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Power Line Noise Measurements and Analysis in an Indoor Environment

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Abstract— In this paper, results and analysis of a comprehensive power line noise measurements campaign in an indoor environment are presented, both in the time and frequency domain. A simple coupler designed for the noise measurements is also presented. For the frequency domain noise, we see that much of the noise is concentrated in the frequencies between 0 MHz and 15 MHz. A simple trend analysis of the frequency domain using polynomial fits show that, on average, as we go from 0 MHz towards 30 MHz, the noise decays. Also, the time domain noise measurements show that there are periodic features in the noise, as well as some aspects of randomness. From the noise measurements, we observe that noise in power lines is complex and cannot be modelled and characterized using pure mathematical derivations. This is the reason why almost all existing power line noise models are derived from empirical measurements.

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Index Terms— Frequency domain noise, Powerline noise, .Noise measurements, Time domain noise

1 Introduction

Most of the powerline communications (PLC) models that have been developed for the PLC channel transfer function as well as noise are based on measurements.
This is primarily so because the PLC channel presents a very complex environment, from a communications point of view. Thus, to get a clear understanding of the power line channel transfer function as well as noise, there is need to do comprehensive measurements for both under different loading conditions and different network configurations. The conditions considered should be able to provide an average feel of the environment that the communication signal is to be sent through. The noise scenario in power line networks presents an interesting complex phenomenon. This is primarily so because the noise in power line networks differs from the classical AWGN found in many other communication systems. The noise in PLC channels is mainly influenced by the impulsive component which leads to a complete departure from the Gaussian behavior of the noise distribution in other systems. Thus, PLC noise needs to be studied thoroughly; especially through measurements and not just through mere analytical methods, so as to understand it properly for communication applications. The objectives of this paper are:

1. To present a detailed description of the measurement equipment used in our noise measurement campaign.
2. To present a brief on the coupling circuitry designed.
3. To describe the procedure used for the noise measurements as well as the environment where the measurements were carried out.
4. To present some results and analysis of the noise measurements carried out in low voltage power line networks in an indoor environment.

2 Measurement equipment description

A Rhode and Schwarz FS300 spectrum analyzer and a four-channel Tektronix TDS 2024B digital storage oscilloscope (DSO) were used to do comprehensive noise measurements in various rooms in both frequency and time domains respectively. This section is dedicated towards the description of the two measuring devices.

2.1 Rhode and Schwarz FS300 spectrum analyzer

The Rhode and Schwarz FS300 (R&S®FS300) spectrum analyzer is a highly accurate spectrum analyzer that offers high quality measurements. The particular one used in our noise measurements is shown in Fig. 1 below, while a summary of the specific measurement characteristics of this instrument are summarized in Table 1 below.

Figure 1: The R&S®FS300 equipment in a set up for background noise measurement in the PLC Laboratory

Below is a more detailed description of the equipment's key features and benefits:

1. Capability to perform high quality measurements

Relatively weak signals can be reliably detected by the device given that average noise level displayed is typically -120 dBm (300 Hz). This is feature is very crucial especially for harmonics and spurious measurements. No inherent distortions occur within the R&S®FS300 intermodulation-free dynamic range, which results in interference free measurements. At times when a high dynamic range is a requirement, this becomes particularly very useful, that is, simultaneous measurements of both low and high levels are to be done. The measurement trace points are displayed with an uncertainty level of <1.5 dB. This value is a key prerequisite for high accuracy in measurements.

2. 200 Hz to 1 MHz Resolution bandwidth

The R&S®FS300 can be adapted to best suit the measurement task by making use of the sixteen (16) digitally implemented resolution bandwidths that range from 200 Hz to 1 MHz. For overall measurements, short sweep times are ensured with wide resolution bandwidths.

On the other hand, narrow bandwidths are best suited for low noise level and high frequency resolution measurements. The R&S®FS300 fulfills every measurement requirement that lies between the two extreme cases.

3. 1 Hz resolution frequency counter

In the whole frequency range, the frequency of the signal can be comfortably measured with the help of a frequency counter of 1 Hz resolution that is a built-in feature of the R&S®FS300. Hence, there is no need for extra frequency counter, which leads to big savings in terms of laboratory bench space.

4. Maximum level of input is +33 dBm

The maximum level of input of this spectrum analyzer allows for the measurement of signals that are way beyond common limits. It is possible to even connect mobile phones with a 2 W maximum output power directly to R&S®FS300 without the use external attenuators.

5. Locating EMC weak spots

Locating weak EMC spots on shieldings, integrated circuits, cables and printed boards , among other trouble spots can easily be done with the use of the R&S®HZ-15 near-field probes. For measurement of emissions from 30 MHz to 3 GHz, the R&S®HZ-15 Near-Field probe set is very adequate. The sensitivity of the measurements is increased with the Preamplifier R&S®HZ-16 up to 3 GHz, with a gain of approximately 20 dB and a 4.5 dB noise figure. In combination with the R&S®FS300/FS315, the near-field probe set together with the preamplifier provide a very cost-effective way of analyzing and locating interference sources during development.

6. The user interface is ergonomic

All users of the equipment, including untrained ones can quickly obtain correct measurements since all operations are menu-guided. Navigation within the menus is simplified using very clear structures. Menu items from other Rohde & Schwarz instruments are included which makes the instrument user friendly; familiarity with other spectrum analyzers from Rohde & Schwarz means that users can easily adapt this version of spectrum analyzer. A 320*240 pixel resolution that gives a very bright TFT colour display allows for the reading of traces even at odd angles or under unfavorable incidence of light.

Table 1: R&S®FS300 specifications [1]

Frequency range	9 kHz to 3 GHz
Resolution bandwidths (–3 dB)	200 Hz to 1 MHz
Video bandwidths	10 Hz to 1 MHz
Displayed average noise level	< –110 dBm, typ. –115 dBm (300 Hz)
Intermodulation-free range	< –70 dBc at –36 dBm input level
SSB phase noise, 10 kHz offset	< –90 dBc (1 Hz)
Level uncertainty	< 1.5 dB, typ. 0.7 dB
Detector	peak
Measurement functions	TOI, TDMA power, frequency counter,

Figure 2: Illustration of EMC weak spots location kit [1]

7. USB Remote control

Another important characteristic of the R&S®FS300 spectrum analyzer is the USB remote-control interface. By simply establishing a USB connection, through a hot plug and play, a user can select external PC control even if it is during instrument operation. This is the first instrument which allows for remote-control via USB without any restrictions. Thus, with the USB cable help, the spectrum analyzer operation is possible even at positions that are difficult in terms of access, for example, in a shielded chamber. The R&S®FS300 comes with a Windows (2000/XP)-compatible driver for various development environments. For result display and recording, and remote control of the R&S®FS300, a PC software package is also available.

8. Compact housing with flexible handle

This spectrum analyzer has a very robust and compact design. Thus, it has very little space occupancy. For example, in a 19-inch rack, two series instruments can be comfortably accommodated next to one another. Also, the adjustable handle performs several functions like carrying it around. The handle can be moved and locked in any required position for the recording of measurements. With the handle aid, the instrument can be set up in a tilted position so that the display can be viewed optimally.

9. High picture refresh rate

Smooth display of measurements is guaranteed with a refresh rate that is as high as 10 pictures per second. Parameters changes during module adjustment are thus quickly displayed which saves time in development and production.

10. Several measurement functions

For signal analysis support, this spectrum analyzer offers a number of marker and measurement functions. One normal and one delta maker or two normal markers are provided for the determination of the signal level. For instance, the normal marker can be positioned as a reference marker on the fundamental, while the delta marker is positioned on a harmonic. In this case, the difference between both levels is representative of the harmonic suppression. For measurement of the power density of noise, the delta or normal markers can be used as the noise markers. The *n* dB signal bandwidth, for example, the 4 dB or 7 dB bandwidth measurements can also be easily done with this spectrum analyzer.

11. Settings and traces internal memory

In the internal memory of this spectrum analyzer, storage of as many as five traces and ten settings is possible. Hence, it is possible to call up settings that are frequently used and therefore the same parameters do not have to be set over and over again. This also helps prevent setting errors on the spectrum analyzer. The information stored in the equipment can be called up later for other uses, for example, external storage or printing.

2.2 Four-channel Tektronix TDS2024B digital storage oscilloscope

The four-channel Tektronix TDS2024B digital storage oscilloscope (DSO) is the most advanced of the 2000B digital storage oscilloscopes series. Compared to its predecessors, it has much more superior performance capabilities. The four-channel Tektronix TDS2024B digital storage oscilloscope used for our noise measurements is shown in Figure 3 below.

3 Measurement Environment, Set Up and Coupling Circuit

Using a Rhode and Schwarz FS300 spectrum analyzer and a four-channel Tektronix TDS 2024B digital storage oscilloscope (DSO), comprehensive low voltage noise measurements were done in various rooms in different buildings in both frequency and time domains respectively. Some of the rooms where the measurements were done included computer LANs, staff offices, electrical laboratories, electronic workshops, and postgraduate research offices and laboratories, among others. The noise measurements were done during busy hours, between 8 am and 5pm and also during off-peak hours when most of the rooms had little or no activity going on. This was to enable the capturing of different noise scenarios and to be able to have a grasp of the different noise components especially the distinction between background noise and impulsive noise components. The measurements were done in a random manner from day to day, and hundreds of thousands of noise samples in both time and frequency domains were collected from thousands of measurements. Figures 4 to 7 are pictures of some of the rooms where the measurements were done.

With no ready-made coupling circuit available for the noise measurements, we designed suitable couplers for our measurements. The schematic of the couplers that were designed for the measurements is shown in Fig. 8. The coupling circuit acts as an interface between the power line network and the measuring device. It provides a galvanic isolation between the ac mains and the measuring device. The coupler is comprised of a broadband 1:1 transformer and a series capacitor. The leakage inductance of the transformer together with the series capacitance essentially creates a series resonant coupling circuit. Transient voltage surge suppressors (TVSSs) are placed on either side of the transformer; with a back-to-back zeners placed on the secondary side and a metal oxide varistor placed on the primary side. The function of the TVSSs is the suppression of voltage spikes that may be large enough to cause damage to the measuring device. Two fully fabricated couplers are shown in Fig. 9 below.

The coupler transfer characteristic is shown in Fig. 10. From Fig. 10, we see that the transfer characteristic is fairly flat between 1MHz to 30MHz, with about 1.60 dB loss as the worst case.

The overall noise measurement set up schematic is shown in Fig. 11 below while some actual noise measurement set ups are shown in Figs. 12 and 13.

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Figure 3: Tektronix TDS2024B DSO used for time domain measurements

Figure 4: An electronic workshop

Figure 5: An Electronics laboratory

Figure 6: Machinery workshop

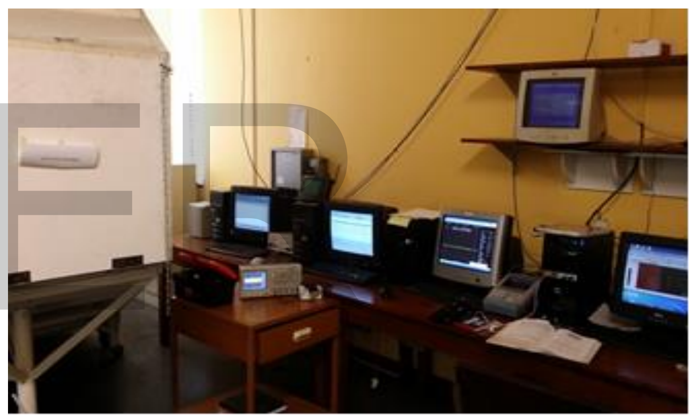

Figure 7: RF communications laboratory

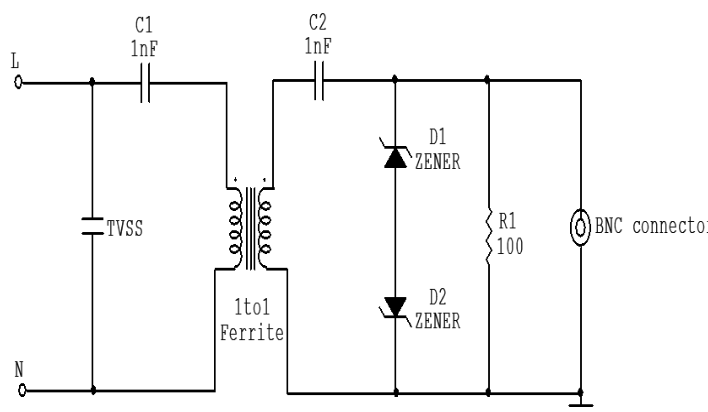

Figure. 8: Coupling circuitry schematic

Figure 9: Assembled couplers

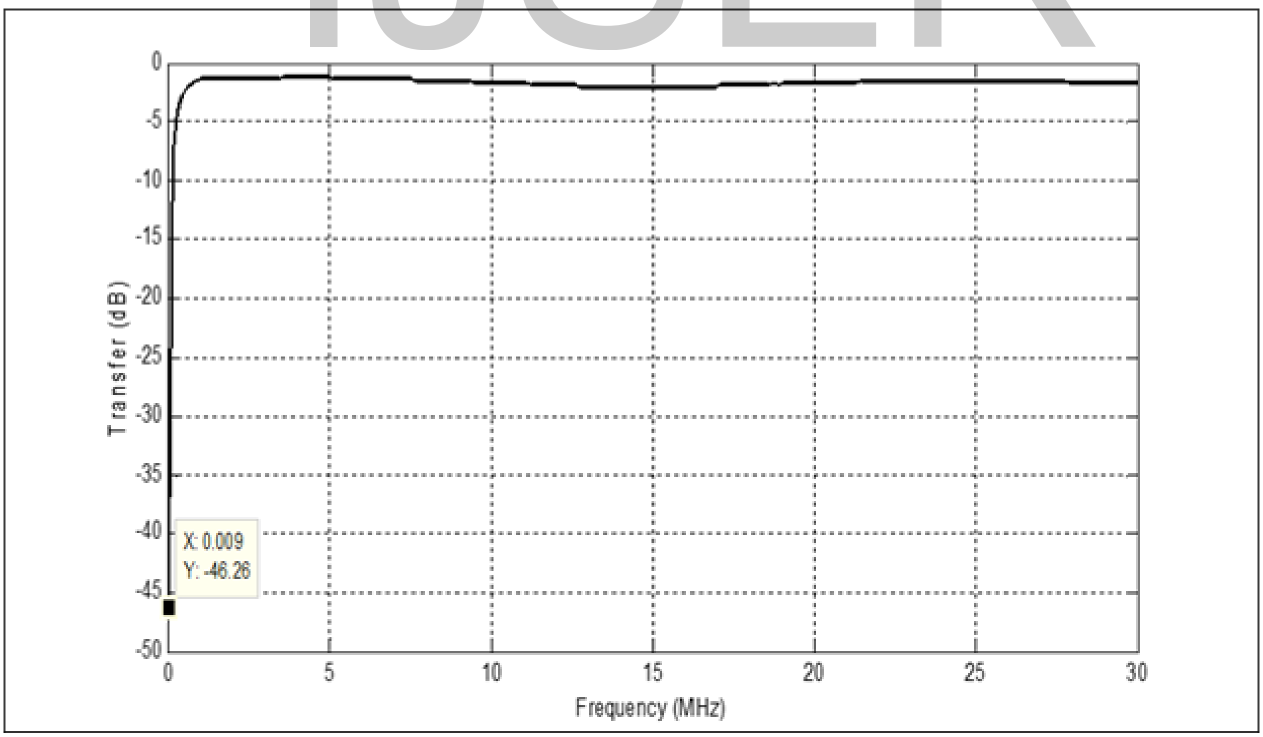

Figure 10: Coupler transfer function

The overall noise measurement set up schematic is shown in Fig. 11 below while some actual noise measurement set ups are shown in Figs. 12 and 13.

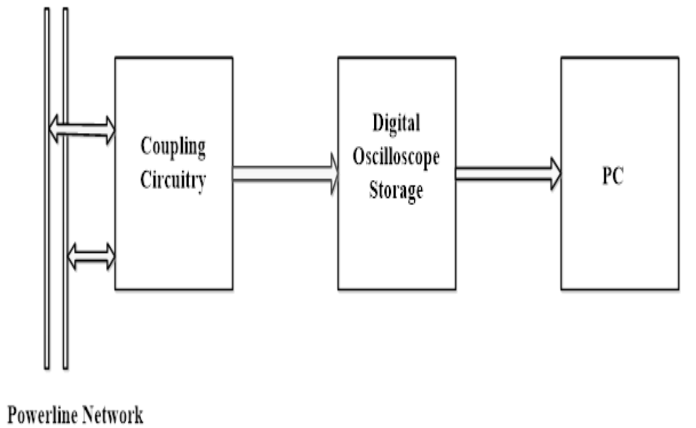

Figure 11: Measurement set up schematic

Figure 12: Frequency domain noise measurement set up in the PLC laboratory

Figure 13: Time domain noise measurement set up in an electronic workshop

4 Noise Measurement Results and Discussion

Due to space considerations, only a few measurements are shown. Some of the measured noise in the frequency domain for different rooms are shown in Fig. 14 to Fig. 16 while Fig. 17 to Fig. 19 show sample noise measured in the time domain. The frequency domain noise is measured in dBm while the time domain noise is measured in volts (V).

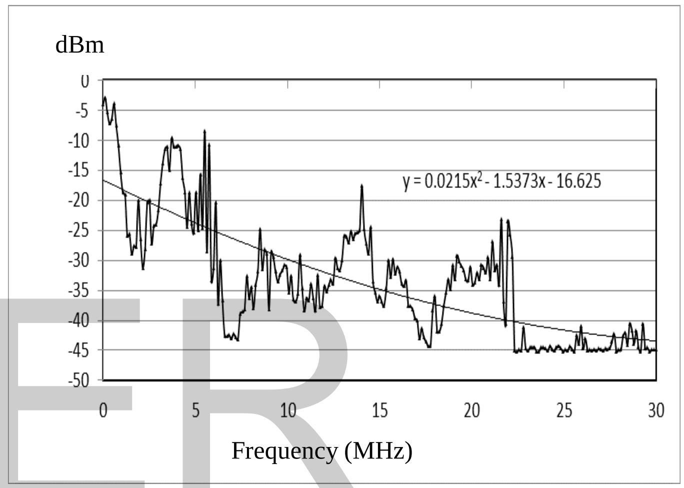

Figure 14: RF laboratory frequency domain noise

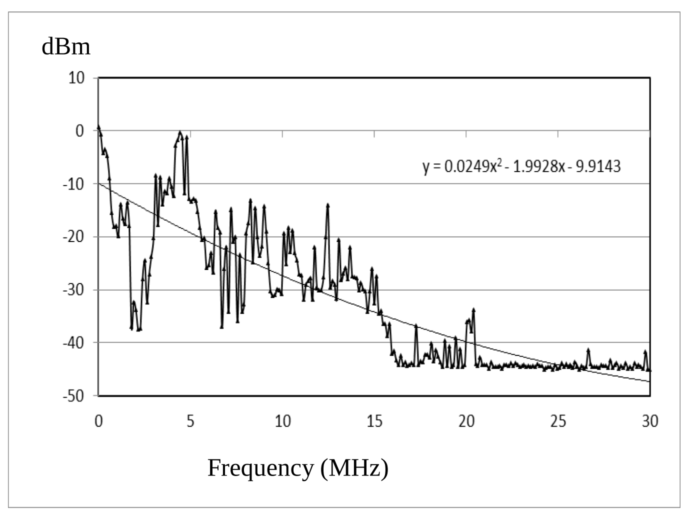

Figure 15: Electromagnetic laboratory frequency domain noise

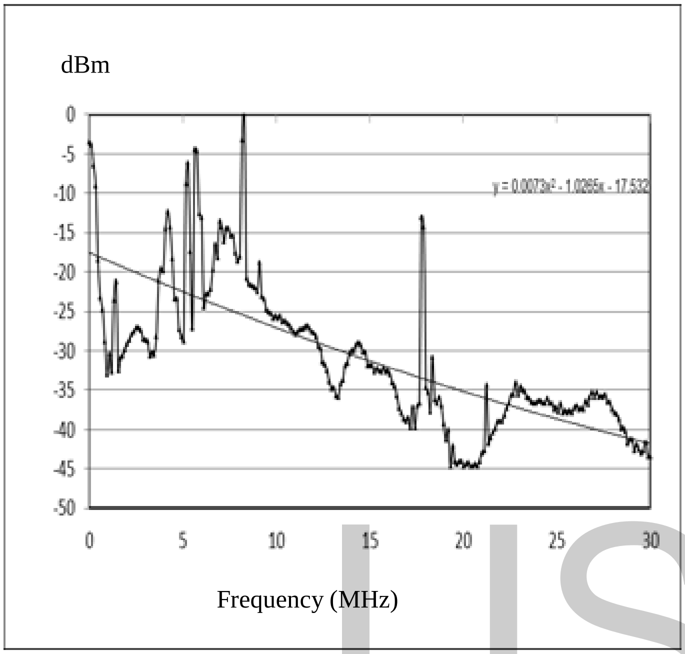

Figure 16: Office frequency domain noise

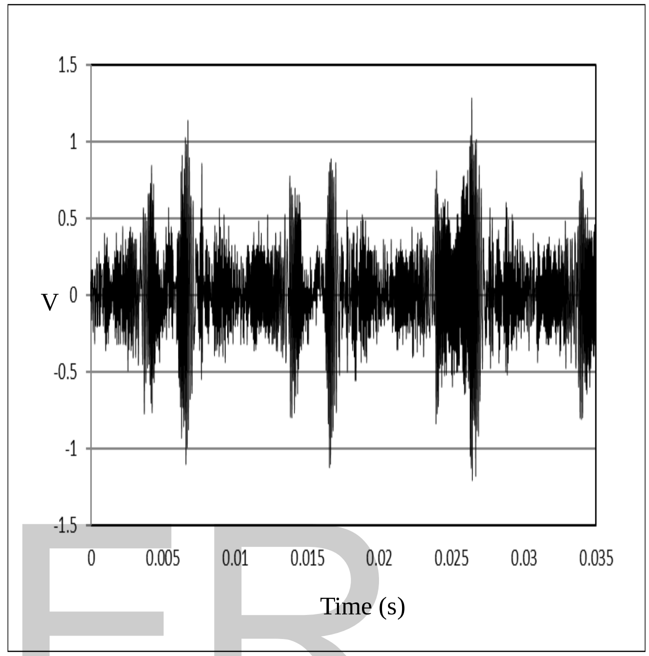

Figure 18: Electromagnetic laboratory time domain noise

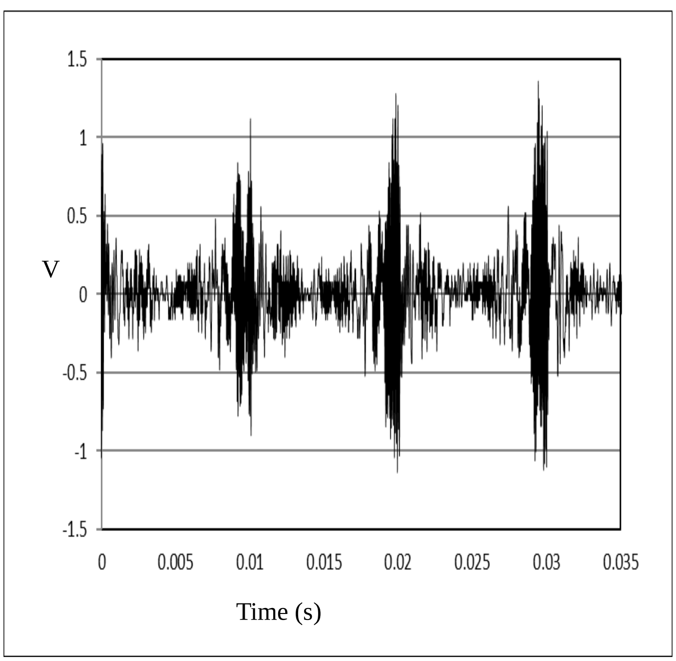

Figure 17: RF laboratory time domain noise

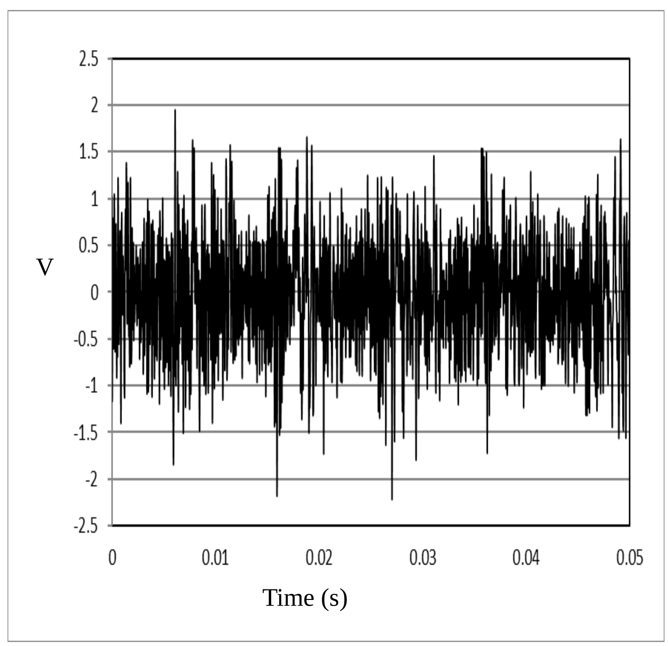

Figure 19: Office time domain noise

For the frequency noise, we see that much of the noise is concentrated in the frequencies between 0 MHz and 15 MHz. A possible explanation for this observation could be the fact that most of the narrowband noise tends to be prevalent in the same band, as well as noise from switched mode power supplies, especially below 10 MHz. A simple trend analysis using polynomial fits show that, on average, as we go from 0 MHz towards 30 MHz, the noise decays. Also, the time domain noise measurements show that there are periodic features in the noise, as well as some aspects of randomness. The periodic nature of the time domain noise in some cases is such that its frequency is two times that of the mains power. Additionally, in other cases, the noise components remained periodic only for a few seconds to minutes, while others remained cyclic and stationary for long periods of observation.

From the sample noise measurements shown above, we observe that noise in power lines is complex and cannot be modelled and characterized using pure mathematical derivations. This is the reason why almost all existing noise models are derived from empirical measurements. In order to capture the random concentration of the noise distribution across different frequency bands in the frequency domain or the voltage level variation concentration (which is an indicator of the impulse power), statistical tools need to be employed to model and characterize the noise into certain probability density functions (pdfs) and cumulative frequency distributions (cdfs). This is crucial because, with the corresponding parameters derived from the noise measurements for the pdf or cdf plot, for example, the mean, variance and standard deviation as well as the associated errors, we can then give a full statistical description of the overall noise characteristics.

5 Summary and Conclusion

In this paper, a detailed description of the measurement equipment used in our noise measurement campaign has been presented. An outline of the procedures used for the measurements in this paper has also been presented. PLC noise measurements form a big part of PLC research since the noise characteristics determine the viability of using the channel in signal transmission. This is because, it is only through measurements that the actual channel characteristics can be properly understood, from which analysis, modelling and characterization, as well as the synthesis of the results obtained can be done ; this is necessary for the derivation of the overall phenomena trends, and to enable the researcher to come up with a conclusive deduction regarding the variables studied; which is the focus in the upcoming stages of this research. The coupling scheme used for the noise measurements has also been described. A pictorial representation of some of the rooms where the measurements were done has also been presented. A decay of the noise in the frequency domain has been observed as we go from 0 MHz towards 30MHz. Also, periodicity and as well as randomness is observed in the time domain noise measurements. It is important to mention here that only a few noise measurements are presented in the results due to space constraints. Overall, we observe that noise in power lines is complex and cannot therefore be studied through mere analytical derivations; hence the need for actual noise measurements in live power networks.

Acknowledgment

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