RESEARCH OF THE CHARACTERISTICS OF AN OPTICAL CHANNEL OF HFC CATV SYSTEMS

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In this article it is presented a mathematical model of the optical channel of hybrid fiber/coaxial (HFC) system for cable television (CATV) and the results of the implemented simultaneous researches of its characteristics. The model describes the dependence of the noise level and the nonlinear distortion products in the optical channel on the parameters of the optical components that build it up and those of the transmitted optical signal. There are given results of the research of the influence of the optical modulation depth, the number of the transmitted programs and the input optical power, on the parameters carrier-to-noise ratio (CNR) and carrier-to-interference ratio (CIR) at the channel output. The obtained optical channel characteristics in the simulation are compared to its experimentally established characteristics in order to evaluate the accuracy of the used mathematical model. The results of the comparative analysis show that the deviation does not exceed 2.1 % , which confirms the possibility to apply the exposed method when projecting HFC CATV systems.

Keywords: Carrier-to-Noise Ratio, Carrier-to-Interference Ratio, Optical Modulation Depth, Optical Input Power, Number of Channel

1. INTRODUCTION

When transmitting signals through an optical channel of a HFC CATV system, the signals reduce and noise and nonlinear distortion products are being added to them. As a sequence *CNR* and *CIR* from the second (SCO) and third (CTB) order of the channel output decrease and therefore the quality and the authenticity of the transmitted information decrease, too. According to the standard minimum value of *CNR* in the subscriber's contact is 43 dB, which makes necessary this parameter to be maintained more than 52 dB in the optical channel output. The following values are the permissible minimum of the *CIR* parameter: 54 dB in the subscriber's contact and 60 dB in the optical channel output.

Quality of the television and radio programs transmitted through the optical channel as well as the authenticity of the data transmitted through it is defined by the channel characteristics. The parameters and the working regimes of the components that build it up – laser, optical modulator and amplifiers, photodiode receiver and optical fiber influence significantly upon the optical channel characteristics. On the other hand the working regimes of the channel optical components depend on the parameters of the transmitted optical signal which are defined by the number of the transmitted RF signals, the optical modulation depth coefficient, the input power of the optical transmitter, the optical power loss in the fiber link and the passive elements.

The aim of this work is to be synthesized a mathematical model of an optical channel of HFC CATV that calculates the influence of the listed factors on its characteristics. This model is destined to simulation researches orientated towards optimizing the parameters of the existing elements used in the channel, as well as the transmitted signals.

2. MATHEMATICAL MODEL OF THE OPTICAL CHANNEL

At the ends of the optical channel of the HFC CATV it is included a laser transmitter that have direct or external modulation and photodiode receiver. The loss in the fiber is compensated by optical amplifiers. To create the mathematical model of the optical channel it is used the configuration on Fig. 1, where the modulation of the optical signal is accomplished at external modulator type „Mach-Zehnder".

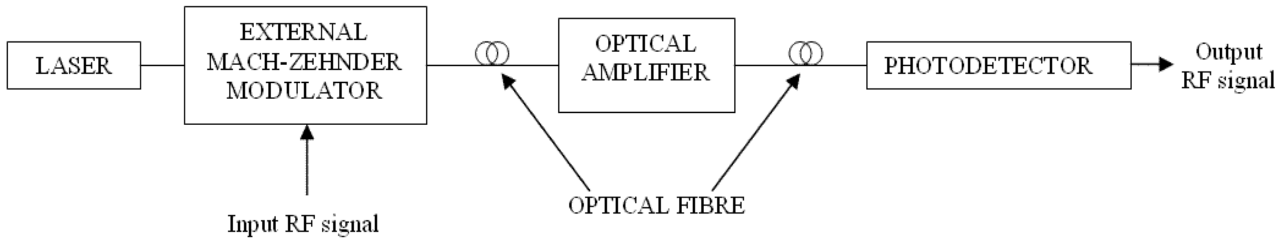

Fig. 1 Optical channel of HFC CATV system

In the mathematical description of the channel noise characteristic are used root mean square (rms) values of the detected photocurrent as well as the currents of the different noise sources passing through the output resistance of the optical receiver. The relative intensity noise (*RIN*), the thermal and the shot noise of the photodiode, as well as the noise added by the optical amplifier – amplified spontaneous emission (ASE) have the most essential influence on the noise level at the optical channel.

The rms value of the detected photocurrent could be presented by the following relation [1]:

(1) $\left\langle I_{PD}^2 \right\rangle \approx 0{,}5 \cdot I_{Rx}^2 \cdot m^2$,

where I_{Rx} is the current received in one RF channel of bandwidth B (4.75×10^6 Hz) and m is the optical modulation depth per channel.

The rms values of currents, created by the laser RIN (I_{RIN}), the photodiode shot noise (I_{SH}) and the receiver thermal noise (I_{TH}) are described as follows [2]:

(2) $\left\langle I_{RIN}^2 \right\rangle = I_{Rx}^2 \cdot RIN \cdot B \qquad \left\langle I_{SH}^2 \right\rangle = 2 \cdot e \cdot I_{Rx} \cdot B \qquad \left\langle I_{TH}^2 \right\rangle = 4 \cdot k \cdot T \cdot F_{RA} \cdot B / R_L$,

where e is the electron charge (1.6×10^{-19} C), F_{RA} is the amplifier noise factor, k is the Boltzman constant (1.38 × 10 23 J/K), R_L is the load resistance.

When calculating the noise current of the optical amplifier should be taken into consideration the components not only of the ASE, but also these, received by the beating between the useful signal and the ASE products and between the ASE products. To calculate the total noise current of the optical amplifier I_{OA} could be used the next formula:

(3) $$\left\langle I_{OA}^2 \right\rangle = I_{Rx}^2 \cdot B \cdot F_{OA} \cdot \left(\frac{2 \cdot h \cdot c}{\lambda \cdot P_{OAin}} \right),$$

where F_{OA} is optical amplifier noise factor, h is Planck constant (6.63 × 10^{-34} J.s), c is speed of light (3 × 10^8 m/s), λ is the wavelength and P_{OAin} is optical amplifier input power. Taking into consideration the expressions above, it could be concluded the following [3]:

(4)
$$CNR_{RIN} = \frac{m^2}{2 \cdot RIN \cdot B}; \qquad CNR_{OA} = \frac{P_{OAin} \cdot \lambda \cdot m^2}{4 \cdot h \cdot c \cdot B \cdot F}$$
$$CNR_{SH} = \frac{P_{Rx} \cdot R_{PD} \cdot m^2}{4 \cdot e \cdot B}; \qquad CNR_{TH} = \frac{P_{Rx}^2 \cdot R_{PD}^2 \cdot m^2}{2 \cdot B \cdot I_n^2}$$

where P_{Rx} is the optical power in the optical receiver input, R_{PD} is the receiver responsivity and I_n^2 is the thermal noise equivalent current of the RF amplifier.

The CNR at the optical channel output can be expressed by [3][4]:

(5) $$CNR_{CH}[dB] = -10 \cdot \lg\left(10^{-\frac{CNR_{RIN}}{10}} + 10^{-\frac{CNR_{OA}}{10}} + 10^{-\frac{CNR_{SH}}{10}} + 10^{-\frac{CNR_{TH}}{10}} \right).$$

The main source of nonlinear distortions in the optical channel is the externally switched optical modulator type "Mach-Zehnder", which is the reason for adding new nonlinear distortion products, due to non symmetric in the both arms and could be described as follows [1][5]:

(6) $$CIR = \frac{16}{m^4 \cdot N_{CTB}} = \frac{128}{m^4 \cdot \left(3 \cdot N_{ch}^2 - 10 \cdot N_{ch}\right)},$$

where N_{CTB} is the number of the CTB products in the frequency band of the transmitted RF signal and N_{ch} is number of transmitted RF channel. To obtain the final formula (6) should be admitted the following: the maximum number of nonlinear distortion products is obtained at channel number $N_{ch}/2$; the value of m is much less than one.

When using a regular modulator type "Mach-Zehnder" the level of the received nonlinear distortion products is unallowably high which makes necessary applying some of the methods of linearization. To perform simulation researches the authors apply the method of cascade connected two identical modulators of this type. This way it could be decreased the level of the *CIR* products by more than 25 dB, respectively increased the parameter *CIR* by more than 20 dB [6].

3. Results of Simulation Researches of the Optical Channel Characteristics

The described mathematical model in expressions (4), (5) и (6) is applied when researching some important characteristics of the optical channel of HFC CATV systems. These expressions are referred to a channel that has components having the following parameters:

- DFB laser diode – CQF938/600, *RIN* = 162 dB/Hz

- Photodiode receiver that uses PIN photodiode – PD-1150, responsivity $R_{PD} = 1$ A/W
- Optical amplifier with input optical power $P_{inOA} = 5$ dBm and noise figure $NF = 5.5$ dB.

On Fig. 2 it is performed the dependence of *CNR* versus *m* under input optical power at the optical receiver (P_{Rx}). It could be noticed that when *m* and P_{Rx} increase then the parameter *CNR* at the output of the optical channel also increases.

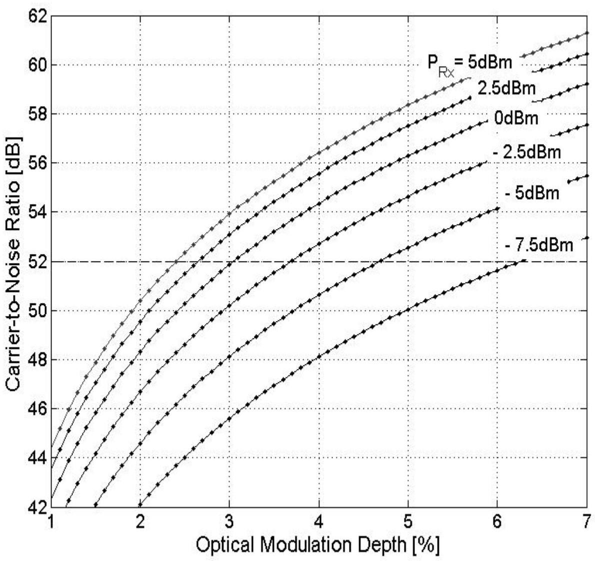

Fig. 2 CNR vs. m under P_{Rx}

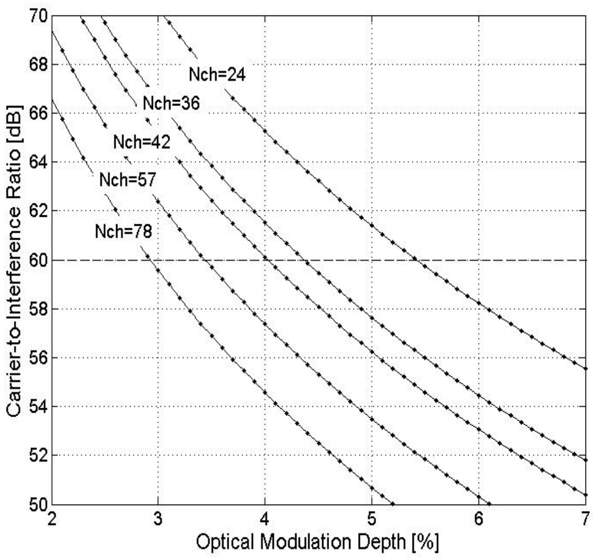

Fig. 3 CIR vs. m under N_{ch}

On Fig. 3 it is performed the dependence of *CIR* in the optical channel output versus *m* under the number of the transmitted RF channels N_{ch}. Unlike *CNR*, the parameter *CIR* decreases when *m* increases. It could also be seen that the increase of the number of the transmitted channels leads again to decrease of the parameter *CIR*. This dependence could be explained the following way: when increasing the N_{ch} then the number of CTB products increase.

The presented mathematical model of an optical channel of HFC CATV system allows to be solved specific problems connected with its projecting. For example such problem is determining the optimal optical power at the receiver input when the parameters of quality *CNR* and *CIR* and number of transmitted channels N_{ch} is assigned.

In this case by the characteristics given on Fig. 3 could be defined the value of *m* and by the characteristics on Fig. 2 – could be found the value of P_{Rx}.

When P_{Rx} is known and the parameters *CNR* and *CIR* are assigned, then the critical parameter for the system is the number of the RF channels N_{ch}. Then by the characteristics on Fig. 2 could be defined the optimal value of *m* and by the characteristics on Fig. 3 – the admissible number of the RF channels which can be transmitted with minimum distortions.

On Fig. 4 it is illustrated the dependence of P_{Rx} versus N_{ch} when CNR = 52 dB, CIR = 60 dB and parameters of the optical components, building up the channel are assigned above. It could be simply calculated that when $N_{ch} = 36$ then the necessary value of the optical power at the photodiode receiver input should be - 3.32 dBm, for $N_{ch} = 42$ – $P_{Rx} = -2.58$ dBm, for $N_{ch} = 57$ – $P_{Rx} = -0.95$ dBm and for $N_{ch} = 78$ – $P_{Rx} = 1.09$ dBm.

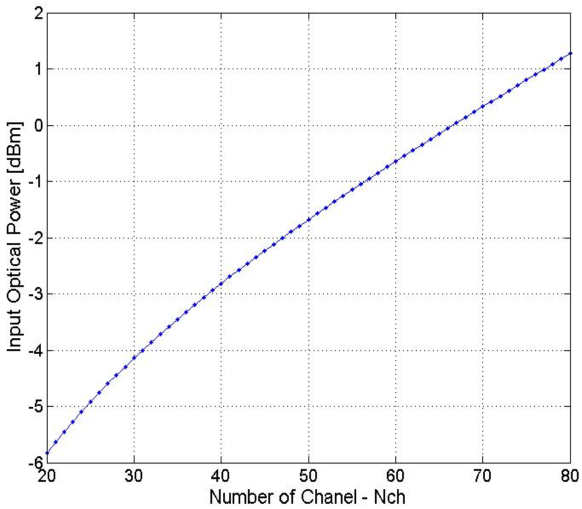

Fig. 4 P_{Rx} vs. N_{ch}

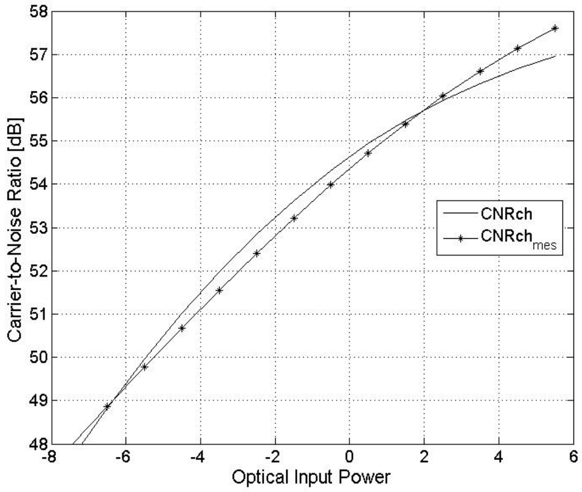

Fig. 5 CNR vs P_{Rx}

4. EVALUATION OF THE DEVIATION IN THE SIMULATION

The received characteristics by simulation research of the optical channel of HFC CATV system are compared to the experimentally calculated characteristics of a real channel having the same parameters of the used optical components and the transmitted signals.

On Fig. 5 is shown the dependence of *CNR* versus P_{Rx}, obtained as a result of the simulation (CNR_{ch}) and the experiment ($CNR_{ch\ mes}$). The data processing shows that the average relative deviation in this case is approximately 1.2 % and the maximum relative deviation is 2.08 % or 1.1 dB. The results of the made comparativeanalysis confirm the possibility to apply the described method when projecting HFC CATV systems.

5. CONCLUSION

The suggested mathematical model of optical channel of CATV gives the possibility to research its basic characteristics with accuracy, well enough for the engineer practice (the deviation of the measured characteristics of a real channel does not exceed 2.1 %). It allows to be analyzed how the optical channel parameters, building up the channel, as well as the parameters of the transmitted signals influence on the quality of the received information. Moreover, the suggested method would make projecting of such system easier, when constructing an optical channel and optimizing the working regimes of the optical transmitters, amplifiers and receivers used in it and they are good basis when optimizing the parameters of a real optical channel.

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