Spectral Approach of the Impulse Noise Empirical Distributions in Digital Loops

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Abstract: This paper presents empirical distributions, measurements technique, statistics instruments, and results for impulse noise in digital communications loops. External sources, statistical properties, and harmful effects of the impulse noise on the digital loops are introduced. Baseband and wideband noise measurements are accomplished in order to plot the statistical profile of the impulse noise length. An estimate of the impulse autocorrelation function (ACF) is used to produce the power spectral density (PSD). Empirical distributions of impulse noise length lead to estimates of ACF parameters. A single long length impulse noise model is developed to enquire the prejudice on the data traffic in digital loops.

Key-Words: digital loop, impulse noise, noise statistics, estimates

1 Introduction
Digital loops are requested to transport impressive traffic volume at high rates for the benefit of an increasing number of electronic services consumers. Both users and e-services providers are claiming reliable networks performing easy access, interoperability, availability of wherever, whenever quality, scalability, and security [1]. Inherently the broadband traffic is exposed to a diversity of electronic noise sources including fundamental processes and/or external equipments. High power equipments or atmospheric electric storms could cause major disturbances within digital lines by delivering electromagnetic fluctuations known as impulse noise. The impulse noise is able to impaire the digital streams either at bit level or at symbol level according to the modulation/code techniques and frame supported by the lines.

The nature of the impulse noise is statistics-wise really sophisticated. Time domain analytical and statistical impulse noise models were proposed [2], [3], [4], [5], [6], [7]. Also, frequency domain models were developed [8], [9].

A vast field of experiments has been explored to describe the impulse noise properties, such as amplitude, length, interarrival times, and spectrum. However, practical investigations have been demonstrating the nocivity the impulse noise is conveying to jeopardize the traffic in broadband links.

In this paper an autocorrelation function-based spectral model of the impulse noise is presented. The model is relying on far-end digital line measurements.

2 Methods
2.1 Impulse Noise Definition
Impulse noise consists of random energy spikes containing random amplitude and frequency spectra. By its nature, the impulse noise is non-stationary even if the fluctuations originate in deterministic electromagnetic fields (as power and frequency are proven from disturbing equipment nearby the line).

Fig. 1 represents an individual impulse noise (event) which differentiates from the gaussian noise.
Two threshold voltages, $V_{th1}$ and $V_{th2}$ are defining the length $L$ of the event. Usually $V_{th1} = -V_{th2}$. The impulse noise exists if the positive and negative trips of the amplitude, $u$, exceed the threshold voltages, i.e. $|u| \geq V_{th}$. The amplitude distribution in fig.1 obeys a complex exponential probability distribution function (pdf):

$$f(u) = \frac{1}{240u_0} \exp \left(-\frac{u}{u_0}^{1/5}\right)$$

where $u_0 > 0$ is a line location-dependent scaling factor.

The digital line was exposed to the aggression of an electromagnetic field generated by an electric motor.

We have assumed the impulse noise is grouping in clusters for an effective disturbance of the line. A cluster is able to deliver much more energy than an individual event so as threatening the traffic line is more energetic. Also, a clustering process allows impulse noise having been manipulated as a stationary single pulse.

### 2.3 Experimental Results

Bargraphs in fig.2 to fig.5 shows empiric distributions of the event length in each test duration bin.

Bars in fig.1 resulted from 200 – 12000 Hz baseband measurements. One could expect the longer the test the longer the impulse length acquired from line. However, the total length is resulting from the random distribution of the aggression force so as we could expect a random length occurs regardless the acquisition time.

Fig.2 presents impulse total length within voice band at the test smallest threshold voltage of -40 dBm. Apparently the impulse noise is threatening longer the digital loop as the test time increases.
Fig. 4 depicts impulse length via a 300 – 500 Hz filter. Fig. 5 bargraphs the impulse length with a flat wideband filter. It seems that high frequency components contribute to group the short pulses in longer clusters so as the total length is longer. Filtering the high frequencies leaves the impulse with most of the energy but clustering suffers from producing longer length.

3 Results

The spectral approach of the impulse noise is using the autocorrelation function (ACF) of a events cluster. The length of a cluster results from the empirical distribution of the length $L$. As the cluster has been supposed a stationary single pulse, an estimate $\hat{R}$of the ACF is [8]:

$$
\hat{R}(t) = \sum_{i=1}^{n} e^{-d t} \cos(2\pi f_i t)
$$

(2)

where $f_i$, $d_i$ are the frequency and the decay factor, irrespective, of the $i^{th}$ component out of $n$.

The number $n$ cosine-modulated exponentials is given by the required precision of the estimator.

An estimation of the frequencies can be obtained from the zeroes rate of $\hat{R}$. Experimental data shows a line location dependancy of the frequencies empirical distribution.

We have found out a similar pdf with the finding in [8] fits the experiments:

$$
g(f) = \sum_{i=1}^{\infty} \frac{p_i}{\sqrt{2\pi}\sigma_i} \exp\left(-\frac{(f - m_i)^2}{2\sigma_i^2}\right)
$$

(3)

where $m_i$ and $\sigma_i$ are the mean and standard deviation, and $p_i$ is the weigh of each Gaussian component.

A diagram of the zero crossing rate generated from (3) is shown in fig.6.
The estimate of ACF (2) has been designed with three cosine-modulated exponentials according to $f$ and $d$ estimations from the empirical distribution.

Fig. 7 shows autocorrelation estimate $\hat{R}$ with $n = 3$ low frequency components.

Fig. 8 presents autocorrelation estimate with three high frequency components. Impulse length is significantly sensitive to the decay factors $d$ in exponentials: the smaller the $d$ the higher the amplitude of the autocorrelation function estimate.

Power spectral density (PSD) is the Fourier transform of the autocorrelation function

$$|S(\omega)|^2 = \mathcal{F}\{R(t)\}$$  \hspace{1cm} (4)

Therefore, the spectral content of the impulse noise is obtained from the fast Fourier transform (fft) of the autocorrelation estimate. Fig. 9 shows the PSD of an impulse noise whose autocorrelation estimate is presented in the upper window of the diagram.
4 Conclusions

The spectral description of an impulse noise relays on the estimate of the autocorrelation function of the impulse.

The ACF estimate has been derived from the cumulative lengths of the events measured in digital traffic loop. The ACF estimate parameters are location dependent, hence the impulse noise-wise statistical profile of a loop is almost unique.

Baseband and wideband data have demonstrated a statistical clustering process of the impulse noise. The impulse noise clustering allows single pulse signal processing techniques and unidimensional Gaussian statistics to employ.

Minutes acquiring time have filled up the time bins with impulse data, rather than the customary 400 µs or 16 ms acquisition window in order to have the clustering process developed. Accordingly, long length single pulse model have the overall measurement process simplified.

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