Optimization of the performance of the hybrid fiber-coax network

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Abstract – **In this paper is represented an optimization method of performance of hybrid fiber-coax network. Analytical results and plots are used for an estimation of the received optical power and the level of RF modulation signal that are required for a given signal to noise ratio (SNR) and intermodulation distortions. The variation limits of output signal level of the wideband coaxial line amplifier are defined. It is shown a signal power distribution in downlink and uplink of CATV distribution network.**

Keywords – **Attenuation in fiber optic/coaxial cable; Effectiveness of optical transmitter/receiver; Gain of optical link; Noise and distortion in a CATV network; optimal output level of an amplifier in CATV network.**

I. INTRODUCTION

The development of CATV distribution networks up to the present was passing through the three generations. The first generation is one-way and only analog signals are transmitted. It is build by coaxial cables and the coverage area is limited by the noises and the distortions in the trunk amplifiers. The next generation is the hybrid fiber–coax (HFC) networks that use a fiber optic to convey a signal from the headend to local area coaxial distribution network. In this way, the coverage area is significantly increased. Further, these networks transmit both analog and digital signals that result in a growth of the number of the transmitted TV channels by eight times.

The special feature of the third generation CATV networks is the two-way capability. This allows additional services to be provided by a control of subscribers access. For example, video films by order, security services, paid TV channels, VoIP and Internet. The third generation CATV networks are composed of main and secondary optical rings, Hubs, transmitters and receivers for uplink and downlink and digital signal processing (DSP) devices. Service of the subscribers of an area under construction is performed by peripheral coaxial distribution networks.

II. CONFIGURATION OF CATV NETWORK

The object of the analysis is a part of hybrid fiber-coax (HFC) networks that includes optical trunk link and several coaxial distribution networks. Optical transmitter that is located in the headend or in a given HUB feed the optical trunk link. The optical signal is divided between *n* feeder links then passes to nodes that convert it into electrical signal and feed the local area coaxial distribution networks.

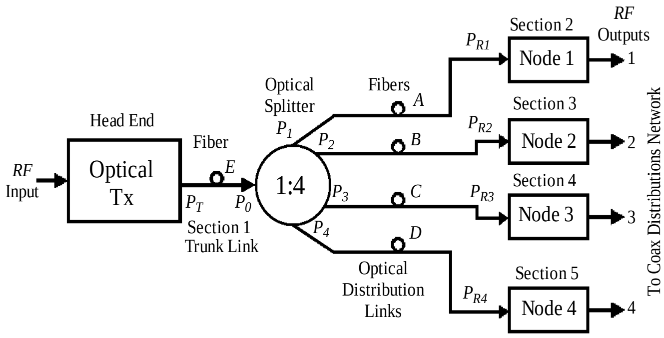

Fig. 1 The "star-shape" topology of the optical part of HFC network

At the present, two main topologies of the optical part of the HFC network are imposed – "star-shape" and "tree-and-branch". In the first topology, the distribution of the signal between several feeder links is performed in one point by optical divider. In the "tree-and-branch" topology the signal power from the optical backbone is diverted to the feeder links in several points. On Fig. 1 and Fig. 2 are shown block diagrams of the two topologies of CATV optical trunk networks.

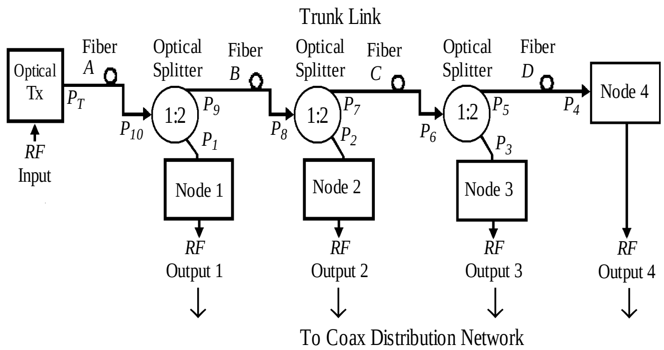

Fig. 2 The "tree-and-branch" topology of the optical part of the HFC network

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The classical coaxial CATV networks are realized by three-stage scheme that consists: trunk link, distribution network and subscriber drop. Along the trunk link at intervals of 400-600m, a wideband amplifier is included due to the great losses inherent to coaxial cables.

In view of fact that each amplifier introduces additional noises and distortions, the number of amplifiers is limited and this reduces the coverage area of the coaxial CATV network.

III. OPTIMIZATION OF THE PERFORMANCE OF THE OPTICAL NETWORK

The design performance of CATV network is estimated by the parameters of the end signals of the network and it must be ensured a predefined quality of the received information. The end of an optical trunk network is the receiver in the optical node and in a coaxial distribution network – subscriber point. The carrier-to-noise ratio (CNR) and the intermodulation distortion – composite second order (CSO) and composite triple beat (CTB) – estimate the quality of the received signal. The levels of CSO and CTB products are given relative to the level of the carrier and denoted by CIR_{CSO} and CIR_{CTB}. In the subscriber point these ratios must be CNR > 43 dB, CIR_{CSO} > 54 dB and CIR_{CTB} > 54 dB.

First, it is necessary to be distributed the acceptable worsening of the quality between the optical part and the coaxial part of the HFC network. This is performed taking into account that the greater noise and intermodulation are inherent to the coaxial part. Furthermore, in an optical trunk network the levels of the intermodulation distortion CSO and CTB are defined by the parameters of the transmitter. The laser transmitters on the market have great margin with respect to these distortions and hence no need to concern about these parameters in the optimization procedure.

The ratio CNR in the output of the receiver of an optical node can be expressed by

$$CNR = \frac{i_{pd}^2}{i_{sh}^2 + i_{th}^2} = \frac{\left(P_R R_{pd}\right)^2}{\left[4kT/R_l + 2e\left(P_R R_{pd} + I_d\right)\right]B}, \qquad (1)$$

where i_{pd} – the average photoelectric current through the load R_l; i_{sh} and i_{th} – the average currents caused by the shot and the thermal noise in the photodiode receiver; P_R – the input optical receiver power; R_{pd} – the sensitivity of the photodiode (typically 0,75 mA/mW); B – the receiver bandwidth; I_d – the current of darkness; $k = 1{,}38.10^{-20}$, mW/[Hz.K] – the constant of Boltzman; T – the temperature in K (290 K ambient); e – the charge of electron.

On Fig. 3 are shown curves of the ratio CNR versus the received power P_R for different number of TV channels. If the ratio CNR is given for each optical node then by the aid of these curves it can be determined the necessary received optical power. Let we assume that the number of TV channels is 79, “star-shape” topology is used for the optical trunk network and the required values of the ratio CNR in the feeder links as follows: $(CNR)_2$ = 48 dB, $(CNR)_3$ = 49 dB, $(CNR)_4$ = 50 dB, $(CNR)_5$ = 51 dB. Then the received optical power must be as follows: P_{R1} = – 3,3 dBm, P_{R2} = – 2,5 dBm, P_{R3} = – 1,8 dBm and P_{R4} = – 1,0 dBm.

The level $U_{RF\,in}$ of the modulating RF signal is the next important parameter for optimization. In VSB-AM systems this level is adjusted in such a way so that the depth of the modulation to be about 4%. When the modulating signal has lower values of magnitude then the ratio CNR is made worse. If there is too strong signal then an undesirable non-linear distortions occur. Let, the third order distortion CIR_{CTB} (in dB) and the number of the TV channels n are given then the maximum allowed power of the modulating signal $P_{RF\,in}$ (in dBm) can be derived from

$$CIR_{CTB} = 2\left(IIP3 - P_{RF\,in}\right) - \left(6 + 10\lg x\right), \qquad (2)$$

where IIP3 is the input intercept point of the third order in dBm (it can be read from the specifications of the laser transmitter), and the term x for $n > 16$ is given by $x \approx (3/8)n^2$.

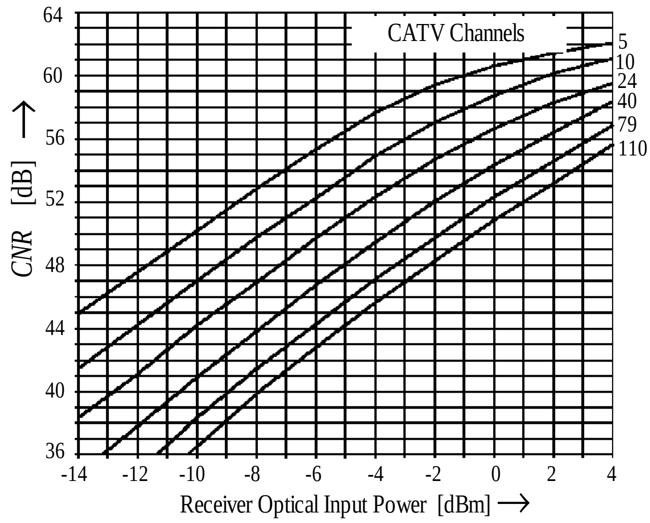

Fig. 3 The signal-to-noise ratio CNR versus the received optical power P_R

According to the equation (2) Fig. 4 is drawn. This plot can be used for an estimation of the optimum level of the modulating signal $U_{RF\,in}$ (in dBmV), when the output power of the laser transmitter P_T (in dBm) and the number of TV channels n are given. Let, we look again at the “star-shape” topology and try to estimate the acceptable output power P_T of the transmitter. Just for that, we must know the losses in the feeder, the trunk links and the four-way divider. The losses L_i in a fiber optic cable with length l_i and attenuation constant α (for λ = 1310 nm α is 0,5 dB/km and for wavelength λ about 1550 nm α is 0,25 dB/km) are defined by $L_i = \alpha l_i$. Let, we assume that the computed value of P_T is 12 dBm and n = 79 then the acceptable level of the modulating signal is $U_{RF\,in}$ = 11 dBmV. The coaxial distribution network requires a level of the RF signal about 50 dBmV, whereas the optical transmitters need comparatively low level of the input signal (usually, from 10 to 20 dBmW).

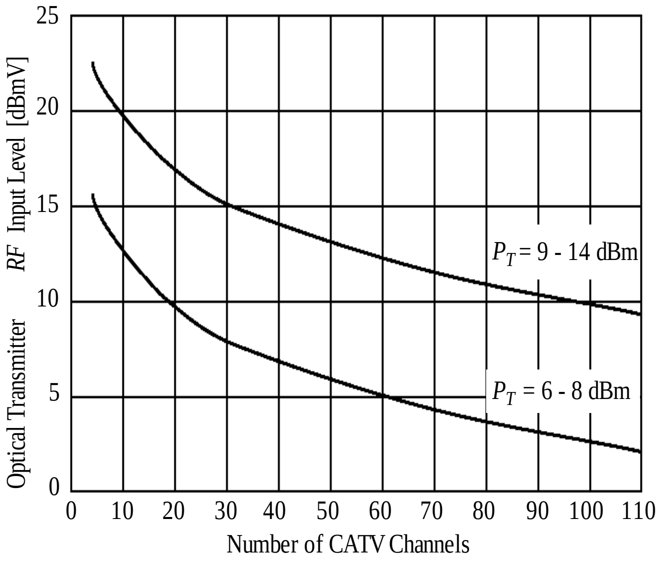

Fig. 4 Plot for an estimation of the modulating RF signal level

The next important parameter for optimization in this part of the HFC network is the gain of the optical link. The optical link is defined as all components of the network between the modulating input of the optical transmitter and the output of the optical receiver. The gain of this link can be expressed by

$$G = (I_{out}/I_{in})^2 (R_{out}/R_{in}) = (\eta_T \eta_R / L)^2 (R_{out}/R_{in}). \quad (3)$$

The parameter $\eta_T = P_T/I_{in}$, [mW/mA] gives an account of the efficiency of the optical transmitter transformation of the input current I_{in} in a modulated output optical power P_T and $\eta_R = I_{out}/P_R$, [mA/mW] – the efficiency of the inverse receiver transformation of the received optical power P_R in a RF output current I_{out}. These parameters can be seen in the specifications of the transmitter and the receiver. The total loss in the optical link $L = P_R/P_T$ includes both the attenuation in the fiber optic and the losses in the passive components (optical divider and connectors).

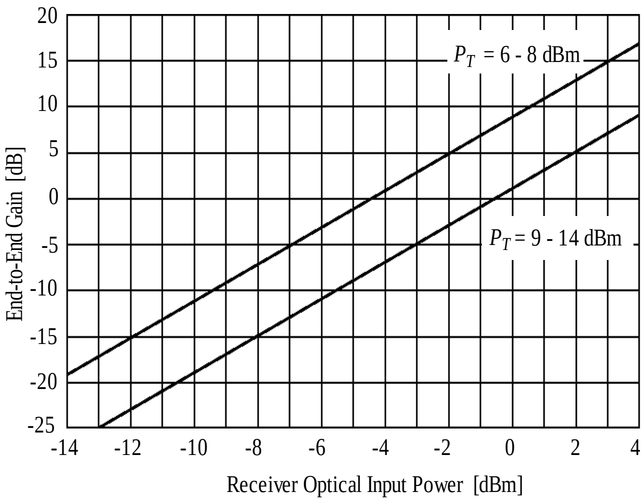

Fig. 5 Plot for an estimation of the optical link gain

Usually in the specifications are shown the relations between the gain of the optical link G and the output optical power of the transmitter P_T and the power of the received optical signal P_R (Fig. 5). For example, the gain of the first optical link shown on Fig. 1 is about 2.5 dB (P_T =12 dBm and P_{R1} = – 3.3 dBm) and the fourth optical link gain is about 7 dB (P_{R4} = – 1,0 dBm). The level of the output RF signal of the node when the optical link gain is known can be calculated from the equation

$$U_{RF\ out}[dBmV] = U_{RF\ in}[dBmV] + G[dB]. \quad (4)$$

In the previous example $U_{RF\ in}$ = 11 dBmV and hence, the level of the output RF signal varies from 13,5 dBmV (73,5 dBμV) to 18 dBmV (78 dBμV).

IV. A LIMITATION DUE TO THE NOISES AND THE DISTORTIONS IN THE COAXIAL NETWORK

The attenuation of the signals in the coaxial CATV network is compensated by a great number of wideband amplifiers and this result in an increase of the noises and distortions. In order to ensure the required signal quality in the subscriber point the amplifiers output level is supported in certain limits. These limits are defined by the minimum ($U_{A\ min}$) and the maximum ($U_{A\ max}$) level of the amplifier output signal. The minimum level is related to the required signal-to-noise ratio CNR and the maximum is to the acceptable non-linear distortion.

The limits $U_{A\ min}$ and $U_{A\ max}$ in dBμV for the ith amplifier in succession are given by

$$U_{A\min} = 2 + NF + K + CNR + 10\lg i \quad (5)$$

$$U_{A\max} = U_{A(k)} - 7{,}5\lg(n-1) - 20\lg i, \quad (6)$$

where NF and K (in dB) are the noise figure and the gain of the amplifier, respectively; $U_{A(k)}$ – the maximum amplifier output level according to the specification (in dBμV); n – the number of the TV channels. In equation (5), the noise caused by the coaxial (about 2dBμV) is included. Automatic Gain Control (*AGC*) circuitry controlled by a pilot signal supports the output level in the acceptable limits.

If the number of the TV channels n and the numbers of consecutive amplifiers are increased then the value of $U_{A\ min}$ approach to $U_{A\ max}$ and for given amplifier they coincide. Exactly, in this point is defined the optimum signal level in the coaxial distribution network that must not be smaller than the minimum acceptable level in the subscriber point (63 dBμV). In view of the attenuation of the coaxial cables on the market and the parameters of the wideband amplifiers, it is estimated that the longest coaxial trunk link is about 7 km and the number of the amplifiers along the line could be no more than 10 ... 15. In [2] the optimization of the performance of coaxial CATV network is described in details.

V. SUPPORT OF THE OPTIMAL PARAMETERS IN THE SUBSCRIBER POINT

It must give an account of two conflicting requirements choosing the distribution network topology. First, it is used as possible as shorter coaxial cables. On the other hand, the coupling between the subscriber points must be smaller. Then only an intentional or unintentional change of the parameters of the subscriber point (interruption or short) has no influence on the signal quality of the other subscribers.

The "tree-and-branch" topology of the distribution network is cheapest, but it has a great disadvantage: the subscriber has a free access to the line that feed a group of subscribers. The subscriber's access to the feeder link is entirely restricted when the "star-shaped" topology is used. However, this topology is very expensive, a great amount of cables is used. The "star-shaped" topology has an important advantage: the possibility for remote control of the subscriber signals. For example, the joint/disjoint to CATV network, collecting of an information about the number and the kind of channels that the subscribers watch on television, restricted access to coded TV channels and etc.

The main problem in the distribution network design is the different attenuation of the passive components that build the downlink and the uplink. For example, the loss in coaxial cables for the maximum uplink frequency (65 MHz) is about 4 times smaller than the losses for 860 MHz (the maximum downlink frequency). In the uplink frequency band, the losses of the taps (directional couplers) and the dividers are about 60% of the losses in the downlink frequency band. Other grave problem is so called funnel effect that is an accumulation of the noise and the interference of the subscriber and another devices in the headend. In addition, problems are caused by the ferrite cores of the taps and the dividers that make non-linear distortions of the downlink signals when the cable modems transmit great powers. This effect can be prevented by the blocking capacitors in the input and the output of these passive devices.

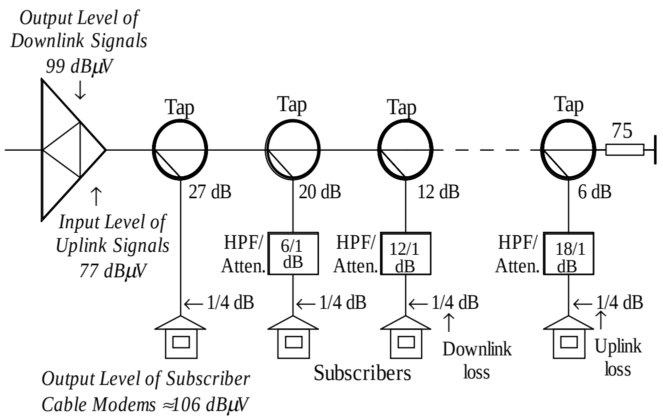

Fig. 6 The signal distribution in the uplink and the downlink of coaxial distribution network.

On Fig. 6 it is shown an example for the distribution of the signal power between several subscribers taking into account the different attenuation in the downlink and the uplink. In order to avoid the noise and the interference infiltration into the CATV network, the high pass filters (HPF) are included in the taps output of subscribers that no use of the uplink. The required level in the subscriber point is ensured by the (forward) coupling of the tap. Attenuators (Atten.) are used for alignment of the subscriber modem levels in the uplink. Attenuation in the passive components in the distribution network are given by two digits, the first is used for uplink signals and the second for the downlink.

VI. CONCLUSIONS

In this paper was described an optimization method of very important parameters of the coaxial and the fiber-optic part of the HFC network. It was the attenuation of trunk and feeder links; the output power of the laser transmitter; the sensitivity of the optical node receivers; the level of *RF* modulating signals; the limits of variation of amplifier output levels; the coupling of taps and etc.

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