fig. 12 shows cross-correlation functions for such data. Clearly, the properties are similar, although somewhat less expressed. From that fact we conclude that there are plenty of noise components which are having fixed positions on frequency axis, indicating presence of non-stochastic interferences, coming from various electronic devices.

6. CONCLUSIONS

In short, the main conclusions are:

- Within frequency band observed, the noise power levels in decibels are Rayleigh-like distributed;
- Interferece-free frequency intervals (i.e. the intervals with noise power level lower than certain threshold) have staircased probability distribution function, with general trend like Cauchy distribution;
- Total noise power within frequency band observed is clearly correlated with the electrical load of the building electrical distribution network;
- Narrow-band components are considerably more correlated with electrical load than background noise power;
- There are clear evidences that most of the noise energy comes from sources of narrow-band electronic noise connected to an actual local building network.

REFERENCES

[1] K. Dostert, *Powerline Communications*, Prentice Hall PTR, 2001.

[2] M. Zimmermann, K. Dostert, "An Analysis of the Broadband Noise Scenario in Powerline Networks", *Proc. 4th International Symposium on Powerline Communications and its Applications*, Limerick, Ireland, April 5th-7th, 2000.

[3] M. Zimmermann, K. Dostert, "Analysis and Modeling of Impulsive Noise in Broad – Band Powerline Communications", *IEEE Trans. on Electromagnetic Compatibility*, 44(1), 2002, 249-258.

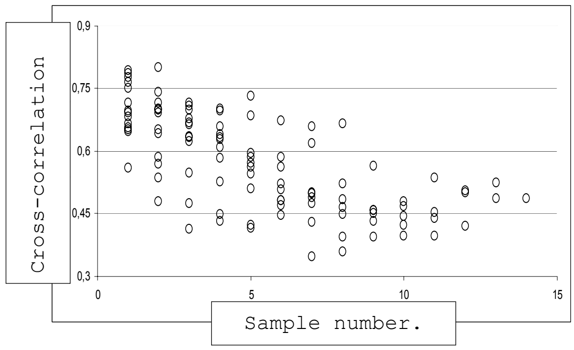

Fig. 9. Cross-correlation coefficients for all possible pairs of noise samples taken at 15 different network terminals during 10 minutes (i.e. approximately at the same time). Note that coefficients are in average quite high valued.

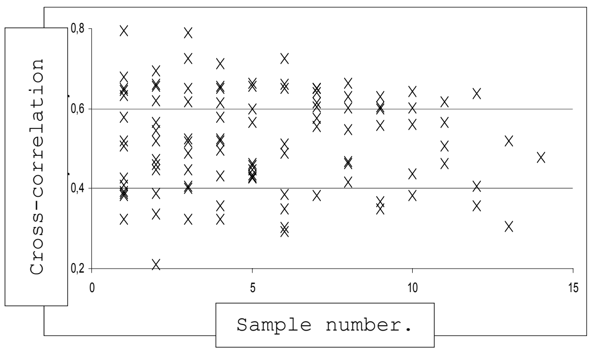

Fig. 10. Cross-correlation coefficients for all possible pairs of noise samples taken at the same network terminal, but at 15 different times, in one-hour raster. Note averagely quite high coefficient values.

[4] M. Zimmermann, K. Dostert, "A Multi-Path Signal Propagation Model for the Power Line Channel in the High Frequency Range", *Proc. 3rd International Symposium on Power-Line Communications, Lancaster*, UK, 1999, available online at URL (June 2004): http://www-iiit.etec.uni-karlsruhe.de/~plc/

[5] M. Zimmermann, K. Dostert, "A Multipath Model for the Powerline Channel", *IEEE Trans. on Communications*, 50(4), 2002, 553-559.

[6] M. Gebhardt, F. Weinmann, K. Dostert, "Physical and Regulatory Constraints for Communication over the Power Supply Grid", *IEEE Communications Magazine*,41(5), 2003, 84-90.

[7] K. Dostert, "High Speed Data Transmission over Power Lines Using Multi-Carrier (OFDM) Techniques", *Frequenz*, 54 (11-12), 2000, 271-276.

[8] D. Liu et al, "Wide Band AC Power Line Characterization", *IEEE Trans. on Consumer Electronics*, 45(4), 1999, 1087-1097.

[9] R. Cortina et al, "Telecommunication Systems on Power Distribution Networks: High Frequency Performances of Carrier Channels*", IEEE Trans. on Power Delivery*, 9(2), 1994, 654-660.

[10] V. Degardin, et al, "Classification and Characterization of Impulsive Noise on Indoor Power Line Used for Data Communications", *IEEE Trans. on Consumer Electronics*, 48(4), 2002, 913-918.

[11] F.J. Canete, et al, "Broadband Modelling of Indoor Power-Line Channels", *IEEE Trans. on Consumer Electronics*, 48(1), 2002, 175-183.

[12] D. Sabolić, "On the Distribution Network Narrowband Noise Statistics", *IEEE Trans. on Power Delivery*, 18(1), 2003, 66-68.