Investigation of Second and Third Order Distortions Influence in the CATV/HFC Networks

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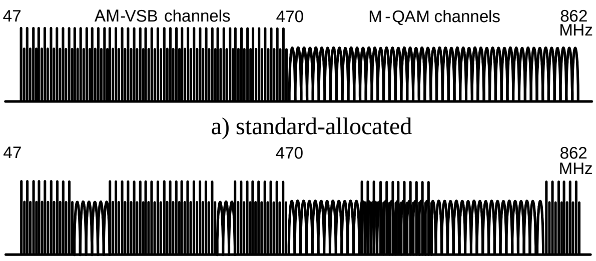
Abstract – **In this paper are presented theoretically and experimentally researches of the influence of composite distortions from second and third order in broadband cable radiocommunication systems and devices. Deduced are some mathematical expressions, that define the parameters characterizing the quality and reliability of the transmitted information signals with the help of those systems and devices, and according to the standard (CENELEC EN50083).**

Keywords – **CATV, HFC, CSO, CTB, Volterra kernels.**

I. INTRODUCTION

In modern broadband communication systems, such as CATV/HFC, analog as well as digital signals are transferred bidirectional. Their frequency spectrum is between 5 and 862 MHz. For standard-allocated (Fig.1a) of the Downstream, the analog channels (AM-VSB and FM) are at the range beginning, and the digital ones (M-QAM) – at the end of it. Also existing are the nonstandard-allocated (Fig. 1b), where analog and digital channels are both spread though the whole range. Independent from the frequency plan, in the active devices (cable amplifiers), as well as in the system as a whole, occur nonlinear distortions due to the nonlinear transmission characteristic. As a result of that occur some nonlinear Intermodulation products, which cause moiré-effects for analog channels, synchronization or chromaticity distortions, and BER deterioration for digital channels.



a) standard-allocated

b) nonstandard-allocated

Fig.1. Spectrum of CATV/HFC system

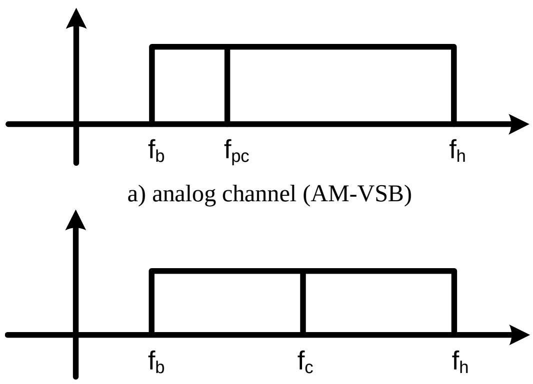
Researching and measurement of the nonlinear products is of great importance for the reliable and secure information transfer. The level requirements for nonlinear products in comparison to those of the signals with fundamental (carrier) frequency are standardized, both for Europe and the world, and for separate countries (Table 1). In this paper is studied the influence of composite distortions from second and third order, which according to the European standard CENELEC EN 50083 are characterized with the CSO and CTB ratios, that in the worst case should be ≥ 60 dB.

Because of the different disposal of the carrying frequencies for analog and digital signals in the respective TV channel (Fig.2), the resulting nonlinear products are occurring in other (different) places in the TV channel [1], compared with ones that have already been described and discussed in other literature sources.

Researching of the nonlinear distortions and of thereof originated nonlinear products is made by proposing a suitable mathematical model and a method for calculating the CSO and CTB ratios for one amplifier and a cascade of same and different cascade connected amplifiers.

TABLE I
CATV PERFORMANCE TEST STANDARDS

Geo-area	Test standard	CSO	CTB	XMOD
International	*IEC 728-1*	Yes	Yes	Yes
Europe	*EN 50083-3*	Yes	Yes	Yes
Japan	*EIJET-2301*	Yes	Yes	Yes
US	*NCTA/FCC (National Cable TV Association*	Yes	Yes	Yes



a) analog channel (AM-VSB)

b) digital channel (M-QAM)

Fig.2. TV channel

II. MATHEMATICAL MODEL AND ANALYSIS

A. Mathematical model

Based on the presented CATV/HFC network spectrum (Fig.1a) and the mathematical apparatus of Volterra series [5], [6], [7], is proposed a single-frequency dependant model [5], which takes in account the nonlinear inertial features of the

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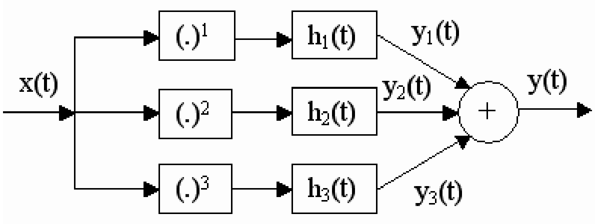

Fig.3. Single-frequency dependent model

system and the electronic amplifiers in it. For perspicuity and to simplify the analysis, every branch is separated in two: a linear inertial and a nonlinear zero memory part. Furthermore each branch describes a nonlinearity of a respective order: 1, 2, and 3.

$$y(t) = y_1(t) + y_2(t) + y_3(t)\,, \tag{1}$$

where in common case

$$y_n(t) = \underbrace{\int_0^{+\infty}\int_0^{+\infty}\cdots\int_0^{+\infty}}_{n} h_n(\tau_1,\tau_2,...,\tau_n)x(t-\tau_1)x(t-\tau_2)... ...x(t-\tau_n)d\tau_1 d\tau_2 ... d\tau_n \tag{2}$$

Moreover, by Inverse Fourier transformation (IFT) in frequency range Volterra kernels are:

$$H_n(f_1,\ f_2, ..., f_N) = \underbrace{\int_0^{+\infty}\int_0^{+\infty}\cdots\int_0^{+\infty}}_{n} h_n(t_1,t_2,...,t_N) \times \exp[-j2\pi(f_1t_1 + f_2t_2 + ... + f_Nt_N)]dt_1dt_2...dt_N \tag{3}$$

where f_1, f_2… f_N are the carrier frequencies of the transmitted signals (channels), where for analog signals – picture carrier (f_{pc}), and for the digital – carrier (f_c), (Fig.2); n=1, 2, 3,... is polynomial order describing transmission performance of the system or amplifier; N is number of channels.

While analyzing the nonlinear distortions and their nonlinear products in this analysis, is used the three-generator method, and the nonlinearity is from second and third order. This way:

$$y(t) = \int_0^{+\infty} h_1(\tau)x(t-\tau)d\tau + \int_0^{+\infty} h_2(\tau)x^2(t-\tau)d\tau + \int_0^{+\infty} h_3(\tau)x^3(t-\tau)d\tau \tag{4}$$

The nonlinear terms in Eq.4 involve only one-dimensional convolution and they in this case can be regarded as being composed of a zero memory nonlinear chain followed by a linear time invariant chain (Fig.3). Since the nonlinearity in an amplifier is usually only a small deviation from the linear design, its transmission performance can be adequately described by the first three terms of the Volterra series expansion in most cases. The analysis and discussion in the sequel will therefore be based on this assumption.

The derived ratios and the resulting formulas are made pursuant to the requirements for the levels of composite distortions from second and third order (CSO, CTB) of the CENELEC EN50083 standard.

For a simplification of the record the summary and the differential frequencies of the nonlinear products [8] will be denoted only with f_b, and will specify of the nonlinear product is from second and third order. The essential here is whether the nonlinear product falls into the channel and not from which, how many or what type of combination of frequencies it has originated.

B. Determination the levels of the nonlinear products

1) Single amplifier

1.1. Two/three channels [9]

1.1.1. Composite distortions from $2^{\text{-nd}}$ order (CSO)

$$CSO = 2G - 20\lg\left|H_2(f_b)\right| - 20\lg A_{out}\ , [dB] \tag{5}$$

1.1.2. Composite distortions from $3^{\text{-rd}}$ order (CTB)

a) by two-component beat

$$CTB^{(2)} = 3G - 20\lg\left|H_3(f_b)\right| - 40\lg A_{out} + 2{,}5\ , dB] \tag{6}$$

b) by three-component beat

$$CTB^{(3)} = 3G - 20\lg\left|H_3(f_b)\right| - 40\lg A_{out} - 3{,}52 \quad , [dB] \tag{7}$$

where:

G- amplifier gain in [dB], $G=20lg|H_1(f)|$;

A_{out} - amplitude of the signal with fundamental (carrier) frequency of the channel;

$|H_n(f_b)|$- Volterra kernel, n = 2, 3;

f_b - frequency of the nonlinear product as a result of beating.

The Volterra kernels are defined in dependence from the amplifier parameters and the signal levels [3] by using the modulation coefficients $MC_n(f_b)$ from second and third order:

$$\left|H_n(f_b)\right| = b_n.(10^{\frac{|MC_n(f_b)|}{20}})^{(1/2)}\text{, where} \tag{8}$$

b_n is obtained from Fig.4.

Since the second/third harmonic is D_n dB below the output level L with fundamental frequency, the modulation coefficient $MC_n(f)$ based on the power unit dBµV is

$$MC_n(f) = D_n(f) - (n-1).L\,. \tag{9}$$

In some cases, it is more convenient to use normalized Volterra kernels $\left|H_n^{'}(f_b)\right|$ to describe the nonlinearity of a system:

$$\left|H_n^{'}(f_b)\right| = \left|H_n(f_b)\right|/(10^{\frac{G}{20}})\,. \tag{10}$$

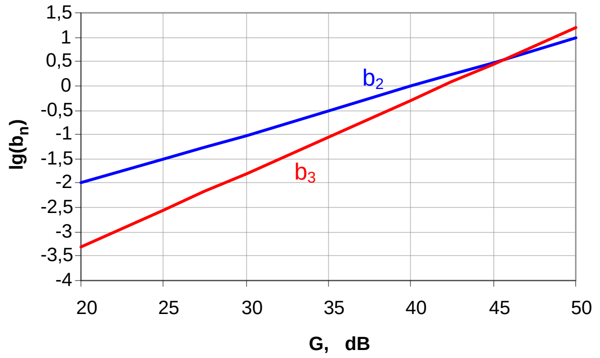

Fig.4. Graphic of the dependence $lg\,(b_n) = func\,(G)$

1.2. For N number of channels

1.2.1. Composite distortions from 2-nd order (CSO_N)

$$CSO_N = CSO - \varDelta_N \text{, } [dB] \text{ where} \tag{11}$$

$\varDelta_N$ is a correction coefficient, that accounts the influence of the number of transmitted channels.

$$\varDelta_N = x.\lg(N-1) \text{, } [dB] \text{ and} \tag{12}$$

the x parameter gets values depending on the method of synchronizing the carrier frequencies of the signals (channels), [10].

1.2.2. Composite distortions from 3-rd order ($CTB_N^{(*)}$)

a) by two-component beat

$$CTB_N^{(2)} = CTB^{(2)} - 2.\varDelta_N - 6 \text{, } [dB] \tag{13}$$

b) by three-component beat

$$CTB_N^{(3)} = CTB^{(3)} - 2.\varDelta_N \text{, } [dB] \tag{14}$$

2) <u>For a cascade of *M* amplifiers and *N* number of channels</u>

2.1. For same amplifiers

2.1.1. Composite distortions from 2-nd order (CSO_M)

$$CSO_M = CSO_N - 10\lg M \text{, } [dB]. \tag{15}$$

2.1.2. Composite distortions from 3-rd order ($CTB_M^{(\bullet)}$)

a) by two-component beat

$$CTB_M^{(2)} = CTB_N^{(2)} - 20\lg M \text{, } [dB]. \tag{16}$$

b) by three-component beat

$$CTB_M^{(3)} = CTBO_N^{(3)} - 20\lg M \text{, } [dB]. \tag{17}$$

2.2. For different amplifiers

2.2.1. Composite distortions from 2-nd order (CSO_M)

$$CSO_M = -15\lg\left[10^{-CSO_1/15} + 10^{-CSO_2/15} + \ldots \right.$$
$$\left. \ldots + 10^{-CSO_M/15}\right] \text{, } [dB]. \tag{18}$$

2.2.2. Composite distortions from 3-rd order ($CTB_M^{(\bullet)}$)

a) by two-component beat

$$CTB_M^{(2)} = -20\lg\left[10^{-CTB_1^{(2)}/20} + 10^{-CTB_2^{(2)}/20} + \ldots \right.$$
$$\left. \ldots + 10^{-CTB_M^{(2)}/20}\right] \text{, } [dB]. \tag{19}$$

b) by three-component beat

$$CTB_M^{(3)} = -20\lg\left[10^{-CTB_1^{(3)}/20} + 10^{-CTB_2^{(3)}/20} + \ldots \right.$$
$$\left. \ldots + 10^{-CTB_M^{(3)}/20}\right] \text{, } [dB]. \tag{20}$$

III. Theoretically and Experimentally Results

Here are presented the results of the theoretically and experimentally study of three amplifiers. In Table 2 is given the data from the theoretically study of the composite distortions from second and third order with N=2 and N=65, and M has values of 1, 6 (8 for VX94G), and 20. The values for CSO and CTB are for the worst case in one broadband radiocommunication (CATV/HFC) system in the range of 111-862 MHz with a standard channel distribution (Fig.1a). The number of analog channels is 50 and has the digital – 15.

Table II

CSO and CTB for three types amplifiers

		CSO		$CTB^{(2)}$		$CTB^{(3)}$	
	M \ N	2	65	2	65	2	65
GLV865	1	67,94	54,39	79,42	46,32	73,40	46,30
	6	60,16	46,61	71,64	30,76	65,62	30,74
	20	54,93	41,38	66,41	20,30	60,39	20,28
VX23B	1	74,44	60,89	83,42	50,32	77,4	50,30
	6	66,66	53,11	75,64	34,76	69,62	34,74
	20	61,43	47,88	70,41	24,30	64,39	24,28
VX94G	1	76,77	63,22	84,29	51,20	78,27	51,18
	8	66,41	54,19	74,39	33,14	68,37	33,12
	20	62,43	50,21	70,41	25,18	64,39	25,16

A comparison of the results from the theoretically and the experimentally research of the three amplifiers, working in a cascade coupling, is presented in Fig.5 and Fig.6 by M=6 for GLV865 and VX23B, and M=8 for VX94G. The number of the programs is N=65. Because the experiments are realized in real operating system, the output levels of the signals for each amplifier are reduced according to the in [10] presented dependences.

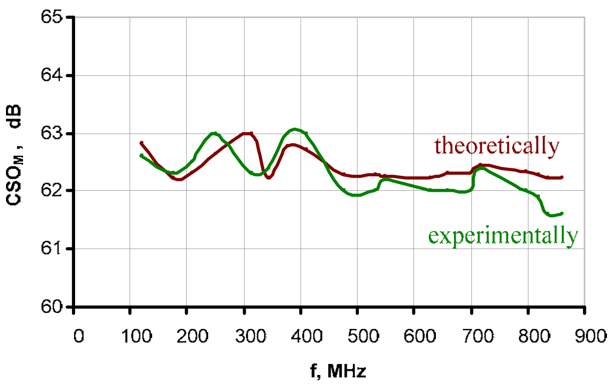

Fig.5. $CSO_M = func(f)$

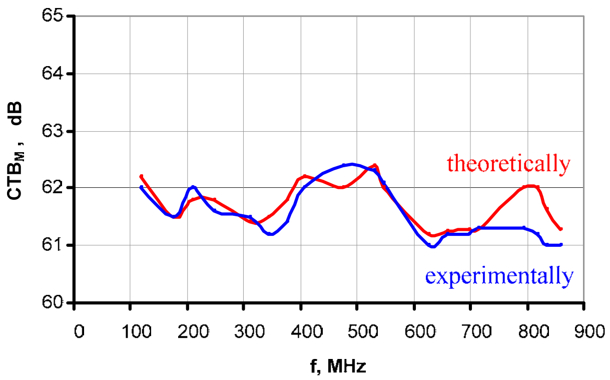

Fig.6. $CTB_M = func(f)$

IV. Conclusion

The proposed method for defining of CSO and CTB allows researching the influence of composite distortions from second and third order as for separate cable amplifiers, as well for systems of cascade connected cable amplifiers.

Experimentally and theoretically values have a difference of barely ±1 dB, which confirms that, the chosen mathematical model and its description with the Volterra series are correct. A precise determination of the CSO and CTB values depends mainly from the measurement accuracy of the Volterra kernels. In this case it is too high, which is also confirmed by the experimental results.

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