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DETERMINATION OF DISTORTION IN BROADBAND AMPLIFIERS FOR DIFFERENT STANDARDS OF SIGNALS IN CATV NETWORKS

Stanimir Sadinov[1], Panagiotis Kogias[2] and Krasen Angelov[3]
[1]Stanimir Sadinov, Faculty of Electrical Engineering and Electronics, dep. KTT, Technical University of Gabrovo, H. Dimitar St. Gabrovo, Bulgaria
[2]Corresponding Author Panagiotis Kogias, Faculty of Electrical Engineering, dep. Electronics and Automatic Control Systems Eastern Macedonian and Thrace Institute of Technology Kavala Greece, Agios Loukas Kavala
[3]Krasen Angelov, Faculty of Electrical Engineering and Electronics, dep. KTT, Technical University of Gabrovo, H. Dimitar St., Gabrovo, Bulgaria
E-Mail: murry@tugab.bg

ABSTRACT
This report relates to the correct calculation of nonlinear distortion in CATV networks - CSO and CTB. Practically this is related to the correct setting of the amplifiers and equalizers need certain places on the network. It is also recognized factors that transmit bidirectional analogue and digital signals and packets having different levels and bandwidth.

Keywords: CTB, CSO, CATV amplifier, QAM, PSK, BER.

1. INTRODUCTION
The main cause of nonlinear distortion in the cable networks amplifiers. These distortions depend on the quality and number or series included in the transmission room amplifiers, their level of input signals and transmitted the number of network television and radio channels. In general, nonlinear distortions are divided into intermodulation and cross modulation as a result of these products come with new frequencies. In cross modulation distortion due to a transmission signal overridden by disruptive new frequency components in the spectrum of useful signal [1], [3], [4]. It is a common practice to denote digital broadcast of TV programs in cable distribution networks by DVB-C. The following conditions are set in order to enable this transmission:

- available cable networks to be usable without changing their structure, their equipment and frequency separation;
- possibility to transmit both digital and analogue signals along the network without causing mutual disturbances;
- selected method of modulation is to allow programs' transmission from a certain satellite (or studio) in the cable network without complicated conversions of digital traffic;
- methods used for processing and encoding of signal should be as close as possible to the methods used with DVB-S and DVB-T;
- selected methods for encoding and modulation should allow for transmission in the network of digital sequence with error density of 10^{-11}.

In the case of DVB-C quadratic amplitude modulation is used which requires high noise to signal ratios, but allows the transmission of larger number of bits per symbol i.e the coefficient of the frequency band is higher. As a rule 64-QAM is used (since the spectrum relationship is three times more effective), however the standard allows the use of 16-QAM, 32-QAM … M-QAM [5], [7], [8].

2. NONLINEAR DISTORTIONS ANALYSIS

A. Inter modulation products analysis
Nonlinear distortions re caused by active devices (amplifiers). In practice we have multi frequency impact at their input - these are the carriers of the individual channels - ω_1, ω_2,… ω_n [1], [2], [4]. CATV amplifier can be regarded as an active four pole piece whose input signal is "x" and the output signal is "y". By approximating by power order of Taylor's function we get $y = f(x)$, where f stands for the translation characteristic at point

$$y = f(x_0) + \sum_{n-1}^{\infty} f^{(n)}(x_0).(x - x_0)^n \quad . \tag{1}$$

Where $f^{(n)}(x_0)$ is the derivative of translational characteristic at operating point x_0.
If we are confined to two signals

$$x = x_0 + a_1 \cos\omega_1 t + a_2 \cos\omega_2 t \quad . \tag{2}$$

Actually only the distortion products of the first two orders are evaluated: IMA2 (second order) and IMA3 (third order - Inter Modulation Amplitude).

B. Calculation of nonlinear distortions
To determine the maximum level of the output signal during translation of a large number of channels according to [5, 7] the usual procedure is to estimate

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intermodulation components by the composite beat of second CSO (Composite Second Order) and third CTB (Composite Triple Beat). In addition, it is known that for amplifiers having upper frequency of *606MHz* test trials are conducted with *29* channels whereas for amplifiers with upper frequency *862MHz* the number of channels is *42*. Estimations of CSO and CTB are carried out along the worst performing channel with predetermined frequency disposition of the channel.

Calculation of maximum output level of the amplifier U_{maxN} (*CTB=60dB*) for distortions of the third order during translation of N number of channels is done by the formula:

$$U_{\max N3} = U_{\max 3} - 10\lg(N/2)\,. \tag{3}$$

Formula (3) shows that with the increase in the number of channels we get the maximum level of the output channel U_{maxN3} drop to the value of $\Delta U_{I(3)}$. By virtue of this when studying the instruction manuals of the selected type of amplifier special note should be taken concerning the assigned values U_{max3}(*IMA =60dB*, *2* channels) and U_{maxN3} (*CTB =60dB*, *42* channels). The difference between them should be about *13 ÷ 14 dB*. If that difference is higher or less than the assigned value, check carefully the parameters in the manuals.

A similar dependence can be derived for a product of the second order (*CSO = 60dB*) by the empirical expression:

$$U_{\max N2} = U_{\max 2} - (3{,}5...4{,}3)\lg(N/2)\,. \tag{4}$$

When conducting real calculations with a large number of channels (N >20) it is preferable to use values close to that recommended by the manuals U_{maxN2} and U_{maxN3} (i.e., according to criterion *CSO = 60dB* and CTB=60*dB*).

$$U_{\max N2} = U_{\max SCO} + (3{,}5...4{,}3)\lg(42/N)\,, \tag{5}$$

$$U_{\max N3} = U_{\max CTB} + 10\lg(42/N)\,. \tag{6}$$

Example 1: Determination of maximum output level of amplifier GPV 841 U_{maxN3} for *29* channels with reference value U_{maxCTB} = *108dBμV* (*42* channels, *CTB = 60dB*).

Solution: By using formula (6) we get:

$$U_{\max N3} = 108 \ + 10\lg(42/29) = 109 dB\mu V\,,$$

which is similar to the reference value *110dBμV*.

Distortions with random output level of the amplifier. By way of analogy with distortions IMA2 and IMA3 with the increase (decrease) of output level of the amplifier signal *D dB*, the intermodulation components of the second order (CSO) are boosted (drop down) to same *D dB* whereas intermodulation components of third order IMA3 are boosted to *2DdB*, i.e.:

$$CSO = 60 + (U_{max\,CSO} - U_{out}), \tag{7}$$

$$CTB = 60 + 2(U_{max\,CTB} - U_{out}). \tag{8}$$

Example 2: Determination of values and CTB when GHV 835 (Hirschmann) amplifier is used with reference parameters U_{maxCSO} = *104dBμV* and U_{maxCTB} = *102dBμV* (*42* channels, *CTB = CSO = 60dB*) at U_{out} = *95dBμV*.

Solution: By using formulae (7) and (8) we get:

$$CSO = 60 + (104 - 95\ ) = 69 dB,$$
$$CTB = 60 + 2(102\ \ - 95) = 74 dB.$$

General case. In this way by using formulae (5 ÷ 8) we get experessions for calculation of CTB including a random number of channels and random output operating level:

$$CSO = 60 + (U_{max\,CSO} - U_{out}) + 4{,}3\,lg(42/N), \tag{9}$$

$$CTB = 60 + 2[U_{max\,CTB} - U_{out} + 10\,lg(42/N)]. \tag{10}$$

Example 3: We find the values for CSO and CTB for amplifier YCM-800-2737 (Standard telecom) of U_{maxCTB} = 114*dBμV* and U_{maxCSO} = 110*dBμV* (*42* channels *CTB = CSO = 60dB* and balance between channels of *9dB*) for translation of *50* channels at U_{out} = *105dBμV*.

Solution: By altering the numeric values in (9) and (10) we get:

$$CSO = 60 + 110 - 105 + 4{,}3\lg(42/50) = 64{,}7 dB,$$
$$CTB = 60 + 2[114 - 105\ \ + 10\lg(42/50)] = 77{,}8 dB.$$

Accumulation of distortions along the lines is effected by formulae:

$$CSO_{\Sigma} = -10\,lg(10^{-CSO1/10} + 10^{-CSO2/10} + ... + 10^{-CSOi/10}), \tag{11}$$

$$CTB_{\Sigma} = -10\,lg(10^{-CTB1/20} + 10^{-CTB2/20} + ... + 10^{-CTBi/20}), \tag{12}$$

Formulae (11) and (12) indicate that distortions of third order (CTB) are generated quite easily as compared to distortions of the second order (CSO). For n amplifiers switched on in cascade with equal values of CTB and CSO the total number of distortions is determined by the formula

$$CSO_{\Sigma} = CSO - 10\,lg\,n, \tag{13}$$

$$CTB_{\Sigma} = CTB - 20\,lg\,n. \tag{14}$$

Thus for *5* amplifiers in a series (example 3) CSO_{Σ} = *57,7dB* (decrease to *7dB*) and CTB_{Σ} = *63,8dB* (decrease to *14dB*).

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Let's consider another example.

Example 4: We find the extreme values CTB_Σ and CSO_Σ provided that the inherent values of CSO and CTB are known at the output of each active device. Main station *CSO = 72dB*, *CTB = 84dB* optic system: *CSO = CTB = 65dB*; highway amplifiers: *CSO = 74dB*, *CTB = 82dB*; subscriber amplifiers: *CSO = 72dB*, *CTB = 66dB*

Solution: By substituting numeric values in (11) and (12) we get: $CSO_\Sigma = 62{,}5dB$, $CTB_\Sigma = 57{,}3dB$.

Example 5: How many amplifiers of one type can be switched on in a series if their individual $CTB_i = 84dB$ (conducted system calculation) with $CTB_{out} = 57dB$. Total CTB of all other devices is $CTB_\Sigma = 64dB$.

Solution: We calculate the permissible value of distortion ΔCTB entering the highway amplifiers from (10):

$$\Delta CTB = -20\lg(10^{-CTB_{usx}/20} - 10^{-CTB_\Sigma/20}) = \\ = -20\lg(10^{-57/20} - 10^{-64/20}) = 62{,}1dB .$$

This means that such CTB are permissible for all highways for storing of final $CTB_{out} = 57dB$

2. We find the maximum number of highway amplifiers (14):

$$n \le 10^{(CTB_i - \Delta CTB)/20} = 10^{(84-62{,}1)/20} = 12{,}4,$$

i.e., we found 12 equal amplifiers each of which has *CTB=84dB*. This guarantee final $CTB_{out} > 57dB$. For requirement (*CTB > 57dB*). Up to 21 amplifiers can be switched on at any equal terms.

Measuring CTB and CSO by [3] are different in the methods they employ, however, all sets of methods boil down to the following:

a. At the amplifier input or the main station we enter N_{test}. unmodulated carrying signal whilst at the output of the tested object we switch on a spectrum analyzer

b. The spectrum analyzer helps fix the levels of useful signal in the tested channel.

c. The spectrum analyzed is set to a maximum sensitivity mode. Combination components are observed, video carriers (by rule they are divided by frequencies which withstand from the carrier by 0, 0.25 and 0,5 MHz) and then their levels are fixed The difference in levels is expressed in dB and make up the CSOs and CTBs

C. Program medium for determining error probability in using digital modulations-BER Calculator

Calculation of BER for M-PSK and M-QAM is done either by estimation of symbol error probability or by evaluation of upper and lower boundaries of noise level. Accurate analysis of system's BER often appears to be too complex and, usually, there should be further processing of results. However, the use of boundaries cannot always guarantee sufficient accuracy as long as the transformation of SER (Symbol Error Rate) into BER is generally not quite true. Thus the mathematical model can reach maximum agreement with the properties of the physical object under investigation [5], [8].

The program used for computer simulation has been developed on Delphi which is similar to MATLAB; however, it has no strictly defined scientific orientation. On the other hand this language is compiled completely which is why performing a large number of calculations (needed in achieving the assigned accuracy in the statistical analysis) does not pose a problem concerning the time necessary for calculations. The program uses individual user's interface (Figure-1), however, for the purpose of compatibility with MATLAB numeric results are written in a data file (BER.dat).

Figure-1 presents the main window of a BER Calculator - module of Delphi. This program is implemented with the purpose of demonstrating the principle of building up a larger program application which allows complete computer analysis of the information system in use and uses a large data base of structures (designs) and parameters. Nevertheless, the presented program allows for drawing up of analysis of systems' performances based on M-PSK and M-QAM manipulations.

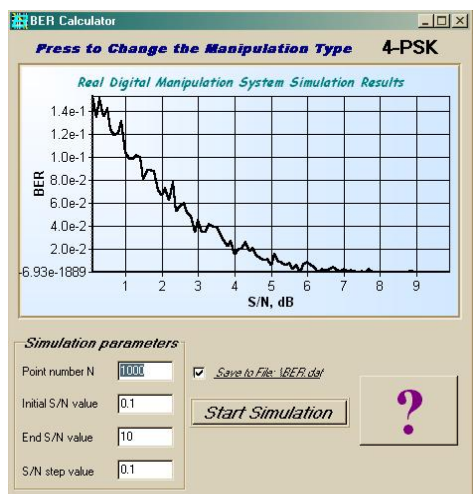

Figure-1. User's graphic interface of BER Calculator.

Are automatically re-calculated. The rest of the data is assigned on the main window at the time of initialization; count of random numbers employed in the Monte Carlo method (in this case N=1000), initial/end speed and a step of change of the signal to noise ratio (by default S/N = 0.1 ÷ 10). BER=BER(S/N), graphic dependency is drawn by the program and the numeric outcome is written in a table in BER.dat file (this function can be overruled with the note *save to file: \BER.dat*).

D. Optimization of amplifier output level

By analyzing the above formulae we draw the following conclusion: the lower the output level of the amplifier the lesser its nonlinear distortion. From this

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follows that it is enough to transmit TV signals at lower input/output levels to solve the problems. In fact it is just the opposite. Apart from the observed nonlinear distortions ther is the requirement which states that the signal to noise (*S/N*) ratio should not be lower than 44dB [3]. *S/N* at the output depends on the noise parameters of the source itself, the noise parameters of the main station, the optic system, amplifiers, operational modes and their values.

This dynamic range is a convenient value for conducting system calculations and shows the magnitude of S/N ratio, which is generated at the amplifier output when “ideal” “quiet” signal is entered at its input [1], [3], [5], [9].

$$S/N_{[dB]} = U_{out[dB\mu V]} - K_{[dB]} - F_{[dB]} - 2{,}4 \qquad (15)$$

It is evident that U_{out} *-K* indicates the level of input signal that is entered directly through the first amplifier (no account is taken for the losses of the input device - attenuator and equalizer). From (15) it is evident that the larger the amplifying coefficient the lower its *S/N* ratio. We discussed the means of selecting proper amplifier in [4]. Here will note that for most highways which employ *7 ÷ 10* amplifiers, when it is necessary to keep maximum possible output *S/N* ratio amplifiers with smaller amplifying coefficients should be selected. This, however, is very expensive due to the large number of amplifiers switched in series.

Developed alone Windows application to Delphi. The program is designed to calculate the main parameters of the cable television network. On fig.2 presented graphic interface software application considered here.

The basic methodology, developed in Cable TV Designer, designed for automated design of network television. The program allows optimizing the number of amplifiers that is the required gain K_{nom} or price of an individual amplifier.

The procedure calculates the maximum number of steps N_{max}, comparing noise (S/N) and nonlinear distorti on (CTB), respectively, minimum and maximum output level (Figure-3).

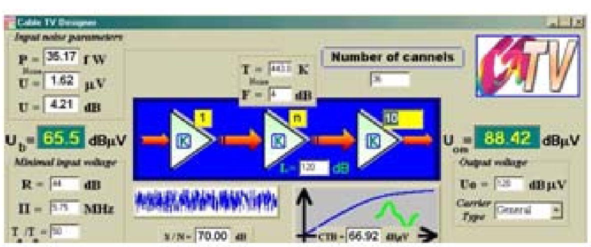

Figure-2. Graphical Interface Cable TV Designer.

On Figure-3 shows the dependence of the signal / noise and nonlinear distortions of the number of amplifier stages. The optimum number of amplifiers is determined automatically by a set limit of the signal / noise. Then optimize the gain of an individual amplifier.

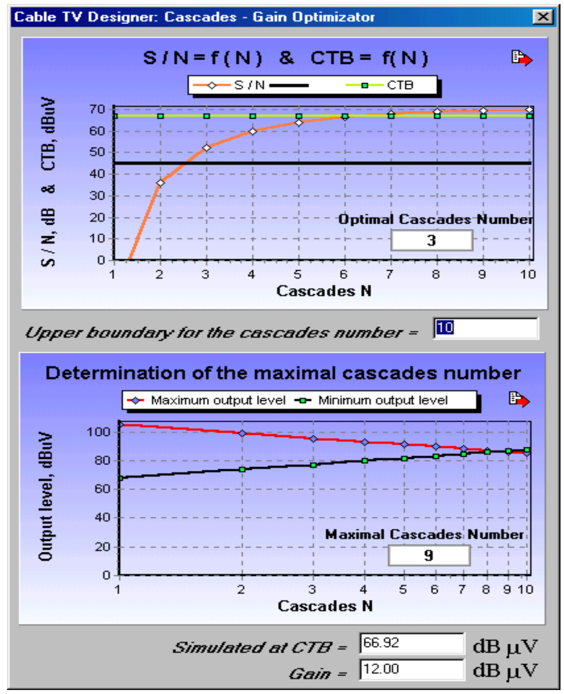

Figure-3. Windows optimizer is the number of amplifiers used.

Identify dependencies and the signal/noise and nonlinear distortion of the number of channels transmitted over the network (Figure-4).

The output signal levelis examined as a function of the ratio S/N and the size of CTB (Figure-5). The program features a fully working in interactive mode by providing concurrent, helpfor all input and calculated parameters of the cable network.

The application is protected from errors by continuous control over user input values. In development is used object-oriented language Delphi. Graphical data can be stored in vector format (meta files) or raster (bit map).

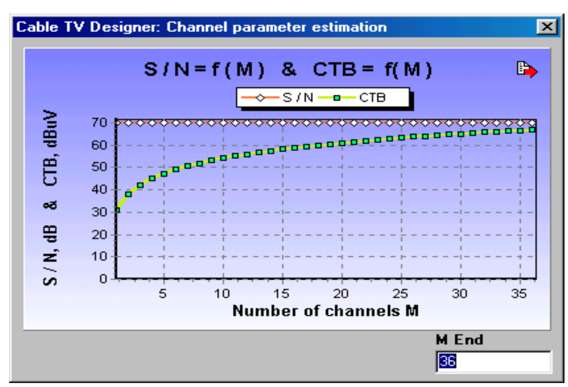

Figure-4. Investigation of the dependence of S/N and the number of CTB translation channels.

ARPN Journal of Engineering and Applied Sciences

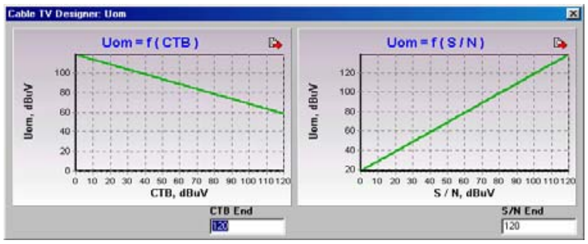

Figure-5. Investigation of the dependence of the output level of nonlinear distortion and the signal / noise.

3. CONCLUSIONS

The optimum level is that output level, which allows for technological reserves (for example, climate conditions when effecting overhead laying of cables) as well as of intermodulational distortions CTB and CSO. Another important factor is the proper S/N ratio when designing and laying CATV networks. Then optimum operating output level for amplifiers could be found by the formula:

$$U_{outopt} = \frac{U_{\max} + 2U_{\min}}{3} \quad , \tag{16}$$

where U_{max} is the maximum permissible value of the amplifier output level provided CTB and CSO were carefully considered while designing the network. U_{min} is the minimum permissible value at the amplifier output, which is affected if the S/N ratio is protective. The number of nonlinear products output amplifiers highway depends not only on the number of input effects, but the degree of nonlinearity of their transmission characteristics. Determination of their number allows to quickly find the optimal solution according to the maximum (minimum) number of transmitted television signals and output voltage of the amplifiers.

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