Impulsive Noise Measurements and Characterization in a UHF Digital TV Channel

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Abstract—This paper presents the results of a study covering measurement and characterization of the wide-band impulsive noise present in a digital TV radio channel. Measurements were conducted at a frequency of 762 MHz in different outdoor and indoor environments using vertical and horizontal polarization. The measurement system was built on commercial equipment only. The calibration process, which is an important stage of this kind of measurements, is described. To analyze the measurements the impulsive noise has been modeled as a pulse train where the pulse amplitude, pulse duration and elapsed time between pulses are considered random variables. It has been found that the pulse duration and elapsed time between pulses is not dependent on the antenna polarization while the pulse amplitude is, especially in the case of the noise generated by a fluorescent lamp. It has also been found that the pulse duration of the noise measured in the outdoor environments presents some clustering features and is correlated with the pulse amplitudes. This correlation may be caused by a RF noise bandwidth that is larger than the bandwidth of the measurement system. The noise in busy streets presents larger pulse durations, larger amplitude, and shorter elapsed time between pulses that the noise measured in a pedestrian area. Several statistical tests have been done to find the distribution function that best fits these random variables. Power Rayleigh, lognormal, exponential, Poisson, and Gamma distributions have been tested. According to the assessment carried out, none of the distribution functions is adequate to model the pulse amplitudes or the elapsed time between pulses, while the pulse duration seems to be Gamma distributed.

Index Terms—Digital TV, electromagnetic radiative interference, impulse noise, noise measurement, UHF measurements.

I. INTRODUCTION

A radio communication system may experiment several kinds of noise. In most of the cases, e.g. thermal, atmospheric, or galactic noise, it can be represented by a Gaussian model. However, man-made noise that appears in urban environments created by the electrical self-starter of cars, power lines, heavy current switches, arc welders, fluorescent lights, etc., cannot be assumed to be Gaussian. As it has a shot nature, it has to be represented by an impulsive model.

Gaussian and impulsive noise models present some differences. The Gaussian model defines a Gaussian probability density function and a constant power spectral density. The power spectral density of the Gaussian noise is affected by linear filtering, while its probability density function is not. Therefore, after filtering, both in-phase and quadrature components are still independent Gaussian noises. Gaussian noise degrades slowly the objective quality of a digital communication system as its power level relative to the signal level increases. The main parameter of the Gaussian model is the noise power.

Conversely, impulsive noise is modeled as a random train [1] of pulses with a very wide-band power spectral density. The probability density function of the impulsive noise changes by the filtering process. The resulting in-phase and quadrature components are uncorrelated but dependent [2], [3]. This kind of noise may jam the system, even in case of high signal-to-noise ratios. Although its effect over the BER could be negligible, the subjective degradation of the signal may be important.

Although the interest on characterizing impulsive noise sources is high, comparatively few authors have performed measurements on this topic [3]–[8]. Shepherd [4] and Maxam [5] have measured the automobile ignition noise in frequency bandwidths of a few kHz. An extensive measurement campaign at several frequencies (40, 100, 150, 200, 300, 450, and 900 MHz) over a bandwidth of 120 kHz in suburban and urban environments is described in [6] and [7]. More recently, Miyamoto et al. [3] have measured the noise radiated by a microwave oven at 2 GHz over a bandwidth of 300 kHz. These measurements have been taken over narrow bandwidths, however, some measurements over wide bandwidths of 40 MHz can also be found in the literature [8].

The impulsive noise may be modeled by a train of pulses characterized by three random variables: the pulse amplitude, the pulse duration and the elapsed time between pulses. Most of the models assume some statistical distribution for the pulse duration and the elapsed time between pulses and concentrate on the analysis of the distribution of the pulse amplitude. Gilbert and Pollack [1] assume that all the pulses have the same shape and that the pulses occur at random times that follow a Poisson sequence. Some other authors [9]
consider that the elapsed time between pulses has a Gamma or a Poisson distribution. Even the more complex analytical model developed by Middleton [10]–[13] concentrates on the characterization of the amplitude of the pulses while the characterization of the pulse duration and elapsed time between pulses is reduced to a parameter called “overlap index.” This model has been shown adequate to predict narrow band receiver performance in an impulsive noise environment [2], [3], [11], [12], [14], [15]. However, in order to simulate the noise impact in wide-band system, Blackard et al. [8] have used an alternative model where the distribution functions for the three random variables are measured.

The characterization of the impulsive noise is important in the design of digital radio systems [2], [3], [11], [12], [15]–[21]. The objectives of the RACE dTTb project were, among others, to obtain a plugs-free reception of digital TV signal with equivalent quality to the one obtained with phase alteration line (PAL) system, in a large variety of different environments. To mitigate the effect of the impulsive noise additional electronics are required in the system. Interleavers with enough memory depth are needed to mitigate these effects. To guarantee an optimum electronic design, it is necessary to have previously measured and characterized the noise in the environments considered by identifying the relevant statistical parameters.

This paper presents measurements of impulsive noise in a digital TV radio channel in several environments. The selected channel has a central frequency of 762 MHz and a bandwidth of 10 MHz, which is similar to the bandwidth that will be used for digital TV. This channel, which corresponds roughly with UHF TV channel 57, was chosen because it was free from radioelectric emissions in the environments where measurements where taken. To characterize the measured impulsive noise, the wide-band model proposed by Blackard et al. [8] was used so the statistical distribution of three random variables, pulse amplitude, pulse duration, and elapsed time between pulses have been obtained.

II. MEASUREMENT SYSTEM AND CALIBRATION

A. Measurement System

The block diagram of the measurement system is shown in Fig. 1. The radio signal is received through an antenna, amplified, and then fed to a spectrum analyzer used to select the channel where the measurement are taken and to demodulate and detect the signal. An oscilloscope and a computer are used for data recording and measurement control.

Two linearly polarized antennas were located vertical and horizontally to collect the vertical and horizontal polarized impulsive noise and thus to separately obtain the statistical parameters for both cases. One of the antennas was an adjustable dipole model 3121C-DB4 from the Electromechanic Company. The other antenna was a wide-band logperiodic antenna from Rohde & Schwarz with a gain of 8.5 dBi. The input impedance of both antennas is 50 Ω.

The antenna amplifier (from Televes, model T94) tuned for channel 57 reception was used to improve the dynamic range of the measurement system. This amplifier was modified so that it had a 17-MHz 3-dB bandwidth, as can be seen in the frequency response plotted in Fig. 2. The input and output impedances are 75 Ω.

The transmission line is made up of two cables from Manhattan Electrical Cable (M4221 RG214/U MIL-C-17D) with characteristic impedance of 50 Ω. The cable lengths are 5.5 m and 9.5 m imposing an attenuation of 1 dB and 2 dB, respectively. There is an impedance mismatch between the cables and the antenna amplifier. The effect of this mismatch on the pulse duration has been evaluated and it can be considered negligible when compared to the group delay of the antenna amplifier.

The Tektronic 2784 spectrum analyzer is used in the “time mode” as receiver because of its filtering, demodulation, and detection capabilities. The analyzer block diagram is also presented in Fig. 1. The detected signal is buffered into a Philips 3323 digital oscilloscope. 512 samples per scan are recorded and stored via an IEEE bus in the control computer.
Two different setups, designed as “setup A” and “setup B” were used for the measurements. The settings of the spectrum analyzer and the digital oscilloscope for both setups are specified on Table I.

In setup A, the IF filter bandwidth of the spectrum analyzer was 10 MHz and the oscilloscope time scale was 2-μs/division, so the time per scan was 20 μs. In this case, the sampling rate of 512 samples per scan corresponds to a sampling frequency of 25.6 MHz and a time resolution of 39 ns. The measurements taken with this setup were used to characterize the pulse amplitude and pulse duration because of the good time resolution. However, the elapsed time between pulses that could be measured is limited to the time per scan, 20 μs, which was considered small.

To increase the limit for the elapsed time between pulses setup B was used. The time scale was set to 20-μs/division so the time per scan increased to 200 μs. At the sampling rate of 512 samples per scan the sampling frequency is reduced to 2.56 MHz and the time resolution to 390 ns. To meet the Nyquist criterion and avoid aliasing in the sampling process the IF-filter bandwidth of the spectrum analyzer was reduced to 1 MHz. As this bandwidth may change the shape of the pulses, this setup was only used to measure the elapsed time between pulses.

The video trace of the signal on the oscilloscope display was shifted vertically, avoiding any saturation of the video signal at the lower and upper parts of the oscilloscope display. The oscilloscope trigger level was decided in each set of measurements just above the thermal noise level so that only the scans with impulsive noise were recorded. A low level would trigger the oscilloscope with high background noise peaks, while a high trigger level will truncate the statistical distribution of the impulsive noise amplitude, as the low impulsive noise peaks would be lost. A conservative point of
view was taken when setting the level in order to not truncate the statistics of the impulsive noise. However, on doing this, some records may have contained only thermal noise.

B. Calibration

The measurement system must be previously characterized to identify its transfer function. A power calibration was conducted to relate the recorded oscilloscope voltage levels to the received noise power at the input of the spectrum. A Marconi Instruments signal generator model 2040 was used as RF source of known power. Two power/voltage scales were calibrated, one for each setup, and plotted in Fig. 3.

The filtering process in the measurement system may affect the pulse shape changing the pulse duration. However, no calibration was conducted to relate the RF pulse duration at the input of the spectrum analyzer with the measured pulse duration in the video signal. A calibration of this kind would require an RF pulse generator, which was not available. The results presented in this paper for the pulse duration are accordingly valid as a limit to the real values. Because of the broadening effect of the IF filter on the noise pulses, the resulting pulse durations represent a worst-case limit, thus being useful in providing conservative performance estimations of communication systems.

III. Environment Description

Two outdoor environments where considered for the measurements. The first one, located at Castellana Avenue in Madrid, was considered a “noisy” place, while the second one is a “quiet” place located in the courtyard of the Azca commercial zone, also in Madrid. These two environments are placed around the Retevisión building, very close one to the other. Fig. 4 shows a photograph of the environment called noisy environment. The possible sources of noises, the cars, were spread all over the down street. Fig. 5 shows the quiet environment. It is a wide square surrounded by high office
buildings. Some air conditioning equipment as well as electric engines present in this environment may act as impulsive noise sources.

Some additional measurements were conducted in the laboratory using a fluorescent lamp, which was kept on a continuous on/off process. In this case, the noise source was placed at a fixed and known position.

IV. STATISTICAL MODEL

A. Mathematical Model

To identify the random variables that characterize the impulsive noise and to make the results useful for the system design, a mathematical description is needed. The impulsive noise \( n(t) \) can be represented [1] as the summation of pulses with random amplitudes \( a_i \), random duration \( u_i \), and random arrival time \( t_i \)

\[
n(t) = \sum_i a_i \prod_{j<i} (t - t_j).
\]

According to this model, three random variables have to be measured to identify the impulsive noise behavior: the amplitude of the pulses, the duration of the pulses, and the elapsed time between pulses.

B. Amount of Data to Be Collected

The amount of data needed to make the results significant had to be determined first. This depends on the statistics of the three variables to be measured that were not known a priori. To estimate the amount of data to be collected, results from a previous measurement campaign [8] were used. In that paper, the mean and the variance of the power of impulsive noise at 918 MHz are reported to be \( \mu = 1.234 \cdot 10^{-11} \) W and \( \sigma = 7.768 \cdot 10^{-13} \) W, respectively. Based on the data of [8], the confidence interval length relative to the mean value is
calculated and presented in Fig. 6 as a function of the number of points measured. The four curves correspond to confidence levels of 90%, 95%, 99%, and 99.9%, respectively. As could be expected, the confidence interval length decreases as the amount of data increases. If the number of measured points is larger than 500, a confidence interval length will be smaller than 2% of the mean value.

C. Measurement Processing

All the registers stored in the computer correspond to the video output of the digital oscilloscope. The first processing step is to convert the video output signal to power level at the input of the spectrum analyzer, using the calibration curves presented in Fig. 3. A sample measurement to determine the noise floor is presented in Fig. 7 and the resulting conversion to the input power is presented in Fig. 8.

As can be seen in Fig. 8, the impulsive noise in the register is mixed with background noise. The second step in the measurement processing is to set a decision level to extract the noise pulse from the background noise. This decision level is different from the trigger level fixed in the oscilloscope during the measurements. Now that the measurement has been taken, additional information can be used to calculate a more accurate decision level. The optimum decision level could be found if the statistical distributions for the background noise and the impulsive noise were known. Because this is not the case, the decision level can only be estimated using some information about the background noise. This background noise can be considered to be a Gaussian thermal noise, with zero mean and a variance determined by the power, which has been filtered by the measuring system. It was concluded [22] that the probability of a background noise peak being over $\mu + 4\sigma$ is less than $9 \times 10^{-4}$.

The background noise level was not the same for all noise registers, so a different $\mu + 4\sigma$ decision level was independently set for each register. The mean and variance of the background noise were estimated by the sample mean variance obtained.
from the measurements. An iterative algorithm was used to
determine the decision level by considering all sample values
as background noise lying below a first conservative decision
level. In this first iteration, all the samples are considered
background noise. With these samples, a new \( \mu + 4\sigma \) decision
level was calculated. The process was repeated until the
decision level converged. As it can be seen in the example
presented in Fig. 9 the decision value converged in a few
iterations.

Once the decision level is fixed, the pulse start and end
points are determined as the points where the measured
signal crosses the decision level with positive and negative
slope, respectively. The pulse duration is taken as the time
elapsed between the starting and the ending points. The
value is rounded because of the finite-time resolution of the
measurement system. The pulse amplitude is characterized
by the peak power the pulse reaches between the starting
and ending points. If more than one pulse is present in the
register, the elapsed time between pulses is measured as the
time between the starting points of both pulses. These data are
used in the subsequent statistical analysis of the three variables
considered in the study.

V. RESULTS

The results of the measurements are presented in this
section. For each of the environments and for each variable,
a histogram of the values measured is plotted. The sample
mean, sample variance and the confidence interval with a 99%
confidence level are given.

A. Measurements in the Noisy Environment

As described in Section III, this set of measurements was
taken in front of a busy street in Madrid. The antenna used
for the measurements—a half wavelength dipole—was placed
on the top of the department store “El Corte Inglés” that can
be seen Fig. 4. This linearly polarized antenna was placed
parallel to the building front, vertically or horizontally, to
collect the impulsive noise for each polarization. In order
to avoid possible frequency-selective fading effects in the
received waveforms at a particular location, the results from
three measurement sets have been averaged.

Up to 687 noise registers were taken using system setup
A and vertical polarization (VP), while 722 were taken on
horizontal polarization (HP). This is larger than the minimum
value of 500 samples specified in Section IV-B. These mea-
surements were used, as said in Section II-A, to study the pulse
amplitude and pulse duration statistics. Using setup B, 372 and
370 registers with two or more noise pulses were measured on
VP and HP, respectively. These measurements were used to
study the elapsed time between pulses.

The maximum measured value for the variable pulse du-
ration is 1.5 \( \mu s \) VP and 2.3 \( \mu s \) on HP. The minimum value
measured is 39 ns because of the system resolution. Fig. 10
shows the histogram with the results for this variable for
both VP and HP. The histogram bar width is 39 ns, which
corresponds to the time resolution of the measurement system.
Despite measurements on each polarization where not taken simultaneously, the results are very similar. As can be seen in the plot, the results seem to be grouped into three clusters. For each of the cluster there is an initial more probable value of the pulse duration at 0.05, 0.25, and 0.5 μs, respectively. From the initial value, the probability reduces as the pulse duration increases. The initial probability also decreases from cluster to cluster as the duration increases.

The results for the pulse amplitude are presented in Fig. 11, in a histogram with a resolution of 1 μW. The probability of pulse amplitude values decreases as the pulse amplitude value increases. The maximum peak power reached is 39 μW on VP and 133 μW on HP. The mean peak power of the pulses is also larger in HP than in VP.

Pulse amplitude and pulse duration are not independent variables (as can be seen in Fig. 12) where the pulse duration versus pulse amplitude is plotted for each of the measurements taken in HP. The cross-correlation coefficient between the variables plotted in Fig. 12 is 0.52. This suggests that the bandwidth of the RF impulsive noise is larger than the bandwidth of the measurement system.

The histogram for the third variable considered in this analysis, the elapsed time between pulses is plotted in Fig. 13. The histogram shows a decreasing probability as the elapsed time increases. Similar results are found on each polarization.

A Kolmogorov–Smirnov test [23] was performed to compare several distribution functions to the empirical distribution functions for the three variables considered. Rayleigh, Lognormal, Poisson, Exponential, and Gamma distribution functions were considered. When analyzing the pulse duration statistics, it was taken into account that the minimum measured pulse duration is limited by the sampling rate to 49 ns. The hypothesis that the distribution of the pulse duration follows a Gamma distribution can not be rejected according to the test. Fig. 14 compares the measured distribution for pulse duration...
Fig. 15 shows the histograms for the variable pulse duration. The histogram bar width has been made equal to the time resolution of the measurement system. The mean pulse duration is similar on both polarizations. There is also a clustering effect, similar to the one observed in the results for the noisy environment. However, the mean pulse duration is shorter in this environment than in the noisy environment.

The results for the pulse amplitude are presented in Fig. 16. The histogram resolution is 0.1 W. The probable number of pulses decreases as the pulse amplitude value increases. In this environment, the mean pulse peak power is similar on VP and HP and it is smaller than in the noisy environment.

The values of the pulse duration and pulse amplitude are correlated (as can be seen in Fig. 17) where the pulse duration versus pulse amplitude is plotted for each of the measurements taken in horizontal polarization. A cross-correlation coefficient of 0.6 was found between the variables plotted in this figure. The correlation between the variables is probably due to the limited bandwidth of the measurement system, as explained in Section V-A.

Kolmogorov–Smirnov tests were also performed on the data from this environment. Again, the Gamma distribution is the one that best represents the empirical distributions. Fig. 19 shows how this distribution fits the measured distribution of pulse duration in vertical and horizontal polarizations. However, according to the test, the hypothesis that the measurements follow a Gamma distribution should be rejected for all the variables considered (pulse duration, pulse amplitude, or elapsed time between pulses).
Fig. 18. Elapsed time between pulses for the quiet environment. (a) Vertical polarization. (b) Horizontal polarization.

Fig. 19. Measured distribution for "pulse duration" and best fit gamma distribution. (a) Vertical polarization. (b) Horizontal polarization.

Fig. 20. Pulse duration of the noise generated by the fluorescent lamp. (a) Vertical polarization. (b) Horizontal polarization.
C. Measurements of the Noise Generated by Switching a Fluorescent Lamp

Additional measurements of specific impulsive noise sources, such as a fluorescent lamp, were also performed. In this experiment, the fluorescent lamp, which was placed horizontally on the ceiling of the laboratory, was continuously switched on and off. A logperiodic antenna pointing at the source and placed vertically or horizontally four meters away from it, was used to take the measurements. In this way, just the noise generated by the fluorescent lamp was recorded. Up to 609 and 616 noise registers were recorded in VP and HP and used in the study of the pulse amplitude and pulse duration.

The histogram of the pulse duration is plotted in Fig. 20 using a 39-ns time resolution. This histogram presents some clustering but it is different from the one observed in the outdoor environments. The probability has not a monotonous behavior with respect to pulse duration as it had in the outdoor measurements.

The pulse-amplitude histogram is plotted with a resolution of 5 µW in Fig. 21. Peak pulses with an amplitude lower than 5 µW are the most probable, with a probability value larger than 80%. Mean pulse-peak amplitude is much larger in horizontal than in vertical polarization, as could be expected when the fluorescent lamp is placed horizontally. As the directional antenna was pointing at the source and was placed close to it, the measured pulse amplitudes in this case are high compared to the outdoor values.

According to the Kolmogorov–Smirnov test, none of the statistical distributions of the variables measured can be represented by the theoretical distribution functions considered. However, the Gamma distribution is close to the empirical distribution, as can be seen in Fig. 22, where the measured distributions of pulse duration in vertical and horizontal polarizations are plotted together with the Gamma distribution.
VI. SUMMARY AND CONCLUSIONS

Impulsive noise has been measured and characterized in a 10-MHz wide-band UHF channel. These results can be useful in the design of any communication system with a similar or smaller bandwidth such as a digital TV terrestrial broadcasting system or UMTS mobile communications systems.

The values of the three statistical variables that characterize the noise depend on the environment and sometimes, although not strongly, on the polarization of the antenna. In the noisy environment, the pulse duration and the elapsed time between pulses are similar on both polarizations, while the pulse amplitude is slightly higher in horizontal polarization. In the quite environment, the pulse duration and elapsed time between pulses are also similar for both polarizations, while the pulse amplitude is slightly smaller in horizontal polarization. The noise pulses in the quite environment have shorter duration, smaller amplitude and a larger elapsed time between pulses than the results in the noisy environment. For these environments, the pulse amplitude and the pulse duration are correlated. This correlation suggests that the RF impulsive noise has a larger bandwidth than the bandwidth of the measurement system.

It is on the amplitude of the noise generated by the fluorescent lamp where strong polarization dependence has been found. As could be expected, for a fluorescent lamp placed horizontally, the noise peak amplitude is larger on horizontal polarization.

The pulse duration statistics present a similar clustering behavior on both polarizations. This effect could be due to the receive filter that may produce some ringing in the measured noise.

Results of a statistical test performed to check how the theoretical distribution functions fit to the measurement have been also presented. The Gamma distribution approximates the measured noise distribution. However, it is not still good enough, according to Kolmogorov–Smirnov test.

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Antonio Mansilla, photograph and biography not available at the time of publication.