Statistical analysis of M-QAM signal impaired by clipping noise in optical CATV systems

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In optical analog/digital multichannel CATV transmission using external modulation system, the clipping of the laser is a potential major disturbance. The clipping noise can be taken as impulsive impairment and leads to the appearance of a penalty in the BER curve. For that purpose, this paper presents a set-up based constellation analyser, which allows to characterize the penalty in the BER curve of clipping-induced impulse noise on M-QAM signal.

I. Introduction

In an external modulation system, clipping occurs when the subcarrier multiplex (SCM) modulating signal occasionally falls both below the low laser threshold current and passes above the high laser threshold. It has been pointed out in scientific literature that distortions generated by this clipping phenomenon have an impulsive nature and significantly degrade the performances of the digital communications [1].

When a clipping-induced impulse noise occurs in the SCM system, there appears a penalty in the QAM bit error rate (BER) in function of signal to noise ratio (SNR). This penalty is led by a floor which appears in the BER curve of QAM signal in function of SNR. Therefore to achieve a same BER as in the case of pure Gaussian noise, we need in the case of clipping-induced impulsive noise to add penalty to surpass the appeared floor.

It is admitted that the amplitude distribution of clipping noise is approximated with Middleton Class *A* model [2]. This approach permits to characterize analytically the clipping noise penalty induced in the BER curve as in the case of simple Middleton Class *A* model [3]. However the clipping-induced impulse noise parameters must be provided to perform this analytical characterization.

Previously two papers have been presented on the analysis of the impact of clipping noise on digital transmission and they give some statistical values of clipping noise parameters. One was involved on voltage analysis of clipping-induced impulsive noise, and was based on high digitizing oscilloscope [4]. The other was interested in BER analysis at the bit level and allows the presentation of temporal statistical distribution of erroneous burst pattern [5].

But the set-up developed in these papers only run when the transmission is disabled. Therefore all the analysis provide there are useful for the modem-cable builder but do not allow the cable-operators to react dynamically against the variation of clipping-induced impulse noise on their networks.

On this basis, in the case of clipping-induced impulsive noise damaging the CATV (Community Antenna Television) QAM transmission, we present one set-up that allows to determining dynamically the penalty induced in BER curve. This set-up, running on the useful transmission, is performed by an analysis of the constellation diagram of the digital transmission.

II. Experimental Set-up description

Clipping noise generator

Fig. 1 depicts the clipping noise generation system. To generate the clipping noise, a *1550* nm external modulator was directly modulated by *41* AM-VSB video carriers (with independent phases) from the *42* carriers CENELEC testing plan [4] in which carrier n° 1 at *48.25* 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.

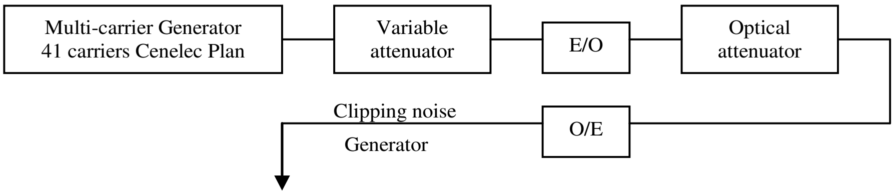

Fig. 1: Clipping noise Generation

Constellation analysis of QAM signal impaired by clipping noise

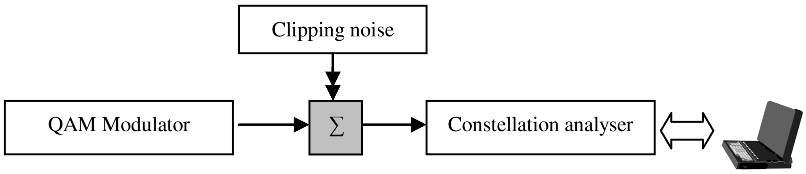

Fig. 2: Constellation analysis block diagram

Fig. 2 depicts the experimental set-up used to study the constellation of an upstream CATV QAM signal impaired by clipping noise. The 16-QAM transmission is placed around *48.25* 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 external laser clipping and the impaired signal is send to the constellation analyser. For this experiment, the QAM signal was not injected into the optical link and the error correction RS (Reed-Solomon) in the QAM modem was disabled in order to study the current impact of clipping noise without any other potential impairments and any correction.

On the constellation diagram, we define the error vector magnitude (EVM) as the magnitude of the difference between the received vector and the demodulated vector (cf. fig. 5).

Further to obtain the noise parameters, we postulate that the statistical distribution of the EVM when the signal is disturbed by clipping noise modeled with Middleton Class A will follow a weighted sum of Rayleigh. If f_{EVM} is the pdf (probability density function) of the EVM distribution, then we have:

$$f_{EVM}(v) = \underbrace{(1-A)\frac{v}{\sigma_0^2} e^{\left(-\frac{v^2}{2\sigma_0^2}\right)}}_{T1} + \underbrace{A\frac{v}{\sigma_1^2} e^{\left(-\frac{v^2}{2\sigma_1^2}\right)}}_{T2} \qquad (1)$$

where σ_0^2 and σ_1^2 are respectively the variance of the background (Gaussian) and the pure impulsive (induced by clipping) component of noise, and A is the impulsive index [7]. Generally A is the average proportion of time in which the signal is damaged by impulsive noise.
In this formula (1) *T1* is dedicated to Gaussian noise while *T2* is devoted to impulse noise. In fig. 6 and fig. 7 we illustrate the contribution of the two terms to the whole histogram according to the values of parameters σ_0^2 and σ_1^2.
In fig. 6 we have choice σ_0 and σ_1 with a ratio of *2*. And we see that, based on the two contributions, the histogram does not clearly present two modes. Although in fig. 7 where σ_0 and σ_1 are chosen with a ratio of *5*, we distinguish that the histogram is constituted by two modes. Thus the shape of the EVM's histogram is directly related to the ratio of the variance of Gaussian and impulsive component of noise.
Based on (1), the penalty p_{snr} introduced by the occurrence of clipping-induced impulsive noise in the QAM BER curve is given by [3]:

$$p_{snr} = 10\log\left(\sigma_1^2\right) - 10\log\left(\sigma_0^2\right) \qquad (2)$$

This penalty is totally independent of the order of QAM signal and only depends on both the variance of Gaussian and impulsive component of noise.

III. Experimental results and analysis

Fig. 8 illustrates the histogram of EVM of 16QAM signal impaired by clipping induced impulse noise. In this figure, results of interpolating formula (1) on the histogram are also depicted and leads to some comments.
The parameter A is equal to *0.35*. It means that *35%* of time is disturbed by impulse induced by clipping noise. This value is very high and expressed low impulsivity.
The parameters σ_0^2 and σ_1^2 are respectively equal to 7.1 10^{-5} and 1.3 10^{-4}. We observe that the variance of impulsive component is approximately two time greater those of Gaussian component only. Direct application of formula (2) leads to a penalty of around *6* dB.
So, for the given OMI (7%), we notice that the clipping noise does not present high impulsivity. Further clipping-induced impulses do not exhibit variance very high compare to the variance of Gaussian noise.

IV. Conclusion

In this paper we have exhibited a set-up that allows to dynamically obtain the penalty which appears in a QAM transmission when it is impaired by clipping-induced impulse noise. This set-up can be connected directly on the transmission, and therefore can be used in adaptive scheme for the management of the quality of transmission.

References

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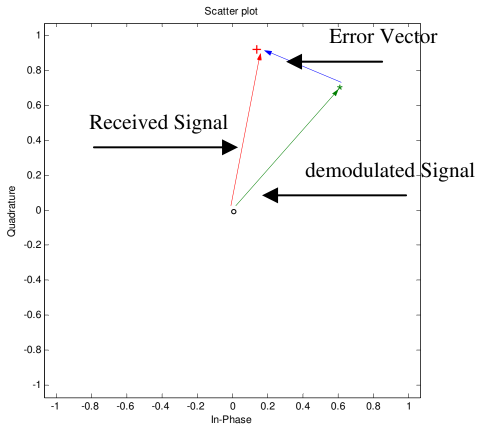

Fig. 5: Illustration of Error Vector definition

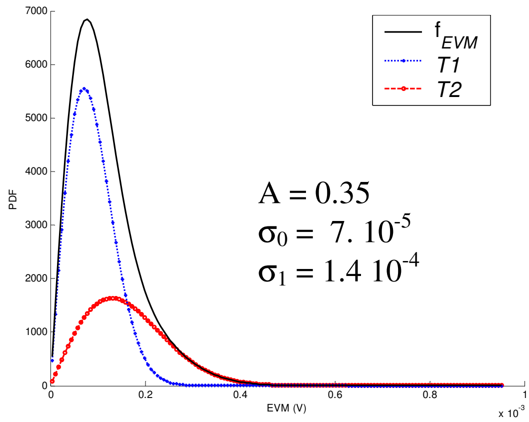

Fig. 6: Illustration of EVM's histogram with one mode

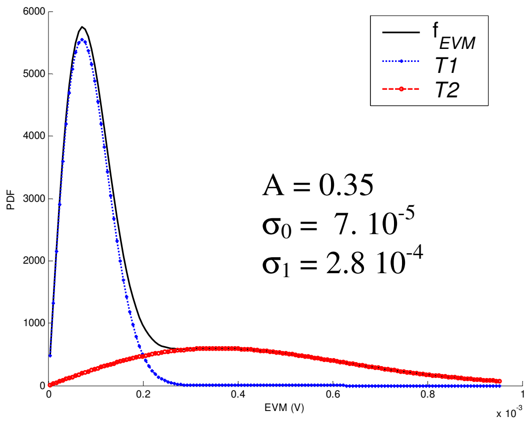

Fig. 7: Illustration of EVM's histogram with two modes

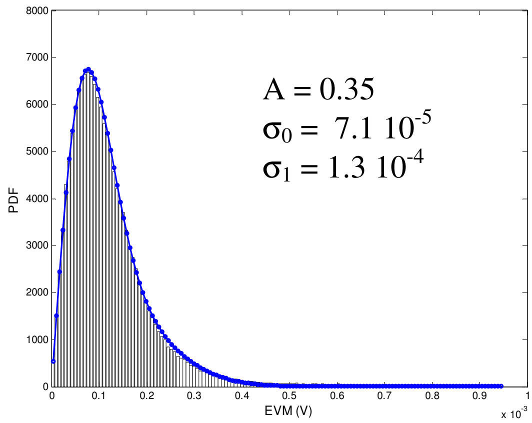

Fig. 8: Interpolation of histogram of EVM of 16QAM signal (OMI of clipping noise 7)