Temporal Binary Error Distribution of QAM Transmission Impaired by Clipping-Induced Noise in CATV Lightwave Subcarrier Multiplex Systems

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AM/QAM CATV lightwave systems are subject to clipping by the laser diode of the subcarrier multiplex signal. Although Reed Solomon forward-error-correction is used in QAM modems, errors due to clipping-induced impulse noise cannot always be totally corrected because forward-error-correction has been designed without precisely taking into account the characteristics of errors bursts. The paper describes an experimental setup based on a classical BER analyzer completed by an original acquisition card able to temporally locate errors at the bit level. Based on this setup, temporal distribution of clipping-induced errors bursts is presented. This could help to better design error correction schemes.

I. Introduction

Nowadays CATV lightwave systems deliver simultaneously broadcast analog video channels (amplitude modulation vestigial sideband AM-VSB signals) and interactive digital video/data channels (quadrature amplitude modulation QAM signals) through hybrid fibre coax (HFC) networks. However, subcarrier multiplex (SCM) lightwave systems are subject to clipping due to the laser diode static characteristic. When clipping-induced impulse noise occurs in AM/QAM SCM lightwave system, the typical bit error rate (BER) curve of QAM signal exhibits a floor [1].

To achieve robust transmission of digital channels, forward-error-correction (FEC) is used by QAM modems. For CATV downstream transmission, European and American normalizations [2] recommend to use Reed Solomon codes and convolutional interleaving. In particular, Europe [2,3] recommend RS(188,204) code and convolutional interleaving with a depth I equals to 12. However, errors due to clipping-induced impulse noise cannot be completely corrected by using this FEC [4]. Indeed, although it allows to correct errors bursts, FEC parameters have been chosen without taking into account characteristics of errors bursts induced by clipping noise. So, studying clipping-induced errors bursts properties to design error correction schemes in SCM systems is widely recommended [4,5].

This paper focuses on the analysis of temporal distribution of errors induced by clipping noise. For this purpose, we have developed an original hardware acquisition card and a related software tool able to locate errors at the bit level. Based on this setup, we present experimental results of temporal binary errors distribution of a QAM transmission impaired by clipping-induced noise. We report statistical properties of clipping-induced errors temporal behaviour that can help to design error correction schemes.

II. Description of the experimental setup

Fig. 1 depicts the experimental setup used to study the impact of clipping-induced noise on a CATV QAM transmission system. The 16-QAM transmission is placed around 343.25 MHz and is characterized by a 16 Mbit/s bitrate (QAM bandwidth equal to 4 MHz and symbol rate equal to 4 Mbaud) with $\alpha = 0.15$. The QAM signal is directly impaired by the noise coming from laser clipping. To generate it, a 1550 nm DFB laser was directly modulated by 41 AM-VSB video carriers (with independent phases) from the 42 carriers CENELEC testing plan [6] in which carrier n° 13 at 343.25 MHz was turned off to avoid the impairments of the QAM channel. A variable electrical attenuator was used to modify the optical modulation index OMI and a variable optical attenuator was used to simulate the fiber link loss and to adjust the optical received power to 0 dBm. For this experiment, the QAM signal was not injected into the optical link and the error correction RS in the QAM modem was disabled in order to study the actual impact of clipping noise without any other potential impairments and any correction.
To perform the analysis of erroneous transmission described in this paper, we have completed our BER analyzer by an original external acquisition card able to locate errors versus time at the bit level.

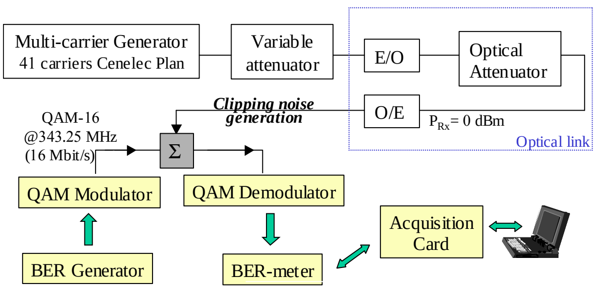

Fig. 1 – Measurement setup.

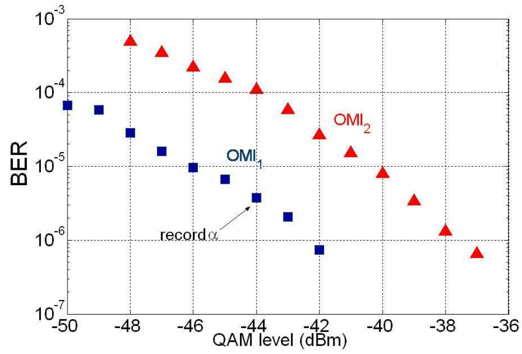

Fig. 2 – BER versus QAM level for 2 OMI values (21 records). Record α is pointed out.

III. Measurement results and analysis

It is well known that the clipping-induced impulse noise depends on the OMI value and on the spectrum of the input SCM signal. In this experiment, two types of clipping-induced impulse noise are generated using two different OMI values (OMI_1 = 5.1% and OMI_2 = 5.6%). In both case, errors acquisitions were performed for different QAM levels (9 records for OMI_1 and 12 records for OMI_2). All measurements lead to the two BER curves presented in Fig. 2. They present the same appearance than those presented in [1]: due to clipping, the two curves deviate from the classical BER curve in the case of gaussian noise (about 2 decades BER variation for a 8 dB QAM signal variation instead of only a 2 dB variation in the case of gaussian noise).

A. Definition

The following results of this paper are based on the definition of a ‘burst’. A ‘burst’ is defined as a group of errors in which the following rule is always satisfied: “elapsed time between two consecutive errors is lower than the *burst time* parameter”. Moreover, the number of errors in ‘burst’ has to be greater than five to be considered as a ‘burst’. In the remainder of this paper, the *burst time* parameter has been chosen to 1 ms.

B. General results and analysis tools

Fig. 3 gives the evolution of cumulated errors along time corresponding to the first 10 seconds of the record α in Fig. 2. BER value for the whole record (10853 errors within 180 seconds) is 3.7 10^{-6}. Fig. 3 clearly shows that errors occur by burst. Indeed, in the case of gaussian noise, about 60 errors should regularly occur every 1 second interval to obtain the same BER. The inset in Fig. 3 shows a zoom of a burst. Thanks to the acquisition at the bit level and based on our 'burst' definition, a software tool able to determine the beginning and the end of a burst has been developed. It is therefore possible to compute the burst duration and the error rate of the burst.

C. Burst distributions analysis

For each record, it is possible to trace the probability density function (PDF) of the duration (in Fig. 4) and of the error rate (in Fig. 5) of errors bursts satisfying the previous definition of a burst. So, those figures correspond to a superimposition of 21 curves. The mean of the 21 PDF (black heavy curve) has also been plotted on both figures.

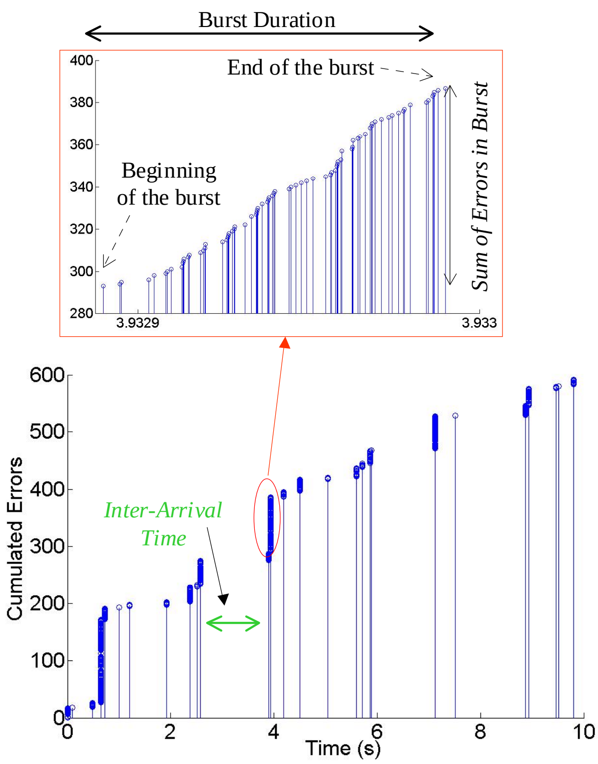

Fig. 3 – Temporal evolution of erroneous bits for the first 10 seconds of record α. The inset shows a zoom of a burst.

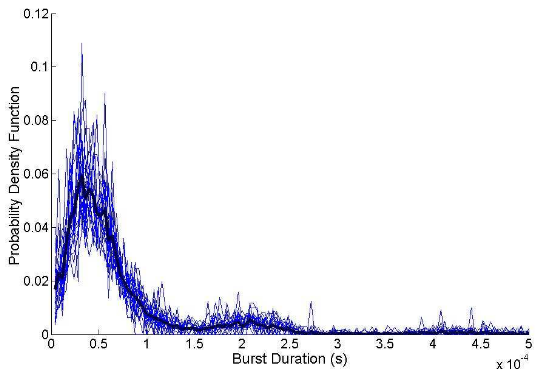

Fig. 4 – Superimposition (21 curves) of bursts duration PDF of each record. The black heavy curve corresponds to the mean of the 21 PDF.

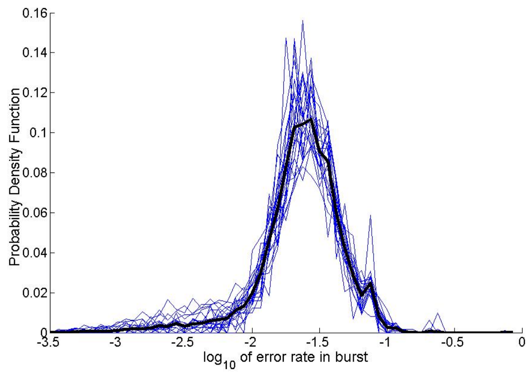

Fig. 5 – Superimposition (21 curves) of bursts error rate PDF of each record. The black heavy curve corresponds to the mean of the 21 PDF

These two figures show clearly that the statistical distribution of duration and error rate of bursts do not depend on the OMI value and on the QAM level since all curves are merging. Consequently, we can conclude that errors bursts induced by clipping noise are always characterized by the same statistic of duration and error rate.

Let us now consider again the BER curve presented in figure 2: we observe BER degradation when decreasing QAM level or increasing OMI value. Since errors bursts possess always the same characteristics, we can conclude that the BER is simply due to the number of errors bursts. So, when increasing OMI value or decreasing QAM level, QAM transmission is impaired by more clipping-induced pulses that cause more errors bursts, but the errors burst properties (time duration and error rate) remain the same.

IV. Discussions and conclusions

This original acquisition card allows, for the first time to the best of our knowledge, the presentation of statistical distributions of errors of a CATV QAM transmission impaired by clipping-induced impulse noise. Experimental results show that probability density functions of duration and of error rate of bursts do not depend on OMI value and QAM level. So, the properties of clipping-induced errors bursts can be simply expressed by the way of the two probability density functions presented in Fig 4 and in Fig 5. Based on these properties, it is conceivable to realize generation process of errors due to clipping by software. This noise generator could then help to study performance of error corrections schemes or to design new ones.

Acknowledgment

Authors take part to the e-Photon/ONe NoE project of the European Union.

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