

# Comparative Analysis of the Impact of CATV Return Path Ingress and Impulse Noises in a 16-QAM Transmission System

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**Abstract:** For the first time, we report the link between, on the one hand, return path ingress and impulse noises measurements and, on the other hand, their relative impact on a 16-QAM transmission. We show that both ingress and impulse noise measurements must be realised in parallel in order to characterise return path noise performance. Diagrams (spectrograms) which exploit both ingress and impulse noises measurements are presented and could help cable operators to select good frequency bands in terms of both ingress and impulse noises.

## 1. Introduction

For many years, classical broadcast tree and branch CATV (Community Antenna TeleVision) networks are evolving towards a bidirectional HFC (Hybrid Fibre Coax) topology able to support voice, data, and video.... Nowadays, HFC CATV networks are commonly used to provide interactive services such as Internet and are direct competitors of xDSL transmissions in countries with high penetration rate (Benelux, USA, ...).

To offer highly reliable communications, upstream noise performance are an important issue. They are worse than downstream noise performance due to two main factors. First, return path is subject to the noise funnelling phenomenon: it is the summation of all unwanted noises (gaussian noise, ingress noise and impulse noise) coming from both the subscribers and the cable plant in the return transmission system. Gaussian noise is identified as filtered white noise coming from equipments, while ingress and impulse noises refer to signals picked up by the network or carried by the network from subscribers (home-made noises). Second, these latter noises are more predominant at lower frequencies (i.e. broadcast AM). So, the frequency band allocated for upstream transmission (5 MHz - 65 MHz) is more affected than the downstream band.

CENELEC [1] defines ingress noise as *"noise caused by electromagnetic interference into cable networks. Its power decreases with increasing frequency. It is permanently present but slowly varying in its intensity as a function of time"*, i.e. short wave broadcasts, amateur radio, citizen bands, ... . Ingress noise occurs when shielding is inadequate or has been broken for some reason. Over-the-air RF signals enter the system and interfere with reverse signals. CENELEC defines also multiple interference as *"interfering signal which consists of more than 2 signals which originate from more than 2 sources"* and specifies that *"on return path, the multiple interference consists of ingress noise and intermodulation distortion products"*. For measurement purpose, it is

impossible to separate the two origins. Therefore, in practice, “ingress noise” term is used instead of “multiple interference”.

Likewise [1], impulse noise is defined as a *“noise caused by electromagnetic interference into cable networks characterised by pulses with a duration typically under 10  $\mu$ s”*. Common sources are generally man-made (vehicle ignition, neon signs, power line switching transients, electric motors, electronic switches, household appliances, ...) but also natural (static from lightning, galactic noise, ...).

Therefore, both ingress noise and impulse noise present in a HFC return path must be monitored. It is also important to determine their proportion as well as to qualify their relative impact on an upstream transmission.

For that purpose, we have performed a field trial on a bidirectional HFC node. This node was technically ready to transmit upstream internet signals but the service was not yet offered to CATV subscribers. Two setups have been developed to separately measure ingress and impulse noises present in the return path. In parallel, a third measurement setup has been deployed to perform BER (Bit Error Rate) tests on a 16-QAM signal affected by upstream noises. Based on these complementary setups, we report, for the first time to the best of our knowledge, the link between the return path ingress and impulse noises affecting the transmission as well as their relative impact on a 16-QAM transmission system.

This paper is organised as follow: first, we explain the field trial configuration and the measurement setups we used. Then, we highlight the way we processed data we gathered during the field trial in order to characterise impairments present on the return path as well as their impact on a 16-QAM test transmission. Next, we give the main results we found and finally we conclude this study.

## **2. Description of the measurement site and setups**

Measurements were performed on a fully installed HFC network in Mettet area (Phillipeville, Belgium) owned by INATEL and operated by NETMANAGEMENT WALLONIE (member of ELECTRABEL). During the tests on the return path, all forward channels were in operation but no internet signals were coming from subscribers. So, the upstream signal received at the ONU (Optical Network Unit) consisted only of all unwanted impairments.

Setups have been running during two weeks (from the 3<sup>rd</sup> to the 17<sup>th</sup> of November 2003) and were located at the digital headend of Vodecée (Belgium) in which different ONU (and in particular the ONU of Mettet area) are connected by 2 optical links.

Because return path was temporary not in service, both the optical receiver output port and the receiver test point were used at the headend location as input signals for our measurements setups. Figure 1 shows the deployed setups. Test point signal was directly injected into the ingress measurement setup. Receiver output signal was divided into two branches in order to feed the impulse noise measurement and the QAM transmission setups. All measurements setups, running in parallel for the analysis purpose, are described below.

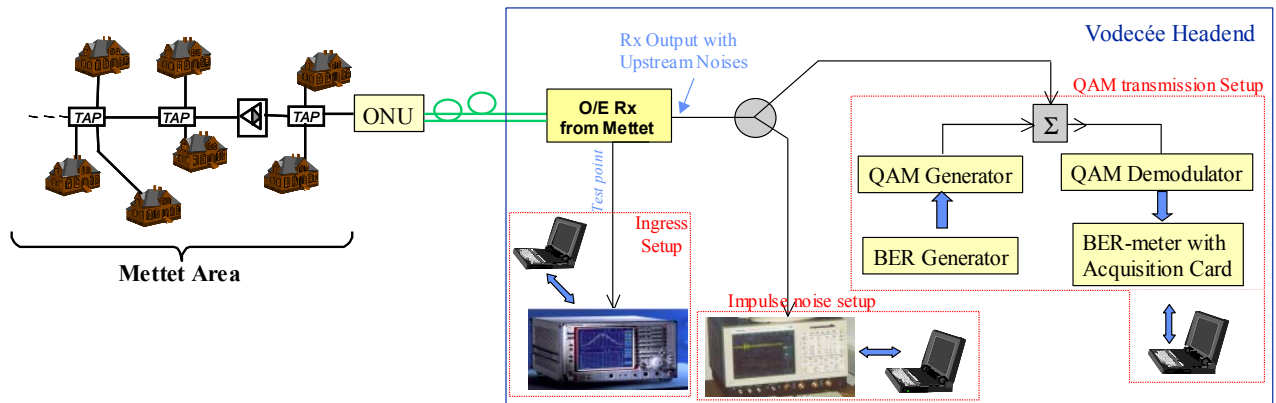


Figure 1 – Deployed setup: ingress noise measurement is realised with a spectrum analyser, impulse noise measurement with an oscilloscope and QAM transmission performance measurement with a QAM-modulator/demodulator combined with a BER-meter

The ingress measurement setup [2] is based on a Rohde & Schwarz spectrum analyser having a GPIB interface connected to a PC. Data were captured following reference [1], which stipulates that during almost 24 hours, the return path spectrum must be stored with an alternation of ‘slow’ traces (resolution bandwidth = 3 kHz; video bandwidth = 100 Hz; every hour of the day) and of ‘rapid’ traces (resolution bandwidth = 30 kHz; video bandwidth = 10 kHz; every 10 seconds). In the frame of our tests, ‘rapid’ traces were captured every second and ‘slow’ traces were acquired every hour with a 3 kHz video bandwidth. The granularity of the frequency scale between 5 MHz to 65 MHz was 120 kHz (500 points).

The impulse noise measurement setup is based on a TDS Tektronix oscilloscope with a high sampling rate (10 Giga Samples/s) connected to a PC through GPIB interface. During long-lasting periods of time, the oscilloscope records all impulses of noise if the input signal exceeds the defined trigger threshold. The latter must be adequately chosen according to the impulse noise level: it must be high enough to avoid measurement of ingress noise present in the link but in the same time low enough to capture the weakest impulses. All other parameters (time base, sampling rate, trigger mode,...) must also be carefully selected to optimise the measurement process. Indeed, it is important to reduce the latency between 2 records. Also, the impulse noise shape must be reproduced exactly (high sampling rate) but the amount of stored data must remain moderate to respect the oscilloscope internal data storage capacity. An original Labview program interface has been developed to ensure the oscilloscope automatic control and to perform data transfers to the PC.

QAM transmission performance measurements were performed with the FSQ/EFA Rohde & Schwarz test QAM-Modulator/Demodulator. Different QAM signals can be generated with various carrier frequency, symbol rate, QAM order or roll-off factor. The generated QAM signal has been directly impaired by the noise signal coming from the return path. A BER-meter analyses the baseband signal obtained at the output of the QAM demodulator. We have completed the BER analyser by an original external acquisition card (developed in collaboration with the ISIPH technical engineer school of Charleroi, Belgium) able to locate errors versus time at the bit level. This complementary tool is very interesting for studying the real impulse noise impact on a QAM transmission and, in particular, can detect and analyse the burstiness of the impulse noise process.

### 3. Data Handling

We have developed for each setup a software program to perform post-processing and to automatically generate graphs.

In the case of ingress noise, a software program in MATLAB environment has been developed to perform analyses based on spectrum trace captures [2]. Two interesting analyses exploited in the following results are the representation of spectrograms and the temporal representation of ingress noise level evolution. Spectrograms representation consists of a 2 dimensional graph (x-axis = time and y-axis = frequency) presenting the noise level in a desired spectral bandwidth as a colour code (see figure 10 as an example). This way of presenting results gives a straight idea of the most perturbed frequencies of the return path and/or when the highest peak occurred. In the case of the second representation, the software integrates all noises present in a specified bandwidth (the QAM bandwidth in particular) allowing to plot the total noise level in the specified bandwidth during a chosen elapsed time (figures 4 and 5).

Another MATLAB software has been developed to analyse gathered impulses of noise. Two software tools allow to process the detected pulses. First, it is possible to fix a software trigger threshold higher than the oscilloscope threshold: it allows to select only pulses above this software threshold. A second option is the spectral filtering of the input signal. Indeed, the oscilloscope detects the impulse content between 5 MHz and 65 MHz (the return path frequency spectrum band). Helped by a FFT/IFFT process, the software processing can filter all detected pulses. Based on processed data or not, two interesting analyses can be made (for a given trigger threshold): the evolution of the number of detected impulses versus time (figures 7 and 8) and the spectrogram of impulse noise (figure 9). This second representation is a two-dimensional graph (x-axis = time and y-axis = frequency) presenting the number of pulses detected in a specified spectral bandwidth (the QAM bandwidth in particular) as a colour code.

A MATLAB software tool has also been developed to analyse the files of errors records. The evolution of the number of errors is plotted versus time (figures 2, 3a and 3b) as well as the relative position of the measured BER value as function of SNR (Signal to Noise Ratio) on the theoretical curve for gaussian noise only (figure 4).

### 4. Results

More than 18 000 files (corresponding to 40 Gbytes) have been collected during the field trial. In all this material, a long common time interval has been chosen in which both ingress and impulse noise measurements were available as well as 16-QAM BER test results. It corresponds to measurements realised from the 12<sup>th</sup> of November 2003 3 pm to 13<sup>th</sup> of November 2003 10 am. For the BER test, a 16-QAM signal at 30 MHz was directly perturbed by noise coming from the return path. QAM was characterised by a 4 Mbit/s bitrate (QAM bandwidth equals to 1 MHz) and by a 17 dBmV level. FEC (Forward Error Correction) was disabled to allow the observation of the real impact of the noises on the QAM transmission.

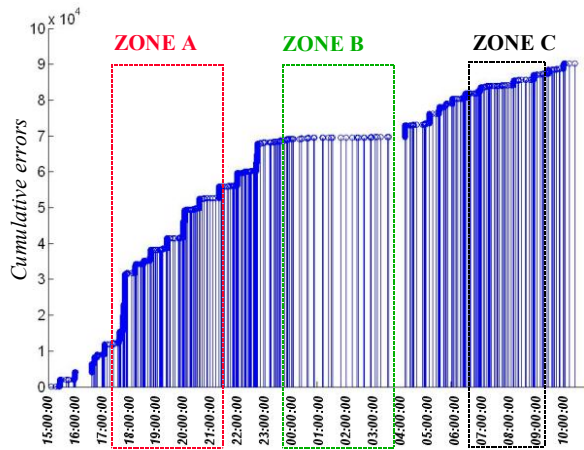


Figure 2 – Evolution of cumulative errors versus time. Zone A corresponds to a high perturbed transmission time interval, zone B corresponds to a relatively low perturbed time interval and zone C is in between

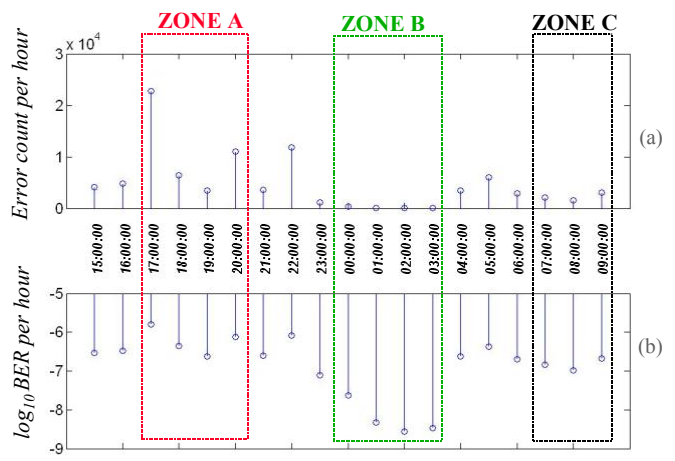


Figure 3 – Detailed analyses of results presented in figure 2: evolution of the total number of errors per hour (a) and the corresponding BER per hour (b)

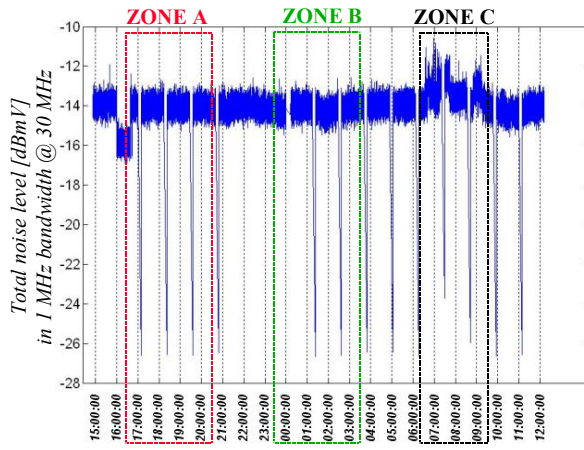


Figure 4 – Instantaneous evolution of total ingress noise level present in the QAM bandwidth (1 MHz around 30 MHz). Lower peak values correspond to slow trace measurements for which a smaller RBW is used (3 kHz instead of 30 kHz).

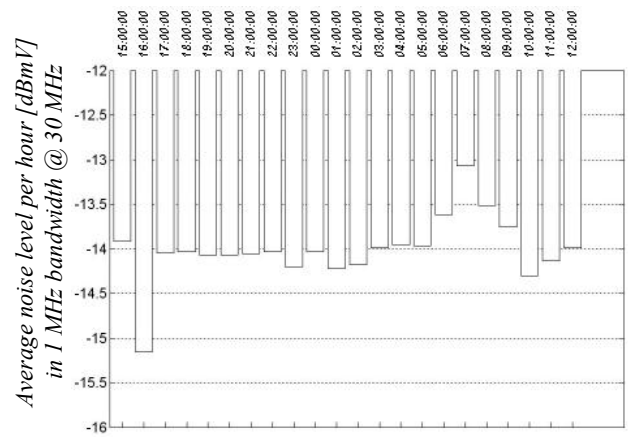


Figure 5 – Average noise level per hour in the QAM bandwidth (1 MHz around 30 MHz) corresponding to results presented in figure 4

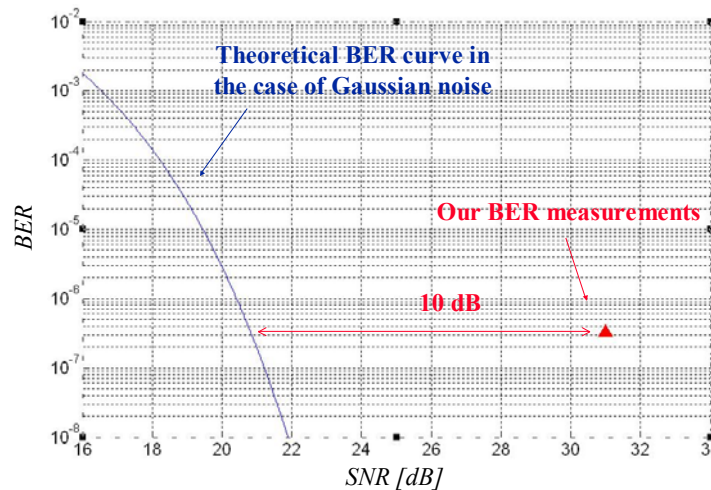


Figure 6 – Our BER measurement ( $3.10^{-7}$  for SNR equals to 31 dB) in comparison with the theoretical BER curve in the case of gaussian noise: a penalty of 10 dB can be observed

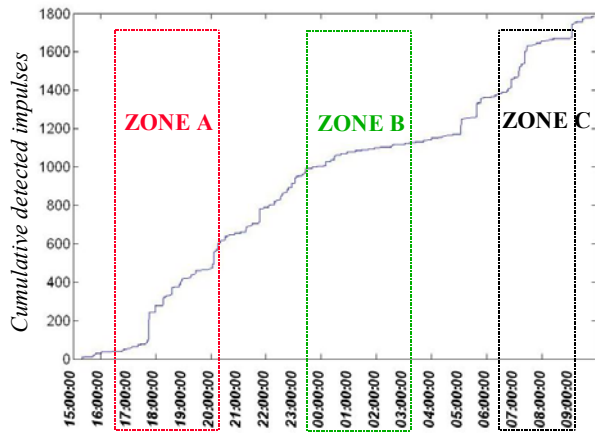


Figure 7 – Evolution of cumulative number of detected pulses in the QAM bandwidth (1 MHz around 30 MHz)

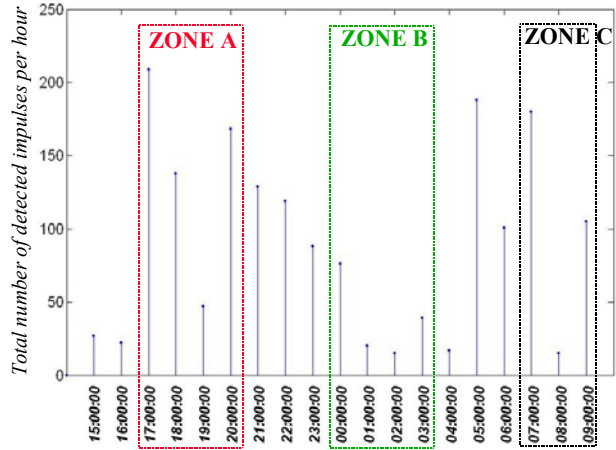


Figure 8 – Evolution of total number of detected impulses per hour in the QAM bandwidth (1 MHz around 30 MHz)

In those conditions, BER value for the whole measurement is equals to  $3 \cdot 10^{-7}$ . Figure 2 represents the evolution of cumulative errors versus time. From it, it is clear that the distribution of errors with time is non-uniform and therefore is not perturbed by a gaussian noise only. Three time intervals have been selected: zone A corresponds to a high perturbed transmission time interval (more than 40 000 errors within four hours), zone B corresponds to a relatively low perturbed time interval (about 500 errors in four hours) and zone C is in between. In zone A, errors clearly occur by burst: i.e. 2 packets of 9000 and 5000 errors during a period of time less than 1 second! To complete this first representation, figure 3a and figure 3b represent respectively the total number of errors per hour and the corresponding BER per hour. These two quantitative analyses show that noise presence in the return path is very different with time: in zone A, BER value per hour is between  $10^{-6}$  and  $10^{-7}$ , while it is between  $10^{-8}$  and  $10^{-9}$  in zone B.

During the chosen period of time, ingress noise measurements have been integrated into the QAM signal spectrum allocation (1 MHz around 30 MHz). The instantaneous evolution of total ingress noise level present in the QAM bandwidth is plotted in figure 4 while figure 5 shows the corresponding average noise level per hour. These graphs show that the highest noise level value in the modem bandwidth is  $-11$  dBmV and that the average total noise level in the QAM bandwidth is relatively constant with time (about  $-14$  dBmV with 1 dB variation). Therefore, no correlation can be made between the ingress noise and the BER evolution of figure 2. Moreover, considering total QAM signal level ( $17$  dBmV) and average noise level in the QAM bandwidth ( $-14$  dBmV), SNR value corresponding to the measurement is about 31 dB. The comparison with the theoretical BER curve in the case of gaussian noise (figure 6) gives a penalty of 10 dB in the positioning of our BER measurement ( $3 \cdot 10^{-7}$ ). So, as conclusion, it is obvious that ingress noise level doesn't explain the distribution of errors versus time or the total BER.

Figures 7 and 8 represent respectively the cumulative number and the total number per hour of detected impulses in the QAM bandwidth. Unlike ingress noise measurements, impulse noise measurements can be directly correlated with BER analysis: distribution of impulses in figure 7 is directly related to the errors distribution in figure 2. Likewise, the total number of detected pulses (figure 8) in zone A is the greatest while it is the smallest in zone B, like in the case of errors measurements presented in figure 3.

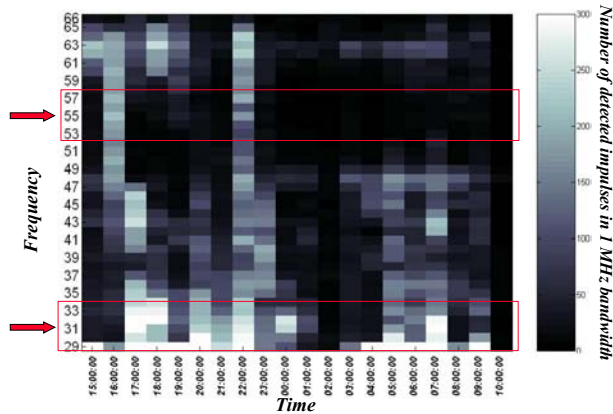


Figure 9 – Spectrograms of the number of detected impulses in the QAM bandwidth (1 MHz) and for each frequency spaced by 1 MHz (in order to cover the higher return path spectrum). This figure shows clearly that the 55 MHz frequency band is better in terms of impulse noise.

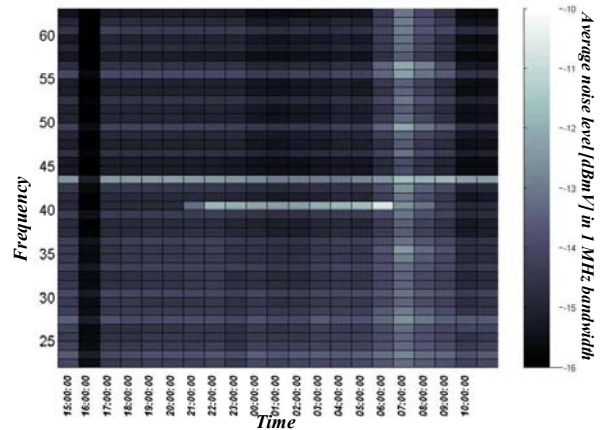


Figure 10 – Spectrograms of average ingress noise level calculated in the QAM bandwidth (1 MHz) and for each frequency spaced by 1 MHz (in order to cover the higher return path spectrum).

So, this comparative analysis of both ingress and impulse noise and their impact on a QAM signal shows that, in the case of our field trial, ingress noise measurement is useless while impulse noise measurements is very informative. In general, ingress noise and impulse noise are always present on the return path but their proportions are different depending on the frequency, the time, the HFC network itself and the QAM level. So, in order to characterise return path noise performance, the two setups must be necessarily deployed at the same time. They allow to obtain spectrograms of both ingress and impulse noises. Figure 9 (for impulse noise) and figure 10 (for ingress noise) represent respectively the number of detected impulses and the average ingress noise level calculated in the QAM bandwidth (1 MHz) and for each frequency spaced by 1 MHz (in order to cover the higher return path spectrum). Figure 9 clearly shows that transmission performance of a QAM signal placed around 55 MHz could be better. Indeed, this bandwidth is less affected by impulse noise than the 30 MHz bandwidth, while ingress noise performance are equivalent in the two bands. These two latter representations can be very useful for cable operators to determine the highest quality band for the QAM transmission in terms of both ingress and impulse noises.

## 5. Discussion

Nowadays, most cable operators only characterise the return path noise performance in terms of ingress noises. This partial noise measurement is sufficient as long as return path is not too much loaded by modem signals. Indeed, with a low modem charge, cable operators are able to give large power margin per channel. QAM modem level is consequently sufficient to not be impaired by impulse noises. However, in order to offer more services or capacity in the future, the number of modems will increase reducing thus the power margin per channel. In this scenario, it will be very important for cable operators to select the best frequency bands in terms of both ingress and impulse noises.

## 6. Conclusion and further work

A setup has been deployed on a return path in order to measure separately ingress and impulse noise. An original BER measurement setup, which allows the analysis of erroneous transmission at the bit level, has also been developed to perform BER test of a QAM signals affected by upstream noises. Software tools have been developed to analyse the quantity of gathered data and to provide results after post-processing. We report that BER performance are directly linked to the impulse noises affecting the transmission and not to the ingress noises. Therefore, impulse noise measurements are vital in HFC networks while ingress noise measurements are interesting but of secondary utility. This study allows to conclude that both noise measurements must be realised in parallel to characterise the return path noise performance. Based on this complete measurement and after post-processing, it has been showed that it is possible to plot two spectrograms that allow to select a better frequency band in terms of noise performance.

To complete this study, it should be interesting to analyse the effects of classical FEC used in upstream transmission on the QAM performance improvement in presence of impulse noise. Also, another interesting development of our setup could be to perform data processing in quasi real-time.

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