An Algorithm to Simulate Impulsive Noise

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Abstract: **In this paper we describe a practical algorithm to generate impulsive noise according to how it appears in the baseband after demodulation in a communication process. This algorithm offers flexibility to vary the parameters that characterize impulsive noise by taking into account former researcher's works. According to it, we also developed a program which generates impulsive noise sequences that can be added to baseband signals before being transmitted in order to test immunity of real or simulated communication systems against impulsive noise. When the received signal is demodulated, the practical results are the same as if the impulsive noise had been added from the communication channel.**

1. INTRODUCTION

We call impulsive noise to pulses of high amplitude that unexpectedly appear in a communication channel. Impulsive noise can be classified according to what it comes from as:

- Natural Noise: Non man-made noise mainly produced by lightning discharges.
- Man-made noise: That can also be separated into:
  1) Intentionally radiated noise: Interference from communications intended for other receivers.
  2) Non-intentionally radiated noise: Due to machine emissions related to electrical discharges:
     a) Transients in transformers and induction motors.
     b) Sparks produced by the manifolds and brushes of universal and DC electric motors.
     c) Ignition noise from petrol engines: cars, motorcycles, and other machines.
     d) Switching transients.
     e) Arc welders, etc.

We could model impulsive noise as a train of pulses (1), where c_i stands for the complex amplitude and phase, p_i for shape, and t_i for arrival of the pulse in the time domain. The combined effect of pulse amplitude, pulse arrival time, and receiver bandwidth may reduce the performance of a digital communication system to a greater or lesser extent, even if signal to noise ratio is high.

$$n(t) = \sum_i c_i \cdot p_i \left(t - t_i \right) \tag{1}$$

Interest in impulsive noise grew with the development of digital communication systems: a very short duration event could have catastrophic consequences in the digital signal reception, specially in frequencies up to the UHF band. A recent ambit of interest for the appearance of such noise events is focused in the radio frequency identification (RFID) systems: they are proposed to be used in different applications: food and other goods traceability, clothes shopping, staff attendance control, and so on. An impulsive noise event could reduce the readability of different RFID tags, which could lead to important problems even economical damages: i.e. we can suppose a RFID system controlling the storage of wine bottles. The bottles are individually labeled with RFID tags, and they cross under a reader arc at the entrance of the warehouse. If the effect of an impulsive noise event is to avoid the reading of a number of tags, the bottles that pass through the arc during these events would not be registered as stored. So, they do not exist at warehouse managers registers. A correct characterization of this possible effect would allow to define some correction measures during the installation of a RFID based system.

If we want to research the effect of impulsive noise on a radio receiver system, it makes it necessary to have a source of radio frequency (RF) impulsive noise, either simulated or real. We can obtain impulsive noise from electric transients like switches, arc welders, or lightning. Nevertheless, using these kinds of sources we cannot produce impulsive noise in a controlled and repeatable way. In some situations it is necessary to have an impulsive noise generator according to some known parameters in order to eventually use it as a source in a vector signal generator or a simulation program. In this way, impulsive noise with the given statistical characteristics could be generated once and again, allowing comparison of different systems under the same repeatable conditions.

That is what we present in this paper, an algorithm and the corresponding program to generate impulsive noise. This noise generator software is intended to be a practical tool, easy to deal with but at the same time, based on solid principles taken from previous researchers [1]-[14].

In order to generate impulsive noise, some other models have been published before [15]-[17], but based on different principles than the ones used here. Impulsive noise tests could also be made using other kinds of generators. For example, we might use prototype DSP generators [18], but we would need to develop, adapt, and implement them. We could also use commercial devices [19], but that would require purchasing specific hardware which is not useful for general purposes.

This paper is organized as follows: In section 2 we explain impulsive noise generation, how the separation between pulses is decided, as well as their amplitude, their phase, the bandwidth and the added Gaussian noise. In section 3 we settle the parameters that will be used to generate the impulsive noise and we explain the algorithm. And in section 4 we present a program made according to what is claimed in the former sections.

2. IMPULSIVE NOISE GENERATION

2.1 Pulse separations

It is commonly accepted that the arrival of pulses follows a Poisson process or a combination of several Poisson processes [4]-[10]. That is why we use an exponential distribution in order to settle the interval between pulses. The density function of an exponential distribution is:

$$t \rightarrow f(t) = \frac{1}{\beta} \cdot e^{-\frac{1}{\beta} \cdot t} \tag{2}$$

where t is the time between consecutive pulses and β is the average pulse separation. Therefore, in order to calculate the number of separation samples for each pulse we will generate a random number, according to an exponential distribution of parameter β samples, and we will round the result to the nearest integer. A similar result could be obtained using a geometric distribution instead.

2.2 Pulse amplitudes

We will consider the pulse amplitudes to follow a log-normal distribution [10]-[12]. According to the property which states that the logarithm of a log-normal variable is a normal variable, we will express the impulsive noise power in dBμV, and therefore in order to generate the amplitude we will generate a normal variable X of mean = A dBμV and standard deviation = B dB. Then, we will convert X [dBμV] to its equivalent amplitude x[μV], which is a log-normal variable, using the formula:

$$x[\mu V] = 10^{\left(\frac{X[dB\mu V]}{20}\right)} \tag{3}$$

2.3 Pulse phases

The in-phase (I) and quadrature (Q) components of impulsive noise are uncorrelated but dependent [13]-[14]. According to this statement, every time we want to generate the phase for an impulsive noise pulse we will generate a random number θ from a uniform distribution between the bounds 0 and 2π. Remembering that x is the amplitude in μV:

$$I = x \cdot \cos(\theta) \qquad Q = x \cdot \sin(\theta) \tag{4}$$

2.4 Bandwidth

Impulsive noise is a very wide band phenomenon, typically from few kHz to many GHz. This makes the detected bandwidth be constrained by the system bandwidth being investigated [1]. That is why our generator does not shape the impulsive noise. Every noise pulse consists of a single sample and it will be the task for the signal generator filter or the simulation program that uses the impulsive sequence to filter the pulses and give them their corresponding shape.

2.5 Gaussian noise

In a practical environment, not all the samples will contain impulsive noise but they all will certainly have Gaussian noise of thermal nature. This noise will be generated using a normal distribution of mean = 0 and standard deviation = σ μV. We will express the noise power $N_{thermal}$ in dBμV, therefore:

$$\sigma[\mu V] = 10^{\left(\frac{N_{thermal}[dB\mu V]}{20}\right)} \tag{5}$$

3. PARAMETERS AND ALGORITHM

The parameters necessary to generate the impulsive noise are the following:

- $N_{thermal}$: Gaussian noise power in dBμV, as in 2.5
- β: Average number of samples between two consecutive pulses, as in 2.1. For example, β=1000 means that we can expect one pulse out of 1000 samples, on average.
- A: Mean of the pulse amplitudes in dBμV, as in 2.2.
- B: Standard deviation of the pulse amplitudes in dB, as in 2.2.

• f: Sampling frequency, in samples/s.
• T: Total generation time, in s.

Let it be L = f T the total amount of samples, the algorithm shown in Fig.1 to generate the sequence of amplitudes would be as follows: We first generate thermal noise for the L samples using a normal variable and the parameter $N_{thermal}$. Then we start generating β exponential values rounding to the nearest integer to settle the position of the next noise pulse till we run out of the total L samples. For the samples at these positions we proceed as follows: We generate a random number from a normal distribution of mean = A and standard deviation = B, then we convert it to the amplitude in μV using equation (3), and then we add the result to that sample.

To determine the phase, we generate a random number from a uniform distribution between the bounds 0 and 2π and proceed as in 2.3.

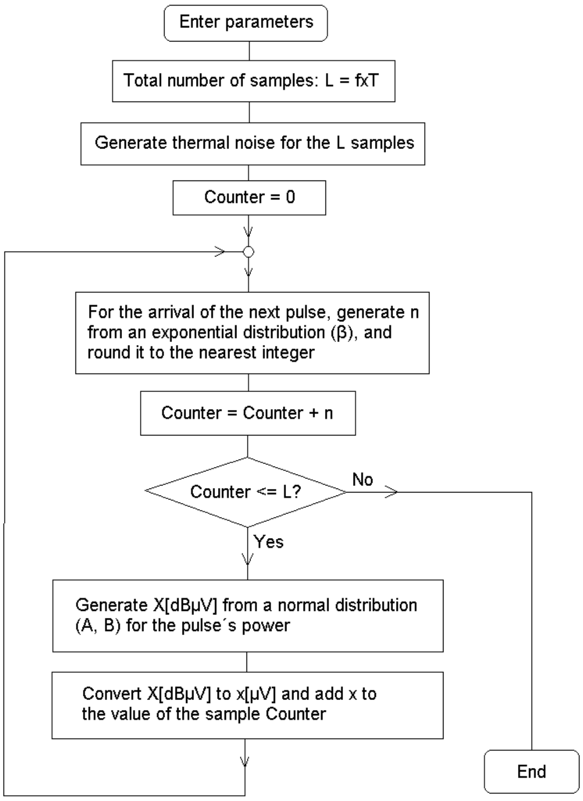

Figure 1 - Flow diagram to generate the sequence of impulsive noise pulse amplitudes

4. THE PROGRAM

As an implementation for the algorithm, a Windows C++ program called ImpNoiseGen has been made for generating impulsive noise, as well as plotting and saving it in order to eventually process the data with simulation programs or using them as a source for real transmitters (this program can be freely downloaded at [20]). The documentation for the program is embedded in it (every time we open a window it has its own help tag). In Fig.2 we show the screen when a new generation process is initiated, it displays the same adjustable parameters as described in the previous section. With the same parameters of Fig.2 we obtained a sequence like the one which is plotted in Fig.3, with the X axis labeled in seconds. In this window, we can see 35 pulses in 30000 samples. If we want, we can generate a text file with two tab delimited columns of numbers: The first column is for the in-phase component, and the second one is for the quadrature component of the sample. This is a normalized format suitable for most vector signal generators; also note that the text file our program generates can be directly converted to an array using Matlab's function "dlmread", therefore it is possible to adapt the data to any desired format, or to simply make computer simulations. When we add the impulsive noise generated sequence to a baseband signal, the practical result is the same as if the impulsive noise had been added from the communication channel.

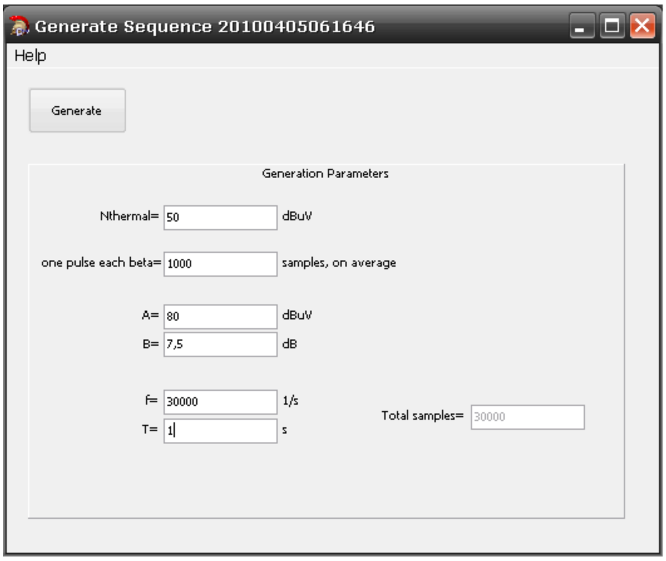

Figure 2 - Window to select parameters to generate the impulsive noise sequence

5. CONCLUSION

An algorithm and a program to generate radio frequency impulsive noise have been presented. With few parameters, impulsive noise sequences are generated according to their statistic characteristics, summarized from the work of many researchers. The sequences can be used as a source for a signal generator or a simulation program.

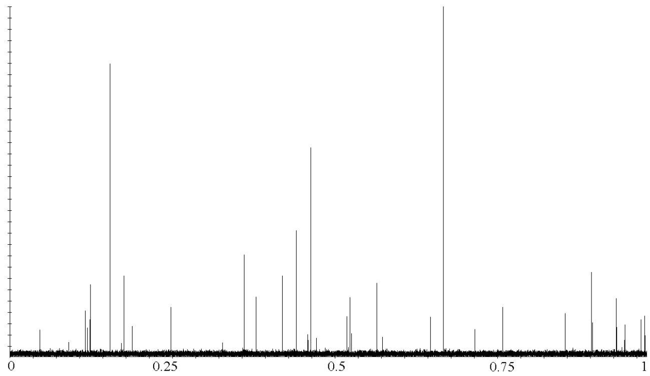

Figure 3 - Window for the impulsive noise sequence plot. X axis labeled in seconds, 30000 samples, 1 s. Parameters: $N_{thermal}$=50dBuV, β=1000, A=80dBuV, B=7.5dB

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