ALGORITHM FOR COAXIAL PART'S DESIGN OF CABLE MULTIMEDIA NETWORK

Dobri Dobrev, Lidia Jordanova

Faculty of Telecommunications, Technical University of Sofia,
8 Kl. Ohridski str., 1000 Sofia, Bulgaria
email: dobrev@tu-sofia.bg

Abstract

In this paper a method for coaxial part's design of hybrid fiber-coaxial multimedia system is presented. The method is based on a study of noise and signal distortion introduced by the amplifiers that are connected in the coaxial line between the subscriber and the optical node. Dependencies are obtained for determining the acceptable output levels of the amplifiers, which take into account both the number of amplifiers and their parameters, and the actual channel loading. Formulas for calculating the required number of amplifiers, their gain coefficients and the distance between amplifiers are derived. An algorithm is presented to design the coaxial channel of hybrid network.

1. Introduction

Modern cable multimedia systems are of the hybrid fiber-coaxial (HFC) type. One of the main problems of these systems is the coaxial part of the cable distribution network. For compensation of the signal attenuation in the coaxial cable, radio frequency (RF) amplifiers are used, but they cause noise and distortion of the transmitted signals. Noise and distortion products accumulate along the coaxial line and worsen the quality of the received image and sound, and the errors in data transmission increase [1-3].

The quality worsening of the received signal in the coaxial part of a cable multimedia system can be estimated on the basis of parameters such as carrier-to-noise ratio (CNR) and carrier-to-interference ratio (CIR) measured at the drop amplifier output. Those parameters evaluate the portion of noise and distortions introduced by trunk amplifiers, feeders and drop amplifiers that are connected in the coaxial line between the subscriber and the optical node.

When designing a HFC multimedia system it is necessary to make advance planning of acceptable degradation of CNR and CIR parameters in coaxial and optical parts of the network. The aim is the values of these parameters measured at the output of the subscriber outlet (SO) to satisfy the requirements: $CNR_{SO} \geq 49$ dB and CIR ≥ 54 dB.

The tree-and-branch topology of the coaxial distribution network is the cause of the noise funnel effect in the reverse path channel. With such an effect the noise and inter-modulation products from all the cable network branches interfere with the signals from the subscriber's cable modems. As a result, the value of the bit error ratio (BER) at the receivers outputs of the headend is increased and the communications over the reverse path get worse or cut-off [4,5].

The main purpose of the paper is to develop an algorithm to design the coaxial channel of HFC multimedia system in order to ensure the given values of quality parameters.

2. Architecture of HFC multimedia network

HFC multimedia networks are usually realized on the hierarchical principle (Fig.1). The highest hierarchical level includes a primary optical ring which includes one primary and several secondary headends. The primary optical ring transports digital information using SDH or SONET standards. The second hierarchical level consists of secondary optical rings that are connected to the primary ring. Distribution hubs are connected to the secondary optical rings. Through optical lines the signals are transported from the hubs to the optical nodes that feed the coaxial network segments forming the lowest hierarchical level of the system.

Classical coaxial multimedia networks are implemented in the three-stage scheme. It consists of a trunk, distribution lines and a subscriber drop (home networks). Wide-band RF amplifiers are included along the coaxial lines because of the great losses inherent to coaxial cables. Since additional noise and distortions are caused by each amplifier, a limitation of the number of amplifiers must be imposed, the coverage area of the coaxial network thus being reduced. Typically feeder lines are built short with no more than two amplifiers to provide a gain high enough to meet the needs.

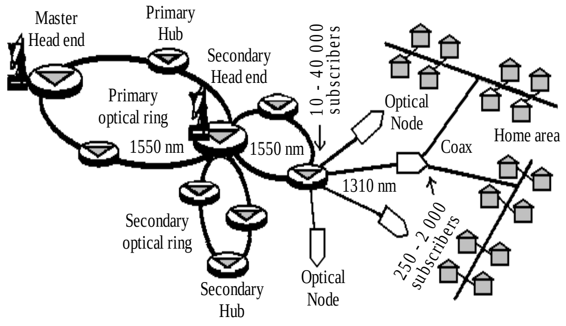

Fig. 1. HFC system topology

In [5] a mathematical model of the reverse path channel is suggested with the funnel effect being taken into consideration. If the carrier-to-noise ratio at the receiver input of the headend is known then the model makes it possible to optimize the topology of the coaxial distribution network and the number of the optical nodes whose signals are summarized in the receiver.

3. Limitations due to noise and distortions in the coaxial network

The quality worsening of the received signal in the coaxial part of a HFC system can be estimated on the basis of parameters such as CNR and CIR measured at the drop amplifier output. Those parameters evaluate the portion of noise and distortions (CSO and CTB) introduced by trunk amplifiers, feeders and drop amplifiers that are connected in the coaxial line between the subscriber and the optical node. The total CNR (in dB) can be expressed by

$$CNR_{\Sigma} = -10\lg\sum_{i=1}^{M} 10^{\frac{-CNR_i}{10}}, \qquad (1)$$

where CNR_i is the carrier-to-noise ratio at the output of the i-th amplifier in dB. For a cascade of M identical amplifiers, all operating with the same output level and tilt, CNR_{Σ} (in dB) can be easily calculated as follows

$$CNR_{\Sigma} = CNR - 10\lg M \qquad (2)$$

The CNR at the output of a single amplifier is given by the formula

$$\begin{aligned} CNR &= U_{\text{out}} - K - 10\lg\left(kTB\right) + \\ &+108.75 - NF = U_{\text{out}} - K - 1.54 - NF, \end{aligned} \qquad (3)$$

where U_{out} is the amplifier output level in dBμV, K and NF are the gain and the noise figure of the amplifier in dB, respectively, k is the Boltzmann's constant ($1.38 \cdot 10^{-20}$, mW/Hz·K), T is the absolute temperature (290 K), B is the bandwidth (4.75 MHz) and $10\lg(kTB) + 108.75 = 1.54$ dBμV is the thermal noise in bandwidth 4.75 MHz.

From expressions (2) and (3) can be determined the acceptable minimum output level of the M-th amplifier (in dBμV). It depends on the required carrier-to-noise ratio at the output of the coaxial channel CNR_{CCh} and can be defined as follows [3]:

$$U_{\text{out min}} \geq CNR_{\text{CCh}} + K + 1.54 + NF + 10\lg M \qquad (4)$$

When M amplifiers are included in the coaxial line connecting the subscriber with the optical node, the following expression can be used to determine the value of parameter CIR (in dB):

$$CIR_{\Sigma} = -k_1 \lg\sum_{j=1}^{M} 10^{\frac{-CIR_j}{k_1}}, \qquad (5)$$

where the coefficient k_1 depends on kind of distortion prevailing: $k_1 = 15$ with CSO and $k_1 = 20$ with CTB. As the influence of CTB is prevalent, for a cascade of M identical amplifiers can be written

$$CIR_{\Sigma} = CIR - 20\lg M. \qquad (6)$$

In the specifications issued by broadband equipment manufacturers CIR of the amplifiers is given for a reference output level $U_{\text{out ref}}$ (dBμV) and channel loading N_{ref} (e.g. 36, 42 or 57 channels). When the amplifier output level and the number of channels differ from those given in the specifications, then the following correction of the amplifier performance must be made:

$$\begin{aligned} CIR &= CIR_{\text{ref}} - k_2\left(U_{\text{out}} - U_{\text{out ref}}\right) - \\ &-10\lg\left(N/N_{\text{ref}}\right). \end{aligned} \qquad (7)$$

where U_{out} is the actual amplifier output level in dBμV and N is the actual channel loading. If expression (7) refers to CSO, then $k_2 = 1$ and if (7) refers to CTB, then $k_2 = 2$. Thus it can be seen that all distortions are worsened when amplifier output level and channel loading raised.

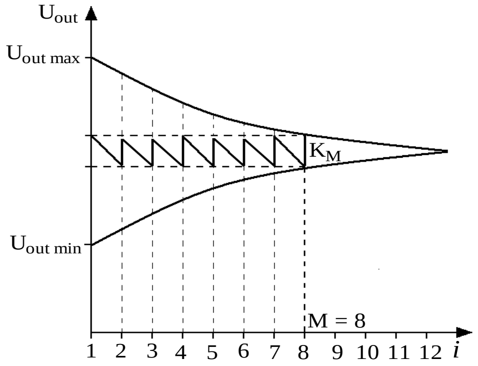

Fig. 2. Acceptable dynamic range of U_{out}

The maximum output level of the M-th amplifier $U_{\text{out max}}$ depends on the required carrier-to-interference ratio at the output of the subscriber outlet CIR_{SO}. Taking into account expressions (6) and (7) the following formula to determine $U_{\text{out max}}$ (in dBμV) is obtained [3]:

$$U_{\text{out max}} \le U_{\text{out ref}} - 10\lg\left(N/N_{\text{ref}}\right) - 20\lg M. \qquad (8)$$

The values $U_{\text{out min}}$ and $U_{\text{out max}}$ come closer to each other and coincide for a given amplifier when the number N of the channels and M of the cascade amplifiers is increased (see Fig. 2). If the parameters of the wideband amplifiers and the attenuation in the coaxial cables on sale are taken into consideration it can be concluded that the coaxial trunk line can not be longer than 7 km and the number of amplifiers in the line can not exceed 10-15.

4. Determining the number of RF amplifiers and their gain

The acceptable level of the signal at the subscriber outlet U_{SO} is provided by adequate signal amplification in the coaxial and the optical transmission lines. The point of the unit gain concept is the transmission coefficient in the separate cable segment to be 0 dB. In other words, the amplifiers gain in this segment should compensate the total losses in it.

If this rule is used for the coaxial part of the network then the gain of the i-th RF amplifier in the cascade K_i (in dB) must be

$$K_i = \left(\alpha/100\right) l_{(i-1),\,i} \qquad (9)$$

The quantity α is the cable attenuation in dB per 100 m given in the cable data sheets, $l_{(i-1),\,i}$ is the length of the coaxial cable between the $(i-1)$-th and i-th amplifier in meters.

Dependencies (4) and (8) and the concept of unit gain can be used to determine the acceptable number of amplifiers in the coaxial lines and their gain. Let's assume that the RF amplifiers are of equal gain and there is an equal distance between them. Then the number M and the gain K_M (in dB) of the amplifiers can be determined by the equations

$$K_M = U_{\text{out ref}} - CNR_{\text{CCh}} - \left(NF + 1.54\right) - 10\lg\left(N/N_{\text{ref}}\right) - 30\lg M \qquad (10)$$

$$K_M = \frac{L_{\text{CL}}}{(M-1)} = \frac{\alpha}{100}.\frac{l_{\text{CL}}}{(M-1)} \qquad (11)$$

where L_{CL} is the total cable loss (in dB) for a coaxial line with length l_{CL} (in meters).

5. Algorithm for coaxial channel design

When designing the coaxial part of a HFC multimedia system the following parameters must be given: the maximum length of the coaxial line l_{CL}, the channel loading N and the parameters of the selected cable (α) and amplifiers (NF, $U_{\text{out, max}}$, CSO and CTB). The purpose is to determine the required number of amplifiers, their optimum gain and the distances between two adjacent amplifiers.

At first, it is necessary to calculate the total signal attenuation in the coaxial line

$$L_{\text{CL}} = \left(\alpha/100\right) l_{\text{CL}}. \qquad (12)$$

The next step is to determine the distance S_i between the first and i-th RF amplifier so that the following condition to be met:

$$S_i = 100\left(i-1\right) K_i / \alpha \approx l_{\text{CL}}. \qquad (13)$$

The gain of the i-th amplifier K_i is calculated using expression (10).

From the results obtained

$$i=2 \Rightarrow S_2 = 1\cdot(100/\alpha)\cdot K_2$$

$$i=3 \Rightarrow S_3 = 2\cdot(100/\alpha)\cdot K_3$$

. . . .

$$i=M \Rightarrow S_M = (M-1)\cdot(100/\alpha)\cdot K_M \approx l_{\text{CL}}$$

it is obvious that condition (13) is satisfied for $i = M$. Therefore, the number of amplifiers that can be included in the coaxial line is M, and their gain is equal to that of the M-th amplifier.

To determine the distance between two adjacent amplifiers the following equation can be used:

$$l_{(i-1),i} = l_{\mathrm{CL}} / (M-1). \quad (14)$$

Finally, it is necessary to specify the admissible amplifiers output levels. They are given by the following formulas:

$$\begin{aligned} U_{\mathrm{out\ max}} &= U_{\mathrm{out\ ref}} - 20\lg M \\ U_{\mathrm{out\ min}} &= U_{\mathrm{out\ max}} - K_M \ . \end{aligned} \quad (15)$$

6. Conclusion

The algorithm here described make it possible easy design of the coaxial multimedia network to be performed when given the parameters of both the cable and amplifiers chosen and the HFC system (such as CNR and CIR at the subscriber outlet). The practical results show very good agreement between computed and measured values of network parameters (error less than 2 %).

7. Appendix and acknowledgments

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