A study of asynchronous noise in indoor power line with applications to power line communication

R Baishya¹*, B Tiru¹ and U Sarma

¹Department of Physics, Gauhati University, Guwahati-14, India
²Department of Instrumentation and USIC, Gauhati University, Guwahati-14, India

*Email: rubibaishya89@gmail.com

Abstract. Power line channels do not have standard models for noise simulation. As such, study and analysis of different types of noise is imperative to developing channel simulator where communication systems can be tested and optimized for maximum efficiency. This is an indispensable part in developing power line communication systems that uses the available power line as a communication channel. This paper analyzes the asynchronous impulsive noise in indoor power line channels. The experimental setup for noise acquisition is described in detail. It is found that the impulse amplitude and the impulse durations follow the t-location scale and the log-logistic distribution better than other distribution tested. Such a distribution is easier to handle in terms of random number generation using the inverse cumulative distribution method. This can be used in the random noise simulation of impulsive noise in the generation of overall power line noise for system testing and optimization.

1. Introduction

An important requisite for developing any communication system is the knowledge of the channel noise that governs important communication parameters like the channel capacity and the probability of error or bit error rate [1]. While selecting the digital modulation schemes, the design goals are maximizing the bit rate and resistance to interfering signals and minimizing the symbol error, the transmit power, bandwidth and circuit complexity. This requires an in-depth knowledge of noise before designing the communication system. This requirement cannot be neglected for power line communication (PLC) that uses the available power line (PL) for data communication. The problem with PLC channels is that the PL noise is non-Gaussian and non-white [2] and standard models and techniques cannot be used to represent the noise [2]. As such, an extensive study of the noise is indispensable before using the infrastructure as a communication channel. PL noise is usually categorized into five types [3]: (a) colored background noise (CBGN), (b) narrowband interferences (NBI), (c) periodic impulsive noise that is asynchronous to the mains frequency, (d) periodic impulsive noise that occurs synchronous with the mains frequency and (e) impulsive noise that is non-periodic and asynchronous to the ac mains. The noise that is always present in PL having a low power spectral density (PSD) is termed as CBGN and is a summation of noise due to many sources that reach any site due to reflections at the discontinuities present. The NBI are mainly caused by broadcast stations, in medium and short wave broadcast band. The type (c) is mostly caused by switching power supplies. The impulses have a repetition rate between 50 kHz to 200 kHz. The type (d) are mainly caused by switching of rectifier diodes. These impulses have a repetition rate of 50Hz or 100Hz as the mains cycle, of short duration (a few microseconds) and have a PSD which decreases with frequency.
The type (e) is caused by switching transients in the network and has different durations. For efficient communication, it is required that every type is studied and modeled so that the PLC transceivers can be optimized in a simulated channel before using in the field.

This paper focuses on asynchronous impulsive noise found in PL channels. The paper is sectioned as follows. In section 2, a literature review of the modeling techniques of PL noise is presented with the importance of the present work. Section 3 describes the experimental arrangement of noise acquisition and the algorithm used is also described. In section 4, the acquired impulsive noise is analyzed in detail, mainly the impulse amplitude and the impulse duration. These are suitably fitted by distribution functions. The paper then discusses the results and also presents the probable applications of this and concludes with the main results and future work.

2. Literature review on modeling methods of power line noise

The researcher has introduced many methods to capture the features of PL noise to regenerate when required. The simulation approach for PL noise regeneration can be divided into two domains, namely the frequency domain and time domain approaches [5]. The CBGN regeneration usually depends on the first approach and both the approaches in the analysis of impulsive noise. Some of the methods used in different types of noise are the Middleton’s model [6, 7] in case of impulsive noise; concept of noisy load which is affected by the frequency response of the channel [5, 8, 9]; Markov models that correlate the impulsive noise with the time variance with loads; white noise passage through linear filters with pre-determined constant multipliers [10] and lastly is adding the individual noise types described by the Zimmermann components [11, 12] to develop the overall noise environment. In the Middleton model, the total noise (impulsive and background) is depicted by two parameters; the impulse indexes (\(A\)) and the background to impulsive power ratio (\(r\)). However, this technique was originally developed to model man made interferences, and many researchers are still inconclusive whether the same can be applied to impulsive noise found in PL [7]. The noisy load concept and the Markov model require knowledge of the channel to be known a-priori [7-9]. This is however the impossible prerequisite as the PL is loaded with different loads at unpredictable times and shows non-deterministic properties. The passage of noise by constant multipliers requires knowledge of large numbers of multipliers. The last technique of adding different types of noises to constitute a realistic noise model is the usual way of developing the noisy PL channel. A block diagram of this technique is shown in figure 1. Here, every component is modelled by empirical formulas and added to give the noise environment. Thus, the power spectral density (PSD) of the CBGN is found to decrease with frequency and usually modelled by a likewise curve [11] and the simulated noise is obtained by passing white noise through this colouring filter. The NBI uses the help of different distribution functions [11] to generate the sinusoids. The synchronous noise uses the cyclo-stationary noise model [13-14] and the impulsive noise by modelling the characteristics of the impulses [11] namely the impulse amplitude, duration/length and the inter arrival time (IAT). Such a pulse which has the required characteristics is then passed through a filter which has a response of the fast Fourier transform (FFT) of the observed impulses. The characteristics of the impulse are usually modelled by suitable distribution fits according to experimental observations and during simulations, random numbers following these distributions are generated so that the simulated pulses have the required characteristics. Table 1 gives some of the characteristics found in papers. As seen from the table, the distributions are not alike in different venues and this necessitates studies in different venues to get an overall picture. For successful simulation of the PL noise, it is a mandate that every component must be modelled carefully to create a realistic channel environment and the success lies in correct depiction of the dependencies of the various components. The impulse amplitude, impulse duration and the IAT also follow complex distributions. Modelling the distribution by complex function makes it difficult to simulate back during the generation process. In this paper, the impulse amplitude and impulse duration has been studied extensively in an indoor PL setting. The parameters are adequately
fitted by suitable distribution that easily enables the same to be regenerated by random number generators. The IAT is left as a future work.

**Table 1. Distribution fits of impulse amplitude, duration and IAT**

| Ref | venue                | \(t_{amp}\) | \(t_d\) | IAT          |
|-----|----------------------|-------------|---------|--------------|
| 14  | Indoor               | MCA\(^a\)  | Random  | Markov Chain |
| 14  | Indoor               | Weibull     | Random  | Markov Chain |
| 14  | Indoor               | FSWGP\(^b\) | Random  | Markov Chain |
| 15  | Industrial/residential | Rayleigh   | Random  | Not defined  |
| 16  | Indoor               | Exponential | Random  | Exponential  |
| 17  | Indoor               | TTG\(^c\), MCA\(^a\) | Random  | Exponential  |
| 18  | Industrial           | \(\alpha\)Stable | ME\(^d\) | Pareto       |
| 19  | Household            | Gaussian    | Random  | ---          |
| 19  | Household            | Weibull     | Random  | ---          |
| 19  | Household            | Log-normal  | Random  | ---          |
| P\(^e\) | Laboratory     | \(t\)-location scale | LL\(^f\) | ---          |

\(^a\) Middleton Class A  
\(^b\) Finite sum of weighted Gaussian PDF  
\(^c\) Two term Gaussian  
\(^d\) Mixed exponential  
\(^e\) Present work  
\(^f\) Log logistic

**Figure 1.** Power line channel noise simulation  
**Figure 2.** Block diagram of the experimental setup for noise acquisition

### 3. Experimental setup for impulse noise acquisition

The block diagram of the impulsive noise acquisition from an indoor PL is shown in Figure 2. It consists of a coupler connected to the phase-neutral line of a PL, a digital storage oscilloscope (DSO) for noise acquisition and a PC for control and perform off line analysis.

#### 3.1. The Coupler

The coupler is a passive high pass filter (HPF) that protects the connected instruments from being harmed by the PL signal. The construction of the coupler is shown in figure 2. It consists of a suitable
A 1:1 transformer (T) and two capacitors (C1 and C2) so that the frequency response is flat over a broad range of frequencies. The coupler uses differential mode coupling and has galvanic insulation. The latter is caused by inductive coupling of the transformer thereby preventing physical connection to the network. This is safer than capacitive coupling. The high voltage capacitors C1 and C2 are chosen so that the impedance at 50Hz is high. The use of the capacitors in a symmetrical configuration meets the requirement of electromagnetic compatibility (EMC) \cite{20}. The windings of T are bifilar around ferrite cores to enable high frequency noise components to pass un-attenuated. A number of protection measures are used to protect the connected instruments from high voltages like the varistor, FUSE and switching diodes. The latter protects the measuring device from voltage spikes. If there is a voltage spike larger than 2.1V across the output, then diodes D1, D3, D5 will turn on and clip the output voltage. Conversely, if the voltage spike is less than -2.1 V then the diodes D2, D3, D4 will turn on and clip the output voltage. There is also a high watt resistor (PROTECT) that discharges the capacitor and protects users from possible shock. A number of couplers are designed, the specifications of which are given in table 2. The frequency responses of the couplers are shown in figure 3. The cut off frequencies of the couplers range from 25 kHz-150 kHz (Coupler 1, Coupler 2, Coupler 3) with a roll off rate from 30dB/decade- 35dB/decade offering high attenuation to the 50Hz signal. Mostly the 25 kHz coupler was used for impulse noise acquisition.

**Table 2. The specifications of the couplers**

| Component       | Purpose     | Specification and values          |
|-----------------|-------------|-----------------------------------|
| FUSE            | protection  | Glass cartridge 5A, 250V          |
| PROTECT         | Protection  | Resistor 1MΩ                     |
| Varistor        | Protection  | MOV\textsuperscript{a} 385VDC, 7 mm |
| Diode           | Clipping    | Switching IN4148                 |
| Coupler-1       | HPF         | 2.38mH\textsuperscript{b}, 1nF\textsuperscript{e} 100kHz\textsuperscript{b}, 30dB/decade\textsuperscript{c} |
| Coupler-2       | HPF         | 550µH\textsuperscript{d}, 1nF\textsuperscript{e} 150kHz\textsuperscript{b}, 35dB/decade\textsuperscript{c} |
| Coupler-3       | HPF         | 460µH\textsuperscript{d}, 100nF\textsuperscript{e} 25kHz\textsuperscript{a}, 35dB/decade\textsuperscript{c} |

\textsuperscript{a} Metal Oxide Semiconductor  
\textsuperscript{b} Cut off frequency  
\textsuperscript{c} Roll off rate  
\textsuperscript{d} Transformer (T)  
\textsuperscript{e} Capacitor C1 and C2

**Figure 3.** The construction of the coupler  
**Figure 4.** The frequency response of the couplers
3.2. The PC controlled Digital Storage Oscilloscope

The coupler is connected to a DSO (Agilent, 1012A, 2 channel, 100MHz, 2 GS/s) that acquires noise from the phase-neutral pair of an indoor PL in a university building. The loads to the PL were the usual laboratory equipment. The accuracy of the DSO is 8 bits and has a maximum waveform record point of $10^4$ points. The DSO is controlled by the Agilent IO library suit software installed in a PC via the MATLAB software. Figure 5 gives the flowchart of the algorithm to acquire noise signal from the PL. At the first stage, a VISA object is created that specifies the vendor, port, buffer size, time out, $N$ etc. of the controlled devices. $N$ is the total number of acquisitions required. Next, commands are given to control the DSO by using the standard command for programmable instruments (SCPI) of the DSO such as the source of the signal to be acquired (channel number), the mode of acquiring, the type and the acquisition mode. The DSO is initially programmed to acquire signal in ‘single mode’ and the trigger level in the DSO is initially selected as that required. The sampling rate of the DSO is fixed at 50MS/sec. For background noise acquisition, the trigger is selected to be at 80mV as this is the noise floor of the CBGN. For impulsive noise, a trigger value of 110mV is selected. Whenever noise of greater than this trigger level, the trigger status is read and the signal is acquired by the DSO and transferred to the controlling PC. The data file consists of a time stamp, a data stamp and also the actual data. After acquisition ends, the DSO is again set for ‘single acquisition’ mode. This loop continues till the required number of impulses $N$ is obtained. As there is a delay for the overall operation to be completed in a single impulse, the IAT cannot be found out using the time stamp as

![Flowchart](image.png)

**Figure 5.** The flowchart for programming the DSO for impulsive noise
the same can be of microsecond level. This signal is then analysed offline. The system is allowed to operate for one week duration and the total number of impulses recorded was nearly 1000. Synchronous noise and NBIs was absent in the site. The acquired impulses are analysed offline.

4. Analysis of asynchronous impulsive noise in indoor power line channels
In this section, an analysis of the acquired asynchronous impulsive noise is done.

4.1. The impulsive noise characteristics
A typical impulsive noise is shown in figure 6. The impulse is designated by its impulse length or impulse duration \((t_d)\), the impulse amplitude and the IAT or \(t_{arr}\). The impulse length is the duration for which the impulse remains. The IAT is the time between two impulses. Here, an analysis of amplitude and length is done.

4.2. The power spectral density of the impulses
The PSD of the asynchronous impulsive noise is shown in figure 7. As seen from the figure, the noise is non white and increases the noise floor to as much as 20dB. The PSD of the impulsive noise usually effects the low frequency range <1MHz. The figure also shows the plot of the PSD of the CBGN.

4.3. The statistics of the impulse amplitude and length
The distribution of the parameters of the impulse characteristics, necessarily the impulse amplitude and duration/length are found out. For this, different types of distribution, like \(t\)-location scale, log-logistic, log-normal etc. are considered. The maximum log likelihood method is used to test the best fit of the distributions. Table 3 and table 4 gives the likelihood parameters \((NlogN)\) for the distributions tested. Figure 8 and 9 give the distribution for the different parameters.

**Figure 6.** The characteristics of impulsive noise

**Figure 7.** The FFT of impulsive noise compared against the background noise
5. Results and Discussion

In this work, the best fit distribution of the impulse amplitude is found to be t-location scale (table 2). The t-location scale distribution function has heavier tails than the Gaussian distribution and the probability density function (PDF) is given by equation (1).[21]

\[
f(x) = \frac{\Gamma \left( \frac{\nu + 1}{2} \right)}{\sigma \sqrt{\pi \nu \Gamma \left( \frac{\nu}{2} \right)}} \left( \frac{\nu + x - \mu}{\sigma} \right)^{-\frac{\nu + 1}{2}}
\]

(1)

In equation (1), \( \Gamma \) is the Gamma Function, \( \sigma \) is known as the scale parameter, \( \nu \) is the space parameter and \( \mu \) is the location parameter. \( \sigma \) gives a measurement of the statistical dispersion of the probability distribution. Table 3 shows that the generalized extreme values (GEV) is the best fit for the impulse duration. However, in the simulation, the log logistic can be more convenient in regard to the Zimmermann technique of noise simulation. The log-logistic distribution is a two parameter distribution specified by the scale parameter (\( \mu \)) and shape parameter (\( \sigma \)) as given by

\[
f(t) = \frac{e^z}{\sigma t \left( 1 + e^z \right)^2},
\]

(2)

where

\[
z = \frac{t' - \mu}{\sigma}
\]

(3)

\[
t' = \ln(t)
\]

(4)

where \( 0 < t < \infty, \ -\infty < \mu < \infty \) and \( 0 < \sigma < \infty \)

Modelling the impulse amplitude and the impulse duration by these two distributions can easily enable the random number generation by the inverse cumulative distribution function (ICDF) also termed as
inverse transform sampling. In this method, if $U$ is a random number that is uniform and, in the range $(0, 1)$, then the ICDF of the desired distribution applied to $U$ will generate a set of the random numbers $V$. These new set of random numbers will have the desired distribution. Thus, if $F$ is the cumulative distribution function (CDF) of the desired distribution, then using the non-linear transformation $V = F^{-1}(U)$ generates the necessary samples satisfying the required distribution. Figure 10 and figure 11 give the distribution of the generated data using this method. The $(\mu, \sigma, \nu)$ of the simulated data for impulse amplitude having $t$-location scale distribution is given by (-0.0034, 0.0210, 1.2573) and the $(\mu, \sigma)$ for log-logistic distribution for impulse duration is given by (-10.516, 0.4476). It is seen that the generated data has nearly the same distribution to the experimentally observed. Generation of the impulse amplitude and impulse duration having the required distribution will enable simulation of impulses with the observed distribution in the regeneration of the noise components of Zimmermann model.

![Figure 10](image1.png) ![Figure 11](image2.png)

**Figure 10.** Comparison of the $t$-location scale distribution of the impulse amplitude obtained using the experimental and simulated data.

**Figure 11.** Comparison of the log-logistic distribution of the impulse duration obtained using the experimental and simulated data.

**Table 3.** Distribution fits of impulse amplitude

| Distribution  | $N logN$ | Parameters name and values |
|---------------|----------|---------------------------|
| $t$-location scale | 3.4x10^5 | location ($\mu$) -0.0010, scale ($\sigma$) 0.0214, DOF* ($\nu$) 1.1868 |
| logistics     | 2.828x10^5 | location ($\mu$) -0.0025, scale ($\sigma$) 0.0361 |
| Normal        | 2.158x10^5 | location ($\mu$) -0.0029, scale ($\sigma$) 0.0955 |
| GEV*          | 1.662x10^5 | shape (k) -0.1397, location ($\mu$) 0.1296, scale ($\sigma$) 0.0430 |

*a* Degrees of freedom  
*b* Generalized extreme values
6. Conclusion
In this paper, an analysis of the characteristics of asynchronous impulsive noise in indoor PL channels is done. An experimental arrangement is described elaborately that enables the impulses to be captured. The analysis shows that the characteristics can be fitted with suitable models, the ICDF of which can easily help regenerate the noise. The arrangement, however does not allow the IAT to be captured due to the time delay in a single acquisition process of the DSO. Suitable arrangements are required for removing this shortcoming. Such noise generation will improve the replication of the PL channel in software that will enable optimization of PLC devices before implementing in hardware and testing in field. In the future, the impulse characteristics including the IAT will be studied in a number of sites and a more in-depth analysis will be made using the experimental arrangement.

References
[1] Galli S, Scaglione A and Wang Z 2011 Proc. IEEE 99(6) 998
[2] Zimmermann M and Dostert K 2002 IEEE Trans. Electromagn. Compat. 44 (1) 249
[3] Zimmermann M and Dostert K 2000 Proc. Int. Symp. on Power Line Communication and its Applications p131
[4] Meng H, Guan Y L and Chen S 2005 IEEE Trans. Power Del. 20 (2) 630
[5] Andreadou N and Pavlidou F N 2010 IEEE Trans. Power Del. 25(1) 150
[6] Najarkolaee A H, Hosny W, Lota J 2015 Proc. 17th UKSim-AMSS Int. Conf. on Modelling and Simulation (UKSim) (Cambridge, UK) p248
[7] Sancha S, Cantete F J and Entrambasaguas J. T 2007 Proc. IEEE Int. Symp. on Power Line Communications and Its Applications (Pisa, Italy) p 104
[8] Canete Corripio F J, Diez del Rio L, Entrambasaguas and Munoz J. T 2001 Proc. Int. Symp. on Power Line Communications (ISPLC’01) (Malmo, Sweden) p 85
[9] Phillips H 1999 Proc. 3rd Int. Symp. Powerline Communications and its Applications (Lancaster, UK) p 14
[10] Bert L D, Caldera P, Schwingshack D and Tonello A M 2011 Proc. IEEE Int. Symp. Powerline Communications and its Applications (Udine, Italy) p 283
[11] Benyoucef D 2003 Proc. 7th Int. Symp. Powerline Communications and its Applications (Kyoto, Japan) p 136
[12] Nassar M, Dabak A., Kim I, T. Pande and Evans B 2012 Proc. IEEE Int. Conf. on Acoustics, speech and signal processing, ICASSP (Kyoto, Japan) p 3089
[13] Xiao Y, Zhang J, Pan F and Shen Y 2016 J. Circuits Syst. Com. 25(9) 1650105
[14] Umehara D, Shinji H, Denno S and Yoshiteru M 2006 Proc. Int. Symp. on Information Theory and its Applications. ISITA (Seoul, Korea) p 195
[15] Chan Morgan H L, and Robert W. Donaldson 1989 IEEE Trans. Electromagn. Compat. 31(3) 320
[16] Andreadou N, and Pavlidou F N 2009 IEEE Trans. Power Del. 25 (1) 150
[17] Bert D, Caldera L P, Schwingshackl D and Tonello A M 2011 On noise modeling for power line communications, Proc. 2011 IEEE Int. Symp. on Power Line Communications and its Applications p 283
[18] Tran Trung H., Dung D. Do, and Huynh T H 2013 Int. J. Comp. Elec. Eng. 5 (1) 48
[19] Jaroslav K and Zeman T 2014 Adv. in Elec. and Elect. Eng. 12 (1) 20
[20] Downey WJ, Sutterlin P Power line communication tutorial -challenges and technologies. https://www.courselero.com/e/16006749/PLApps- Studywos
[21] Matsumoto EY and Del-Moral-Hernandez E 2013 Proc. Int. Joint Conf. on Neural Networks, ICJNN (Dallas, USA) p 1