Investigation of the impact of CSO/CTB/CNR parameters in designing and operating CATV networks

Stanimir Sadinov[1], Krasen Angelov[2], Kiril Koitchev[3], Ivelina Balabanova[4]

***Abstract* –This article reviews the impact of CSO (*Composite Second Order*) and CTB (*Composite Triple Beat*) upon the channel spectrums. Both coaxial cables and laser optical fiber lines are used as transmission lines which makes it necessary to account for and investigate the effect of pure Gaussian noise within the systems as well as the errors due to it by measuring the parameter of carrier-to–noise ratio (CNR). All CSO/CTB and CNR data are related to the noise level and are directly connected with the active and passive elements used in the system. Their correct disposition and the tunings made in them contribute largely to improved service quality and use of network.**

***Keywords* – CATV, CSO/CTB/CNR spectrums, signal level, nonlinear distortion**

I. Introduction

Availability of a large number of channels in present day CATV networks or of some other types of signals with marked carrier frequencies in channel multiplexing brings about to considerable nonlinear signal interaction. For most cable TV frequency plans products which have resulted from beat, accumulate in given frequencies and to a large extent affect network quality. Usually discrete CSO (*Composite Second Order*) and CTB (*Composite Triple Beat*) composite inter-modulation products are the ones which exert the greatest impact. The CSO/CTB spectrum is a sum total of the products of the nonlinear interaction of all possible combinations of second and third order input signal frequencies and the level of nonlinearity of amplifiers. It contains hundreds and thousands of inter-modulation frequencies distributed along the entire frequency band of the cable TV network. There are many cut-and-try formulae used to calculate only one value: the worst value of CSO/CTB from the test plan, however, all these formulae are of various coefficients and therefore are difficult to summarize.

For the purpose of analyzing a network it is necessary to have not only the worst value of CSO/CTB in the frequency band, but also the concrete distribution of that spectrum over the channels.

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Very often a concrete inclination (slope) of amplitude frequency response (AFR) components is set for the purpose of improving network parameters. In this case the calculation of CSO/CTB spectrum will get more complicated. In some cases this inclination (slope) can cause worsening of inter-modulation noise depending on the type amplifier used. For this reason the use of cut-and try formulas in calculating the value of CSO/CTB is very problematic.

In this connection there arises the actual task to calculate the full spectrum of CSO/CTB for randomly selected operational frequency plan with random non-uniformity of the input and output signals for a certain network elements.

Another interesting task is the search for optimum plan that will ensure the lowest value for CSO/CTB in the channels.

II. Calculation of CSO/CTB spectrum of non-linear elements

It is assumed that the input signal of the non-linear element (the amplifier) contains *N* (*Continues Wave – CW*) *RF* (*Radio Frequency*) carriers:

$$x = \sum a_i \cos(\omega_i + \varphi_i). \qquad (1)$$

For the given element it is possible to determine the non-linear transfer function *A* which depends on element's characteristic and does not depend on the type and parameters of the input signal. By means of this function it is possible to express the output signal *y* as some function of the input signal *x*. This can be rendered as $y = Ax$.

It is very difficult to draw such transfer function even for the simplest type of amplifiers given the considerable number of spurious parameters. Nevertheless, the function can be synthesized for the given non-linear element on the grounds of the results from the tested spectrum of CSO/CTB in any plan. Since such a transfer function does not depend on the type of input signal (and the non-uniformity of input AFR as well) it is possible to calculate the full output spectrum including the CSO/CTB spectrum for random frequency plan of channels which can be different, due to various needs, from the frequency plan of channels during their first test and synthesis of the non-linear transfer function. An algorithm for calculation of coefficients of such non-linear transfer function is considered in [1, 3].

Fig.1 and fig.2 present CSO/CTB spectrums which are calculated for amplifier No2 (Model NWA-M1). Short columns are the control values for CSO/CTB tested in lab settings. Channels are indicated by vertical grey stripes.

To calculate CSO/CTB spectrums and noises in a laser optical cable TV network it is possible to use the physical model of the laser with accounting of its physical parameters in accordance with the results from the tests of CSO/CTB spectrums. It is also necessary to take into account the impact of the spurious modulation within the laser (chirp) as well as the availability of dispersion inside the optical fiber. This allows to calculate the full spectrum of the inter-modulation CSO/CTB products and the noises in the cable TV network for all frequency ranges. For lasers with direct modulation it is also possible to use the above method for calculation of CSO/CTB spectrums whereas lasers with external modulation require a little different approach and accounting of additional factors.

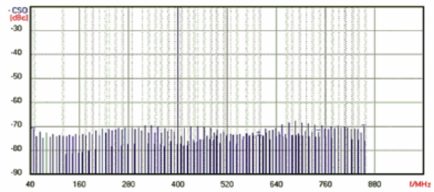


Fig.1.Calculated CSO spectrum for amplifier №2

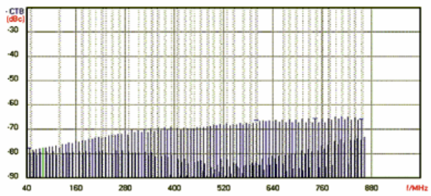


Fig.2.Calculated CTB spectrum for amplifier №2

III. Impact of CSO/CTB/CNR spectrums on BER in digital QAM channels

The use of MPEG-2 (*Motion Picture Expert Group*) standard for compression and transmission of TV image allows the simultaneous transmission of up to ten TV programs in the *8MHz* frequency band. The idea of MPEG-2 standard is based on transmission which in turn is based on changing parts of TV image calculated as interim image frames and using Reed-Solomon (RS) error correction codes which allow correction of definite number of erroneously received symbols and quadratic amplitude modulation QAM. Initially digital data (presented as ones and zeros) is integrated into packages of definite length and synchronizing symbols and then is filled in with a series of correction symbol which are calculated for the concrete package. QAM modulation is done in accordance with the definite data symbol (the combination from ones and zeros) and two orthogonal I and Q signals with concrete combinations for amplitude and phase for each of them. In the receiving end of the line takes place demodulation QAM of the signal and correction of erroneous symbols by means of FEC scheme (*Forward Error Correction* – progressive error correction). Such presentation of output data allows for substantial reduction of required frequency band for transmission. Correction codes such as Reed-Solomon allow to correct a certain number of symbols in the package. For example in a packet with Reed-Solomon code (*204*, *188*) it is possible to correct up to *8* faulty reception symbols. A very important characteristic of quality of transmission of digital signals is the *BER* (*Bit Error Rate*) parameter – the ratio between error bits and the total number of transmitted bits.

In terms of history at first *BER* deterioration was connected with white Gaussian noise. Reed-Solomon code allows effective correction of errors caused by Gaussian noise. After that a number of papers showed the large share of pulse noise as well [4, 5] combined with white Gaussian noise for BER [1, 2] deterioration in laser optical lines with mixed AM/QAM channels.

A number of articles [4, 5, 7] present measured time characteristics of the sum total of noises and the inter-modulation products within the optical line and in the frame of QAM channel of intermediate frequency. Despite that QAM signal is decoded not at intermediate frequency in the *8MHz* band, but in the basic frequency band *0 – 4,0 MHz*, in which I and Q components are separated back by means of mixing the signal in the middle of QAM frequency band at intermediate frequency as that of the local oscillator (heterodyne) signal. In this way the basic frequency band of the channel for I and Q components proves to be twice as large as compared with the band for QAM high frequency channel., therefore ,the frequency spectrum and its relevant time characteristic will be quite different. Time and spectrum measurements in the basic frequency band *0 – 4 MHz* for 64-QAM signal for mixed AM/QAM channel plan are dwelt upon and presented in [7].

Fig.3 presents an experimental formulation for measurements in a hybrid AM/64-QAM transmission system. QAM channels are generated by 64-QAM modulator according to the Digital Video Broadcasting standard. The packet contains Reed-Solomon (*204*, *188*) code. Bit transmission rate is e *41,25Mbps*, symbol rate is *6,875Msym/s*, and the channel band – *7,8MHz*. The matrix generator generates unmodulated CW carriers according to the European frequency plan from *48,25MHz* to *855,25MHz* with different number of channels (*60* to *90*). The levels of 64-QAM channels are in accordance with the standard; by 10dB lower than CW carriers. Combination of CW and QAM signals creates and an input signal for coaxial cable TV line or a modulated signal for DFB laser when measurements takes place in an optical line.

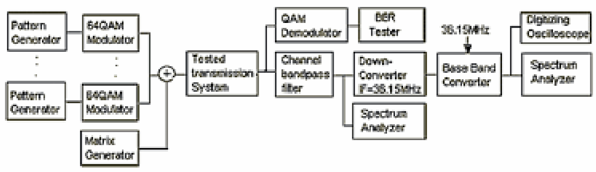


Fig.3. Experimental formulation for measurements in a hybrid AM/64-QAM transmission system

Output high frequency signal from the measuring transmission system (from the output of the optical receiver is for optical transmission system and from the output of the last amplifier is for coaxial transmission system) is diverted to QAM demodulator and BER-meter and also to the other branch of the diagram above which is connected with frequency and time measurements in the QAM channel. The channel is split by means of a band filter and additional attenuator for the purpose of minimizing the impact of adjacent channels. White noise impact is measured by means of spectral analyzer also taking into account *CNR* and CSO/CTB spectrum in the channel.

The step-down converter transfers the high frequency channel in the medium frequency band whose centre is at 36,15MHz. Then follows signal mixing of medium frequency 36,15MHz inside the heterodyne converter in the basic frequency band whereby the medium frequency signal is converted into basic frequency band *0 – 4 MHz*. In this way the individual I or Q component of the QAM signal is modeled. Time characteristics of distortions are measured by means of digital oscilloscope with a triggered scanning starting at a point when the signal reaches certain amplitude. Spectral analyzers are used to monitor the frequency spectrum of distortions in the basic frequency band. Signals in the measured channel as well as those in the adjacent channels are switched off when measuring noise and interferences. All CSO/CTB and CNR data are related to the level of CW signal.

Generally, an optical transmission system consists of a DFB immediately modulated laser, optical single mode fiber of *6km* in length, and an optical receiver. A coaxial transmission line contains three cascade amplifiers with attenuators as equivalent to the coaxial line. First is to be investigated the impact of Gaussian noise in the coaxial system. Errors that are due to mere Gaussian noise with *CNR* greater than *32dB* (in this case all CW channels are switched off) are corrected very well by the FEC circuit as $BER = 10^{-5}$ before the FEC circuit and $BER = 10^{-10}$ after it.

Like the optical lines discussed in [6, 7], the situation also changes here when there are discrete CSO/CTB products (switching on of channels). With 65 CW and 10 QAM channels what is obtained is that in a 64-QAM channel of *434MHz*, *CSO/CTB = 52dB* и *CNR = 48dB* there will be $BER = 10^{-6}$ before and $BER = 10^{-7}$ after FEC. In his particular case when CW channels are on then the efficiency of FEC drops down to *0*, i.e. there is no correction of faulty reception symbols. In this case efficiency boundary of forward error correction is observed not only for the modulated laser, but in the coaxial system with amplifiers. Consequently, it gives ground for the assumption that the efficiency boundary of FEC for multichannel AM/QAM system for cable TV displays similar nature both in coaxial and optical transmission system.

Fig.4 and Fig.5 show spectrums of inter-modulation products in a basic frequency band in QAM channels of coaxial and optical line. After conversion inside the basic frequency band, CSO/CTB products form harmonic order with first harmonic $f_1 = 0,25MHz$.

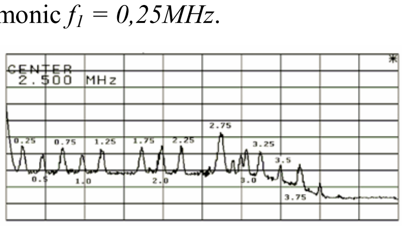


Fig.4. Coaxial transmission system–harmonics in basic frequency band of 434MHz channel

The highest level harmonic has a frequency of $f_m = 2,75MHz$. Harmonic sequences in fig.4 and fig.5 will be formed inside the basic frequency band with time sequence having a period $T = 4\mu s$. The values in fig. 4 and fig.5 are given in MHz; the horizontal divisions are of *0,5MHz* whereas those in vertical direction are *10dB*.

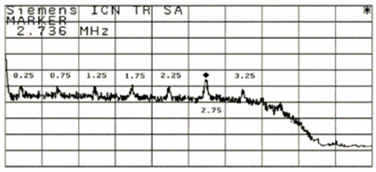


Fig.5. Optical transmission system –harmonics in the basic frequency band in a 858MHz channel

Fig.6 and fig.7 present results from time measurements in the basic frequency band for the a QAM channel. It is evident from the dependences that in the optical and the coaxial line the spectrum of CSO/CTB inter-modulation products in QAM channels form inside the basic frequency band of QAM channel some periodic pulse sequence with period $T = 1/f_1$ where f_1 is the first harmonic in the basic band of the digital channel. This is cyclic pulse sequence caused by the spectrum of CSO/CTB and appears to be the reason for the decrease of efficiency of the error correction circuit.

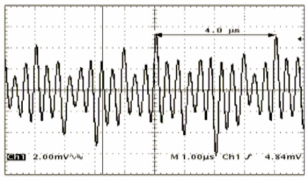


Fig.6. Measurement of interferences in time progression inside the basic frequency band of 434MHz channel (coaxial transmission system)

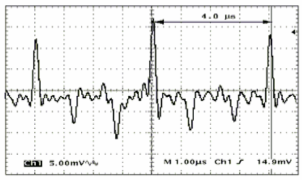


Fig.7. Measurement of interferences in time progression inside the basic frequency band of 858MHz channel (optical transmission system)

The first harmonic inside the basic frequency band of 64-QAM channel for European and American frequency plan of TV channels is almost always equal to *0,25MHz*. In reality phase ratios in the input sequence are changed with time and therefore the amplitude of pulses should also be changed. Fig.8 shows a burst of pulses inside the basic frequency band for *858MHz* channel.

The space between individual divisions on fig.8 is *10µs*. The duration of the measured burst is 60 - 90µs, which is two times more than the data packet.

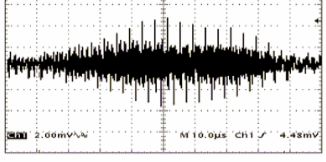


Fig.8. Burst of pulses inside the basic frequency band of 858MHz channel for coaxial transmission system

IV. Investigation of inter-modulation noise in coaxial and optical linear elements of cable TV network

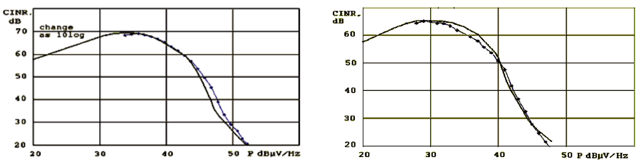
Inter-modulation products of these channels will have noise-like spectrum due to , as is the case with the CSO/CTB spectrum of discrete inter-modulation products, non-linearities of second and third order. Since the frequency spectrum of QAM or QPSK channels is sufficiently uniform in the channel, it is possible to regard the input signal of the laser or the reverse channel amplifier as white noise. The non-linearity of laser or the amplifier will bring to the formation of its own broad band noise caused by the second or third order inter-modulation interactions for the input signal frequencies. There is no multi-channel system for measurement for the reverse channel frequency range. Accordingly, there arises the question how can non-linear, distortions and the non-linear elements' noise be determined.

In [2, 7] there is an interesting method proposed for measurement of inter-modulation noise and estimation of the quality of the optical laser system for the reverse channel; that is the Notch-filter method which has become the standard one for the reverse channel. At the input of the measured optical line or amplifier a broadband noise burst is fed by noise generator which has a notch cut out by means of a narrowband rejection filter with a high level of bounding (about *80dB*). From this output the signal is transferred to a spectrum analyzer.

On fig.9 are shown curves measured (thick line) and calculated (point line) in accordance with CINR for amplifiers for the reverse channel as a function to the density of the output channel.

Fig.9 a) is about amplifier №1 with frequency band *5* to *30 MHz* and frequency of the notch-filter: *18MHz*.

Fig.9 b) is for amplifier №2 with frequency band *5* to *65 MHz* and frequency of the notch-filter: *35MHz*.



a) b)

Fig.9. $CINR = f(P_{out})$ a)for amplifier №1, b) for amplifier №2

It is evident that the increase of the frequency band of the reverse channel amplifier causes a shift of the largest value of CINR towards the side of the lower signal levels. The reverse channel amplifier cannot work in areas of quick loss of CINR. The initial point of the quick loss of CINR can be regarded as the upper limit of the admissible density of the output (input) signal in the reverse channel.

V. Conclusion

It can be said in conclusion that the peculiarity of inter-modulation interferences is in the fact that their levels depend largely not only on the size and complexity of cable TV network, but also on the number of channels, their frequency plan and the level of signals. By forming pulse sequence of video frequencies the CSO/CTB spectrum brings about to characteristic screen interferences whilst in the case with MPEG-2 channels can substantially deteriorate the effectiveness of the error correction system.

In the reverse channel there are noise-like inter-modulation interferences which may sharply rise up in number provided there is an increase in the signal level above a certain limit in the reverse channel. Accounting of the influence of the inter-modulation interferences is done by means of the Notch-filter method.

There are certain challenges in calculation of reverse channel noises and interferences when designing return connection channel and they are connected with the necessity of accounting the impact of accumulated noises which have penetrated from any point in the network as well as with recorded noises within the entire network.

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References

[1] Angelov K., K. Koitchev, S. Sadinov, N. Varbanova. Technical aspects of upstream channel design in broadband cable television network. Journal Materials, Methods & Technologies – International Scientific Publications, Vol.2, Part 2, 2008, ISSN 1313-2539, pp.110-131.

[2] Panagiev O., Intermodulation composite distortions theoretically research in HFC networks. ICEST, Proc. Of Papers, vol.1, Ohrid, 24-27 June 2007, pp.325-328.

[3] Germanov V., "Calculating the CSO/CTB Spectrum of CKT Amplifiers and optical Receivers", IEEE Trans.on Broadcasting,vol.44 No.3 pp.363-366, Sept. 1998.

[4] Maeda K., H. Nakata, K Fujito, "Analysis of BER of 16QAM Signal in AM/16QAM Hybrid Optical Transmission System", Electron. Lett.vol.29, No.7, pp.640-642, April 1993.

[5] Tsushima H., K. Kitamura, "Preclipping Experiment for subcarrier-multiplexed AM/64QAM optical transmission", Electron. Lett. vol.31, No.21, pp.1863-1865, Oktober 1995.

[6] Ovadia S., C. Lin,"Performance Characteristics and Applications of Hybrid AM-VSB/MQAM Video Lightwave Transmission Systems", J. Lightwave Technology, vol 16, No. 7, pp.1171-1185, July 1998.

[7] Германов В., Некоторые аспекты моделирования и расчета распределительных сетей кабельного телевидения, Теле-Спутник №8(94), 2003, С.-Петербург, стр. 50-53.