IMPROVEMENT OF THE HFC SYSTEM REVERSE PATH PERFORMANCE

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The paper deals with what causes the signal parameters in the reverse path channel of hybrid fiber-coaxial CATV system to worsen. Besides the analysis, a mathematical model of the channel is also 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 optical nodes whose signals are summarized in the receiver. Experimental and analytical results are shown that enable the engineer to determine the RF signal dynamic range at the modulation input of the reverse path lasers if both the bit error ratio at the receiver output and the acceptable laser clipping are given.

Keywords: CATV, reverse path channel, noise, intermodulation distortion, penetrating interference, funnel effect

1. INTRODUCTION

The funnel effect due to tree-and-branch topology of the cable distribution network is one of the main causes to worsen communications over the reverse path channel of a CATV system. With such an effect the noise and inter-modulation products from all the cable network branches interfere with the signals in the subscribers' cable modems. In result, the carrier-to-noise ratio and the carrier-to-intermodulation product ratio at the receiver input of the cable modem terminal system (CMTS) are reduced to an unacceptable value.

Besides, powerful RF interference from different sources can penetrate the CATV reverse path channel due to inappropriate coax-cable screening or poor quality of the connector (loose or cut-off). Interference in the LF range of the reverse path channel could exceed the information signal level with more than 20 dB thus causing signal limitation in the amplifiers and the laser transmitter or blocking the CMTS receiver. In result, communications over the reverse path channel get worse or simply break off due to an increase of the channel bit error ratio (BER).

The carrier-to-noise ratio at the CMTS receiver input should be kept greater than a given value in order to provide the necessary quality of communications over the reverse path channel of the CATV system. The paper aims at providing dependences that will help to minimize the funnel effect influence and avoid unacceptable distortion and limitation of the signal in the reverse path lasers.

2. NOISE MODEL OF THE REVERSE PATH CHANNEL IN HFC SYSTEMS

The electronic blocks of the optical-to-electronic transducers, cable amplifiers and subscriber devices (converters and cable modems) are the main source of noise in the reverse path channel of CATV systems. The carrier-to-noise ratio at the receiver input of CMTS (C/N_{Rx}) must be greater than a value corresponding to the given BER in order to provide communications of a necessary quality over the reverse path channel. Cable modems, telephone, LAN etc. provide services that require different BER values varying in the range of 10^{-4} to 10^{-7}. With parameter C/N_{Rx} the admissible worsening of the carrier-to-noise ratio over the coaxial (C/N_{CR}) and the optical part (C/N_{OR}) of the system are taken into consideration.

The carrier-to-noise ratio at the output of the coaxial reverse path channel (at the receiver input of the optical node) can be determined if the following empirical relation is used:

(1) $C/N_{CR}\,[\text{dB}] = C/N_A\,[\text{dB}] - 10\cdot\lg(\sqrt{M\cdot N})$,

where C/N_A is the reference value of the carrier-to-noise ratio of the amplifier applied in the reverse path channel, M is the total number of amplifiers and N is the number of branches over the coaxial network.

Analysis has shown that C/N_{CR} can be increased if the coaxial part of the system is developed according to a symmetrically branched topology of a limited number of branches. If, for example, 40 amplifiers of $C/N_A = 65$ dB are applied in an 8-branch coaxial network, then $C/N_{CR} = 52{,}5$ dB. It can be proved that the value of C/N_{CR} will then be 3,5 dB greater than in the case there are no branches in the network but cascade amplifiers linked in one coaxial line. Increasing the number of branches N will increase parameter C/N_{CR} until at $N = 40$ it equals that of a network without branches. If C/N_{CR} and the type and total number of amplifiers are known the optimum value of N can be easily calculated by the use of the diagrams (Fig. 1) obtained with (1).

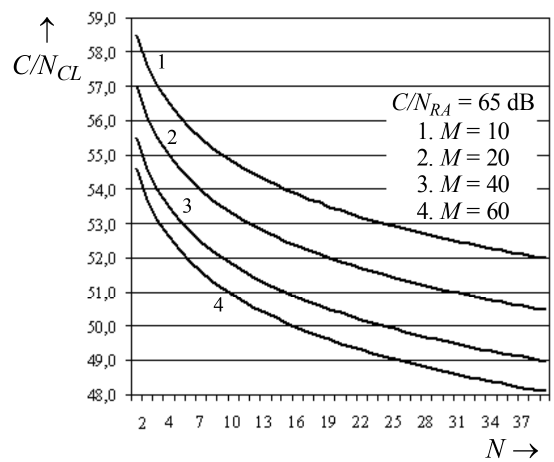

Fig. 1. Diagram to calculate the number of branches over the coaxial network

Since the signals of the optical nodes (W in number) are summarized in the optical part of the network the value of the C/N_{OR} component at the CMTS receiver input turns out to be reduced by $10\lg W$, dB. If an increase ΔL (in dB) of the loss in the network due to various factors affecting stability is taken into consideration, then the following formula can be applied to calculate C/N_{OR}:

(2) $C/N_{OR}\,[\text{dB}] = C/N_{OR(1)}[\text{dB}] - \Delta L[\text{dB}] - 10\lg W$.

The value of $C/N_{OR(1)}$ refers to a network segment of only one optical node where no destabilization effect of the environment is taken into consideration. The acceptable attenuation of the signal in the backward channel of hybrid cable networks is usually given as $\Delta L = 10$ dB.

The following formula is applied to calculate parameter C/N_{Rx}:

$$\text{(3)}\quad C/N_{Rx}\,[\text{dB}] = -10\lg\left[10^{-\frac{C/N_{OR}\,[\text{dB}]}{10}} + 10^{-\frac{C/N_{CR}\,[\text{dB}]}{10}}\right].$$

The noise model of the reverse path channel described by (1), (2) and (3) takes into consideration the influence of the funnel effect. Thus the system topology can be optimized in order to obtain the desired value of C/N_{Rx}. When determining the acceptable number of branches over the coaxial network and of the optical nodes whose signals are summarized the requirements of the existing standards must be taken into consideration as follows: 1) $C/N_{CR} \geq 55$ dB for a coaxial network of 30 amplifiers and a reverse path channel of 4,75 MHz bandwidth; 2) $C/N_{OR} \geq 41$ dB for a reverse path channel of a single optical node transmitting 20 RF carriers at 7 dB loss; 3) As a total, $C/N_{Rx(1)} \geq 39$ dB for a HFC system segment of one optical node, but $C/N_{Rx(W)} \geq 31$ dB if the signals of 4-5 optical nodes are combined; 4) On the average $C/N_{Rx} \geq 25$ dB when QPSK signal is transmitted over a reverse path channel whose bandwidth is 1,6 MHz or 3,2 MHz (DOCSIS).

Since the bandwidth of the CATV reverse path channel differs from the referred one ($B_{ref} = 4{,}75$ MHz) the following correction of C/N_{ref} must be done:

$$\text{(4)}\quad C/N_{new} = C/N_{ref} + 10\lg\left(B_{ref}/B_{new}\right).$$

It is obvious that the improvement of parameter C/N_{Rx} will be 1,72 dB if the bandwidth is $B_{new} = 3{,}2$ MHz or 4,72 dB if $B_{new} = 1{,}6$ MHz respectively.

3. DISTORTION AND PENETRATING INTERFERENCE IN THE CATV REVERSE PATH CHANNEL

Intermodulation distortion appearing both in amplifiers and lasers and in passive devices is due to the ferrite material saturation in splitters and directional couplers or to the diode effect in damaged connectors etc. The diode effect is due to the thin layer formed by oxidation of two contacting metal surfaces. When the forward signals pass through such a "semiconductor diode" second and third-order distortion products are generated periodically each 7 or 8 MHz, depending on the channel allocation of the RF signals transferred. The amplifiers of a high-grade system include diplexers to cut off inferior intermodulation products from the superior ones. Loose-contact connectors however can form diode transitions that cause intermodulation products of a high level to appear in the reverse path channel.

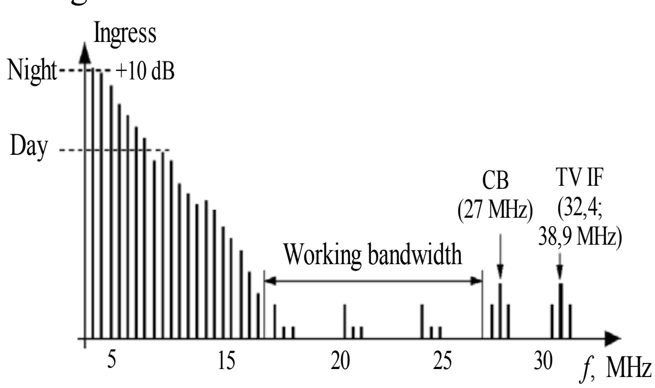

Fig. 2. Distribution of the interference penetrating the reverse path channel

As a rule about 70% of the interference in the reverse path is due to cut-off or loose contacts of the connectors in the subscriber facilities. Besides, powerful RF interference from different sources can penetrate the CATV reverse path channel due to inappropriate coax-cable screening or poor quality of the connector (loose or cut-off). Short-wave RF transmitters, radio amateur stations in the range of 4, 7, 14, 21 and 28 MHz, citizens band radio stations in the range of 26,96 - 27,45 MHz, PMR telephones (49 - 57 MHz), etc. can become such a source. In Fig. 2 the frequency and amplitude distribution of interference penetrating the reverse path channel is shown. That kind of interference is hard to control and there are no means to cut it off once it has penetrated the reverse path channel.

The carrier-to-intermodulation product ratio C/I_{Rx} or the carrier-to-distortion ratio C/D_{Rx} for the highest distortion level at the input of the CMTS receiver respectively must be kept higher than a threshold value in order to provide high quality communications over the reverse path channel. If these ratios drop below a given limit an abrupt rise of *BER* occurs as shown in Fig. 3.

Analysis has shown that the desirable level (low enough) of noise and distortion in the reverse path channel of a CATV system can be provided in two ways. The first one is to optimize the RF signal level and to use appropriate filtration in order to suppress noise and distortion immediately after they have been generated. The second one is to reduce the influence of the funnel effect.

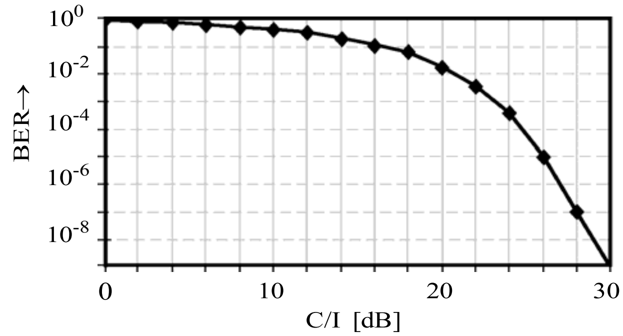

Fig. 3. Dependence of BER on C/I_{Rx} and C/D_{Rx} resp.

4. CRITERIA TO DETERMINE THE LEVEL OF THE MODULATING RF SIGNAL IN THE REVERSE PATH LASER

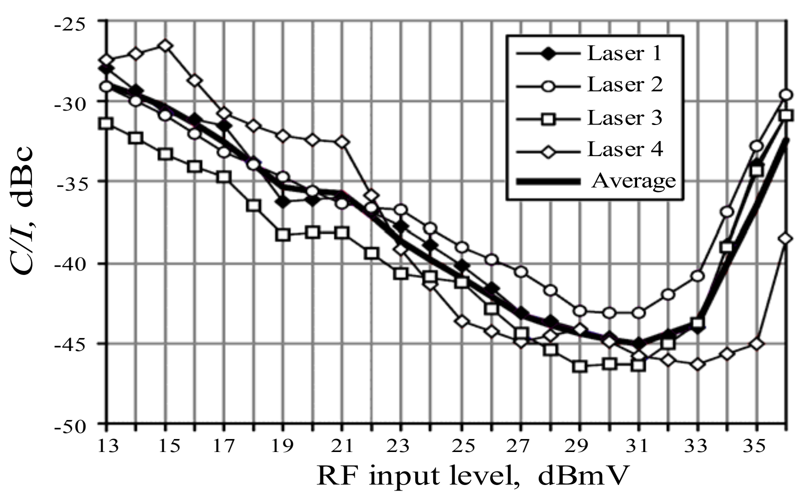

Fig. 4. Dependences of C/I for reverse path lasers on the RF signals modulation level

If the RF signal level at the laser modulation input is risen over a given value unacceptable intermodulation distortion and signal clipping caused by the laser occur. Investigations show that an optimum RF signal level can be found for each laser in the reverse path channel, the corresponding nonlinear distortion thus being reduced to the minimum. Experiments with lasers of the Scientific Atlanta Company have been carried out and the corresponding dependences for different allocations of the third-order intermodulation products are shown in Fig. 4. It can be seen that the optimum RF level of the laser under investigation is about 30 dBmV.

The optimum depth of optical modulation m for a single channel must be taken into consideration when the level of the modulating RF signal is determined. It can be proved that the greater the chosen value of m the better the C/N_{Rx} value. But this will lead to higher levels of the intermodulation products as well (C/I_{Rx} is getting worse), so a compromise must be found. Due to the random character of noise and distortion in the CATV reverse path no analytical expression can be derived to determine the optimum value of m. Hence, an experiment turns out to be necessary.

As seen in Fig. 5 where the experimental dependence of BER on the mean-square value of the modulation index μ is shown, $BER = 10^{-6}$ with $\mu \approx 22$ %, and $BER = 10^{-7}$ with $\mu \approx 20$ %. The value of m can be easily determined by the well known formula $\mu = m(k/2)^{1/2}$, where k is the number of reverse path channels.

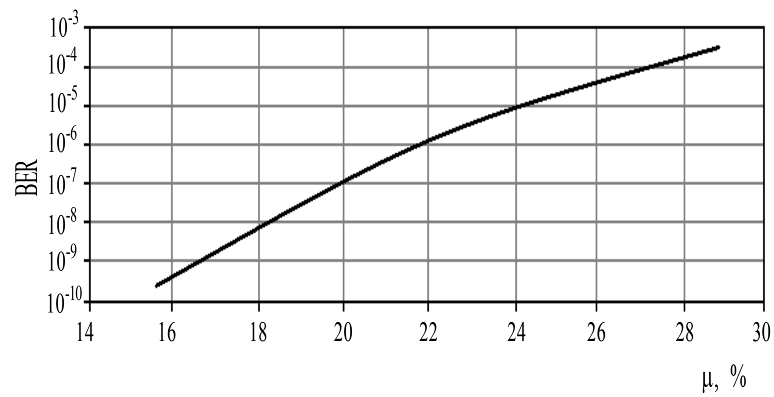

Fig. 5. Experimental dependence to calculate μ

The unwanted limitting effect of the laser can be avoided if the total power of the RF signals in the reverse path channels at the laser modulation input is greater than the value $P_{L\,max}$ as referred for the laser, i.e.

$$(5)\quad P_{Tx}[\text{dBmV}] = 10\lg\left(10^{\frac{P_{s1}[\text{dBmV}]}{10}} + 10^{\frac{P_{s2}[\text{dBmV}]}{10}} + \ldots\right) < P_{L\max}\,.$$

The levels of the RF signals for the different services provided can be determined by the following expression

$$(6)\quad P_{si}[\text{dBmV}] = P_d\,[\text{dBmV/Hz}] + 10\lg B_i[\text{Hz}],$$

where B_i is the frequency bandwidth for the signal to provide the i-th service and P_d is the mean power of the RF signal for a unit frequency band. Parameter P_d is calculated as follows

$$(7)\quad P_d\,[\text{dBmV/Hz}] = P_{L\max}[\text{dBmV}] - 10\lg B_{RCh},$$

where B_{RCh} is the frequency bandwidth of the system reverse path (from 5 MHz to 65 MHz).

5. CONCLUSION

The relations described in the paper have been applied to design the CATV systems reverse path. Experiments carried out with operating systems show that the suggested noise model of the channel and the criteria for determination of the signal levels provide a reserve of about 2 dB for parameters C/N_{Rx}, C/I_{Rx} и C/D_{Rx} as required by the existing technical standards.

6. REFERENCES

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