Analysis of the reasons for limiting the dynamic range of the signals in CATV systems

Valentin I. Topchiev[1] and Lidia T. Jordanova[2]

Abstract: **In this article are considered the principals of building up a CATV System and is given a general characteristic of the elements that build them up. It is defined the dynamic range of the signals in CATV systems and also are analyzed the reasons for its limitation. It is discussed the different sources of noises and nonlinear distortions in the optical and coaxial part of the system.**

Keywords: **CATV, dynamic range, noise, nonlinear distortion, laser, photodiode receiver, optical fibre, optical and RF amplifier.**

I. INTRODUCTION

Community antenna television (CATV) systems are utilized for providing general-access and extra services of enormous number of customers. General-accessible services include fairy and satellite radio and TV programs. In this case the signals are transmitted from one provider to many subscribers. The extra services include the high-speed internet, the IP telephony, the video-on-demand, the home automation and control etc. The extra services are individual and the signals are transmitted from one provider to one subscriber, which requires also the building up of reverse channel. [1]

In order to project a CATV system and optimize the dynamic range of the RF signals in critical points, it is necessary to analyze the reasons for the noise and nonlinear distortion appearance. Moreover, a very good knowledge of the architecture of the CATV system and the parameters of the components that build it up (lasers, photodiode receivers, optical fibres, optical and RF amplifiers) are required. [2]

II. HIERARCHICAL PRINCIPLE OF BUILDING UP A CATV SYSTEM

The contemporary CATV system is a type of hybrid fibre coaxial (HFC) system [3]. As a carrier area in the optical part are used single-mode optical fibres for two ranges of the wavelength – 1310 nm and 1550 nm. [4] In the coaxial part is used standard coaxial cable with wave resistance 75 Ω.

The architecture of the HFC system is built in a hierarchal principle and is shown on figure 1. In the general case the system includes four hierarchical levels. [1]

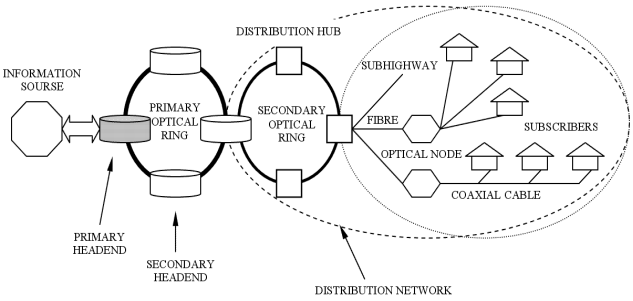

Fig. 1. Architecture of CATV system.

The first level in the hierarchy of the CATV system is a superhighway system, which includes primary optical ring, primary and secondary headends. The primary headend combines few small autonomous systems and provides service to more than 200 000 subscribers, while the secondary ones are local and serve usually to between 50 000 and 200 000 subscribers. [5]

The second hierarchical level is a highway system (secondary optical ring), providing connection between the distribution hubs and the optical rings [6]. One distribution hub serve up to 16 distribution points or 40 000 subscribers.

The third level in the hierarchy of the system is subhighway network. It connects the distribution hubs with the fibre nodes, where the conversion of the light stream into electrical current occurs and vice versa. The fibre node has two or four inputs/outputs and is able to serve between 250 and 1 000 subscribers. [7]

The fourth hierarchical level is the subscriber system, which is a coaxial cable distribution network (CCDN). It connects the optical nodes with the subscriber's home.

The tendency in building the CATV system is the optical fibre to reach the customer's home. Fibre to the home (FTTH) is the ideal optical communication architecture. FTTH meets the requirements for high-speed data transmission, high-fidelity sound, as well as high-fidelity video signal. [8, 9]

III. GENERAL CHARACTERISTIC OF THE CATV SYSTEM ELEMENTS

The main components which build up the optical channel of one CATV system when using direct (a) and external (b) modulation of the laser are shown on figure 2. In the first case, the modulating signal is added to the laser pre-voltage, whilst in the second – goes to the input of the external modulator. [10]

In CATV System, as a light-source are preferred laser diodes of the distributed feedback (DFB), distributed Bragg

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reflector (DBR), vertically cavity surface emitting laser (VCSEL). They emit in a very narrow frequency band and have low level of the insertion noise and nonlinear distortions. [11, 12] The most frequently used optical modulators in these systems are: Mach-Zehnder modulator, electro-absorption modulator and phase modulator. [13, 14]

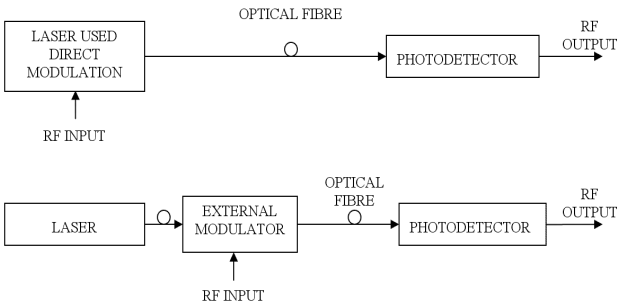

Fig. 2. Optical channel with direct a) and external b) modulation.

The optical fibers used in the range of 1310 nm have insertion loss about 0.35 dB/km, while in the range of 1550 nm – about 0.2 dB/km. It is typical for the optical fibres is the phenomenon dispersion (chromatic and polarization), which leads to transmission speed and optical line length limitation. If $\lambda = 1310$ nm then the chromatic dispersion in single-mode fibre decreases to zero, while if $\lambda = 1550$ nm it has comparatively high values, which requires the use of fibres with displace dispersion. To compensate the loss in the optical fibre and the passive components are mainly used erbium-doped fiber amplifiers (EDFA) and Raman amplifier. [15, 16]

The main element in the structure of the optical receiver is the photodiode (avalanche and PIN), whose way of working is based on the photoelectric effect. Moreover, the optical receiver includes circuit for impedance coherences, RF amplifier and control and alarm system. [16]

The CCDN of the CATV System ensures the connection of its optical part with the subscribers. To compensate the insertion loss in the coaxial cable and the passive elements are used RF amplifiers. [17]

IV. DETERMINATION OF THE DYNAMIC RANGE OF THE SYGNAL IN CATV SYSTEMS

The dynamic range is defined as the difference between the largest and the smallest signal power, which could be feed to the input of the communication channel. The maximal value of the input RF power is limited by the largest acceptable level of the nonlinear distortion products in the channel output. The minimum level of the input signals is limited by the minimal carrier to noise ratio (CNR). [18]

The bigger area range of the CATV System leads to increased number of sequentially plugged into the network sources of noises and nonlinear distortions which reduces the dynamic range of the input RF signals. This is one of the reasons for the limitation of the communication channel length.

The dynamic range of the signals in the optical channel is defined by the minimum and maximal level of RF signals, entering into the input of the laser transmitter. There are three types dynamic range – compression dynamic range (CDR), spurious-free dynamic range (SFDR) and working dynamic range (WDR), which are defined on figure 3. [1, 2, 19]

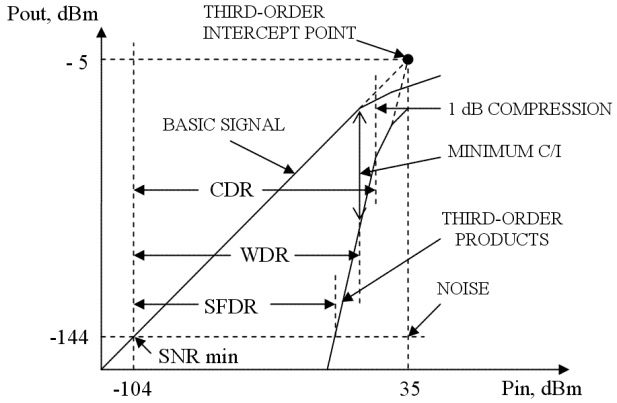

Fig. 3. Dynamic range of the signals in the optical channel.

The dynamic range of the signals of CCDN depends mainly on the parameters of the RF amplifier, the number of the cascade connected amplifiers and the number of transmitted radio- and TV channels.

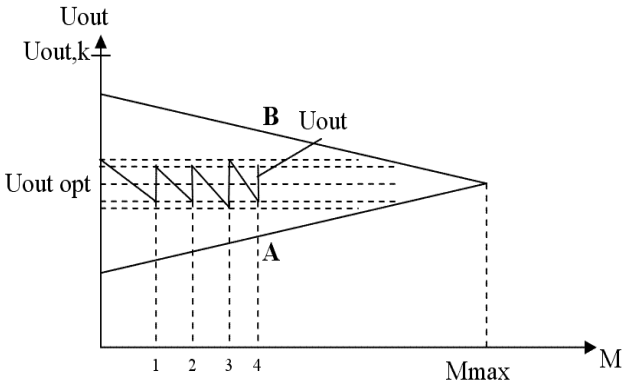

Fig. 4. Dynamic range of the signals in CCDN.

The acceptable limits of variation of the RF signal levels in each RF amplifier outputs are shown on figure 4. The lowest level (“A”) is defined by the minimum CNR in the subscriber’s contact. The limitation of the RF signal maximal level (“B”) is related to the acceptable nonlinear distortions in the subscriber’s contact. [20]

V. ANALISIS OF THE REASONS FOR OCCURRENCE OF THE NOISES IN CATV SYSTEM

When transmitting signals through CATV System, noises from different sources are added. It is very important when defining the total noise to know the kind, the typical properties and the area of generating the noise. The most

significant influence when defining the total system noise has the thermal noise, the shot noise and the relative intensity noise (RIN) of the laser. In the CATV System are also generated many other noises, whose influence is not so essential.

The thermal noise is generated while electrical current passes through each electronic element and depends on the working temperature, the frequency band and the value of the equivalent active resistance. The main sources of thermal noise are circuits for impedance coherence in the optical transmitter and receiver and also the optical and RF amplifier. CCDN which has a resistance 75 Ω is also considered as a source of thermal noise, whose level is about 2 dBμV (T = 17 °C, B = 5 MHz). [21]

When the light sources convert the electrical signal into light stream different noise components are added to the useful signal. The most significant is the influence of the laser RIN, its phase noise and the refractive noise.

RIN has a quantum nature and is caused by the imperfection of the conversion process (electron – photon) in the laser material. In the active laser layer occur random emissions of a wide number of photons, causing random modulation og the generated light. RIN depends on: working temperature, laser exciting current and optical feedback, created by the reflection of the optical fibre. [22, 23]

The phase noise has random nature and is caused by the spontaneous photon emission in the emitting layer of the laser. It leads to phase fluctuations of the output signal and extending of the spectral line, which for FP lasers ranges between 1 – 10 nm, while for DFB is less than 100 MHz. [24]

In the optical modulator except the considered thermal noise is generated signal-spontaneous noise and spontaneous-spontaneous noise. The former depends on the total light power and the latter, which is dominating – on the modulator gain.

Besides the noises, generated in the exciting laser, the optical amplifier creates also noises by signal-spontaneous beating, spontaneous-spontaneous beating, multipath interference, double-Rayleigh backscatter and amplified spontaneous emission (ASE) [25]. ASE is due to the natural redistribution in the different power levels and generated shot noise in the receiver. The level of the caused by ASE noise is much lower than that of the generated by the mean optical power of the signal noise and for this reason could be neglected. [26]

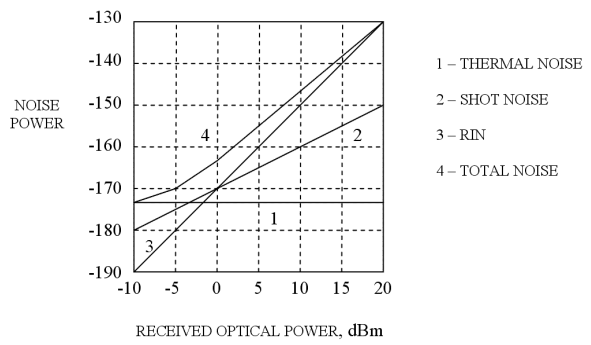

Fig. 5. Noise in CATV system.

Defining for the optical receiver are the shot and thermal noise. The shot noise has quantum nature and is generated in the receiver photodiode. The reason for its occurrence is the imperfect conversion “photon-electron”.

The polarized noise has a random nature and is related to the gain dependence on the polarization and the polarized mode dispersion of the fibre. It is characterized with unequal attenuation of each mode in the output signal and leads to serious losses as a result of the polarization and therefore to reducing the CNR at the input of the optical receiver.

The noises created in the optical part of the system are given on figure 5. When the level of the received optical power is low, then the thermal noise of the photodiode receiver dominates, while in case of high level – dominates the laser RIN. [1]

VI. NONLINEAR DISTORTIONS IN CATV SYSTEM

The nonlinear distortions are reason for creating new frequency products in the spectrum of the useful signal, as a result of which the reliability of the received information deteriorates. The main sources of the nonlinear distortions are the optical transmitter, the optical fibre and the RF amplifiers. In the firm documentation of the optical transmitters are given the optimal value of the parameters which guarantee the defined level of the nonlinear distortions. The nonlinear distortions in the optical fibre are due to few events which happen when the level of the transmitted signals are very inadmissible high. They could be divided into two groups – nonlinearity, related to the scattering (stimulated Brillouin scattering and stimulated Raman scattering) and nonlinearity related to the Kerr effect (four-wave mixing, cross phase modulation, self-phase modulation) [27].

Stimulated Brillouin scattering (SBS) is a nonlinear event which happens when optical power, larger than a defined threshold value, is feed to the fibre. SBS threshold depends on the width of the laser spectrum line and its output power. SBS leads to scattering of large part of the optical power transmitted through the optical fibre and this is the reason for reducing SNR at the input of the optical transmitter. In general when using the sources with narrow spectral line and external modulation, the SBS threshold varies from 5 to 10 mW. If using lasers with direct modulation then this power varies between 20 – 30 mW. [28, 29]

The event stimulated Raman scattering (SRS) is similar to SBS. SRS threshold power is much bigger than SBS one and reaches values about 1 W. The final effect of SRS is transferring signal power from the channels with low wavelength to channels with large wavelength. That power transfer in some cases has a positive effect, for example Raman amplifier. [28, 29]

Self-phase modulation (SPM) is an event that happens when digital signals are transmitted through the optical fibre. It is a result of changing the reflect coefficient of the optical fibre depending on the power feed to it. SPM leads to parasite phase modulation of pulse fronts (chirp). The pulse widen, interference between the symbols increases and limits the transmission speed. SPM is one of the reasons for decreasing the step between each channel. [29, 30]

Cross-phase modulation (XPM) mainly happens in systems with WDM and DWDM. It is similar to the SPM and dues to the signal interaction from two neighbour optical channels. When the signals transmit through one optical fibre each of them changes its reflect coefficient keeping the law of changing of the optical power. Investigations show that the effective fibre surface is necessary to be increased in order to decrease the XPM. [29, 30]

In WDM and DWDM systems is also typical the event four wave mixing (FWM). It is the reason for creating products with new frequencies, some of which may fall into the used channels. There are two main factors which affect to the level of FWM products, therefore the mixing efficiency – channel spacing and the dispersion of the chosen optical fibre. [1, 29]

As mentioned above, the main source of nonlinear distortions in the coaxial part of the CATV System are the RF amplifiers. To escape these distortions it is necessary the maximal output level of the RF signal not to exceed the defined by half-line "B" level on the diagram on figure 4. [20]

VII. CONCLUSION

In this article it is performed an architecture of a CATV System, built on a hierarchal principle. There is given criteria for determining the dynamic range of the signals in the optical as well as the coaxial part of the system. The reasons for creating noise and nonlinear distortions in the main elements of the system – laser, photodiode receiver, optical fibre, optical and RF amplifiers are also analyzed.

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