A Synthetic Impulse Noise Environment for DSL Access Networks

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Abstract: In this paper a multi-statistics model of the impulse noise is presented. An impressive experimental noise data collection acquired from digital access loops provides the synthetic noise environment with the most convenient probability density functions. Internal and external impulse noise sources within communications copper lines are briefly surveyed. A wide-band noise measuring circuit is used to determine the impulse noise properties. Our model gives a full description of the impulse statistics in the time and frequency domains, enables generation of impulses with statistically appropriate both time and spectral characteristics. It is based on recent measurements and reflects the current statistics of impulse noise in digital networks, is based on wide-band measurements, agrees with empirical statistics from different access networks in different places.

Key words: DSL, digital transmission, impulse noise, noise statistics.

1. Introduction

The high speed network access DSL (digital subscriber line) technology has been proving supportive for delivering multimedia services. Relying upon a very large customer base, DSL is enabling many of the broadband integrated services from the broadband strategy [1]. A major impairment for DSL is impulse noise in the lines. Data errors caused by the impulse noise are significant due to its complex statistical nature and the complicated error mitigation and farming techniques used in DSL systems.

BT (British Telecom) proposed an analytical impulse noise model that defines a continuous-time

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being deployed into the communications system. Also, the impulse noise model has been contributing to improve coding/modulation algorithms for digital access loops.

In this paper a multi-statistics model of the impulse noise is presented. Our model gives a full description of the impulse statistics in the time and frequency domains, enables generation of impulses with statistically appropriate both time and spectral characteristics. It is based on recent measurements and reflects the current statistics of impulse noise in digital networks, is based on wide-band measurements, and agrees with empirical statistics from different access networks in different places.

The paper is organized as follows: Section 2 presents the impulse noise definition, parameters and statistical models. Section 3 presents the impulse noise generator. Section 4 gives conclusions.

2. Methods

2.1 Impulse Noise Definition

Impulse noise is a non-stationary stochastic electromagnetic interference which consists of random occurrences of energy spikes with random amplitude and spectral content.

The causes of impulse noise on digital loops are diverse and vary from on/off – hook events, through noise from home, office and industrial electric appliances and electric traction vehicles, to atmospheric noise from electrical discharges.

The communications networks are supplied with impulse noise by both internal and external sources. Internal sources are dominant within networks where cross-talk between adjoined pairs in the same cable or intercommunication cross-talk occurs. Also, signaling systems (busy sound, ring tone) generate impulse noise into the digital transmission pairs when links are connected or discarded from the commutated network. External causes belong to commutated processes from power equipment (AC/DC high voltage stations, electric traction machineries, fluorescent lighting, a.s.o) or electric storms. The electric currents induced into the cable jacket by commutated processes produce transient voltages into cable pairs.

2.2 Impulse Noise Parameters

The impulse noise consists of positive and negative voltage trips over a Gaussian noise threshold which cross-talk and thermal noise are usually producing within a telecommunications cable. The impulse noise randomly distributes in impulse packets called events. An event is a regular sequence of impulses in order, whose amplitudes exceed a preset voltage threshold. An event comes next after a Gaussian noise period of time, called quiet time. The quiet time exceeds certain duration, typically 100 μs.

The parameters describing the impulse noise properties are:
- Event span (Fig. 1);
- Pauses between impulses (Fig. 2);
- Maximum peak voltage (the highest positive/negative voltage amplitude that the sampling process of the impulse noise is acquiring over certain time);
- Samples block (a block comprises all of the samples taken within certain time);

![Fig. 1 Pulse event.](image1)

![Fig. 2 Pauses between pulses.](image2)
2.3 Impulse Noise Statistical Parameters

The impulse noise analysis has been regarding measurements on impulse amplitudes, time gaps between impulses, events spans and impulse maximum peak voltages.

The measurements have been accomplished at the main distribution frame on either subscriber lines or intercommunication lines.

Fig. 3 shows the circuit to measure and analyse the impulse noise [10]. The impulse noise from the transmission line is amplified and filtered via a 4.25 MHz cut-off frequency low-pass filter to avoid aliasing effect. A trigger component in the amplifier unit generates a 4.7 \( \mu \)s wide impulse every time the impulse noise exceeds the positive and negative threshold voltages.

Samples from the impulse noise are acquired at the speed of \( f_s = 10.24 \) MHz. A 12 bit-depth conversion is used to encode noise amplitudes.

The threshold voltage has been chosen 4 times the highest Gaussian noise level. The sampling block extends for \( 4096 \times 1/10.24 = 400 \) \( \mu \)s. The system records 51,200 blocks within 20.48 seconds.

The measurements on 100 subscriber lines have produced statistical distributions as shown in Fig. 4a and Fig. 4b for 90% of the subscriber lines. 10% of the tested lines produced excessive impulse noise and were removed from the data record.

An aggregated exponential—power law has been used to describe the amplitude probability density function:

\[
    f_{\text{ampl}}(V) = \frac{1}{240V_0} \exp \left( -\frac{V}{V_0} \right) \left( \frac{V}{V_0} \right)^{1/5} \tag{1}
\]

where \( V \) is the voltage and \( V_0 > 0 \) is a scaling parameter which changes the value with place and switch.

This PDF reflects the fact that the voltage distributions are heavy-tailed and offers a good approximation for the measured impulse noise voltage amplitude distributions collected in the networks.

The distributions curves demonstrated that the impulse noise amplitude ranges from 6 mV to 25 mV.

Alternatively, a Weibull density has also been investigated to generate random noise with prescribed amplitude and spectral characteristics. The two approximation densities almost overlap [11].
Very short time pauses between impulses (< 300 ns) distribute differently than longer pauses as such short intervals are correlated. Therefore, we have considered pauses longer than 300 ns which fit a generalized Poisson law:

$$f_{\text{pause}}(t) = \frac{10^\alpha}{\ln 10} \left( \frac{t}{100} \right)^{\beta-1} 10^{\mu - \mu / \beta} \exp\left(-\frac{\mu t}{\beta}\right)$$

(2)

Where $t$ is pause time in ns, $\beta$, $\mu$, $\gamma$ are parameters widely ranging with location and $\alpha$ is a parameter resulting from

$$\int_0^\infty f_{\text{pause}}(t) \, dt = 1$$

(3)

Inter-arrival times between impulses exhibit a complex statistical behavior. Their range is extremely large, from hundreds of microseconds to minutes or even hours. The probability of short inter-arrival times is high, and the empirical distribution tail is long and irregular. Inter-arrival times indicates a high degree of clustering, successive intervals tend to last similar extent. A Pareto distribution is a good approach for modeling random series of events. The inter-arrival times between events in the Poisson process have an exponential PDF defined as:

$$f_p(t) = \frac{\theta t_0^{\theta - 1}}{t^{\theta + 1}}, \quad t \geq 0, t_0 > 0, \theta > 0$$

(4)

Where $t_0$ is a scale, and $\theta$ is a shape parameter.

### 2.4 A Multi-Statistics Model of the Impulse Noise

Fig. 5 shows the system to generate the impulse noise in laboratory conditions [11].

Three independent sources produce random numbers for amplitudes, pauses and impulse duration. The source generating the event span and the source producing the pauses between impulses alternatively commutate to launch events and event-free states into

Fig. 5  Impulse noise model.

Fig. 6  Multi-statistics impulse noise generator.
the virtual line. The amplitude source provides output signals at the speed of the clock unit.

3. Results

The impulse noise model has been implemented in MATLAB environment to produce a multi-statistics impulse noise generator. Amplitudes, pauses and inter-arrival times sources are inputted with the statistics models best fitting the experimental data. The impulse noise generator enables noise with pre-determined statistical characteristics, such as length, number of bursts, and the time slot the impulse noise apply. The performance of the impulse noise generator is demonstrated in Fig. 6. The generated impulse is shown in both the time and frequency domain. The results demonstrate that this impulse noise generator archives realistic impulse properties both in the time and frequency domain.

4. Conclusions

The probability density function of the impulse noise amplitudes is best described by an exponential-power law with parameters strongly depending on switches and places where measurements have been accomplished. However, the cumulative distribution function displays similar shape, regardless of the data source place, therefore an extended 5 mV to 34 mV safer range of the impulse noise amplitudes should be taken into account.

The pauses between impulses do not follow an original Poisson law but rather generalized Poisson law carrying strongly traffic-dependent parameters. The Poisson law excludes events with very short time pauses from the distribution map.

The hyperbolic distribution is conveniently describing the inter-arrival times.

The multi-statistics impulse noise model relies on recent measurements and describes the current statistics of impulse noise in our DSL access networks. This impulse noise model can be further used to recreate impulses with complex spectral contents.

Last but not least, the impulse noise generator enables impulse noise with desirable statistical properties both in the time and frequency domain.

References