Noise in CATV Networks

This article describes the sources of noise and their effects on the performance of CATV systems

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CATV business is among the fastest developing telecommunication fields. Modern CATV networks offer a large number of television and FM radio channels with high quality picture and sound. They represent a significant general communication capacity and at the same time can be used for data communication, telephony and security services.

From the technical point of view, CATV networks represent a rather complicated RF system. Each network is a broadband communication system transmitting a number of analog (digital transmissions are still very new) signals at long distances with an extreme degree of branching (e.g. 1:50000).

Classical coaxial networks contain many cascaded amplifiers that compensate for cable attenuation in the magnitude of several hundreds of dB. Modern hybrid optical-coaxial networks replace the substantial parts of the high-attenuation coaxial cables with very low attenuation optical fibers. In both cases, because of the analog mode of transmission, it is necessary to solve substantial problems concerning sufficient signal-to-noise ratios and influences of intermodulation products, since several thousands of intermodulation products can fall into one TV channel.

Like the standard RF system, network behavior can be influenced considerably by reflections. A special CATV problem lies in the design of the remote powering of active components (amplifiers, optical receivers) over coaxial cables, which requires a solution of the resistive networks with a number of non-linear hyperbolic loads.

This article focuses on noise, which is one of the most important CATV network design parameters. Since the exact calculations of the system noise parameters are complicated, all presented formulas were derived in the form directly applicable in computer simulation and network optimization.

Noise parameters

Noise properties of CATV systems are mostly defined by a C/N (carrier-to-noise) ratio, where C represents the power of the picture carrier (W), and N represents a total noise power in a noise bandwidth B (W) (B is close to the channel bandwidth, e.g. B=4.75 MHz for a PAL B,G standard). The C/N ratio usually is stated in dB and can be measured or calculated:

$$\frac{C}{N_{dB}} = 10\log\left(\frac{C}{N}\right) \qquad (1)$$

For evaluating the system C/N it is necessary for the noise properties of all network components used to be taken into account (all CATV components generate noise). Noise parameters of CATV components are defined with the help of their noise figures:

$$F = \frac{N_2}{N_1}G = 1 + \frac{N_a}{(kT_0BG)} \qquad (2)$$

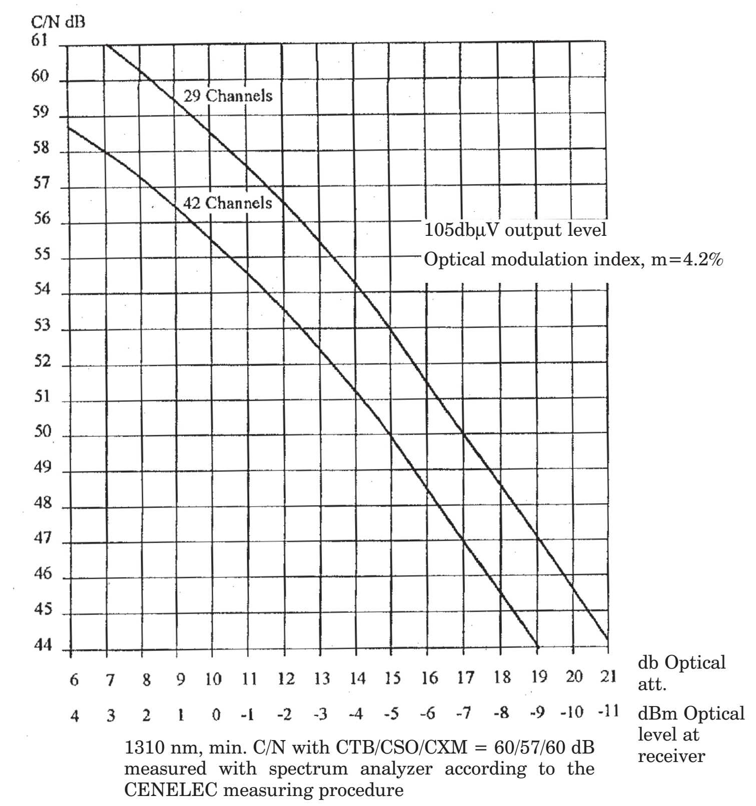
where N_1 is an input noise power generated by the 75 ohm termination (at T_0=290K) connected to the component input, N_2 is a total noise power at the component output (W), k is the Boltzman constant ($k=1.38\times10^{-23}$ J/K), B is a noise bandwidth in Hz, G is the component gain (negative), N_a is a noise power added by the component (in W). CATV amplifier noise figure values can be found in manufacturers' data sheets. Noise figures of passive components are derived in the CATV amplifier section of this article. In most cases the noise figure is expressed in dB:

$$F_{dB} = 10\log F \qquad (3)$$

CATV head-end noise characterization

In CATV networks, the head-end (HE) represents that part of the system where the frequency multiplex of TV and radio channels is put together. The HE consists of a number of satellite and terrestrial receivers, decoding or descrambling circuits, modulators, upconverters and output combining circuits. Knowledge of HE output parameters is important because they serve as input parameters for a distribution network analysis or design.

Noise properties of HE components usually are defined with the help of their inherent C/N (or S/N) ratios. Inherent C/N ratios are measured with the help of 75 ohm input termination and correspond to standard input signal levels. Resulting HE output C/N_{HE} values are given by analysis of the whole signal processing cascade. Resulting C/N_r (in dB) of two components with inherent carrier-to-noise ratios C/N_1 and C/N_2 connected in a cascade is given by (power sum):



■ **Figure 1. C/N_{OTX} [dB] versus P_{in} [dBm] plot (transmitter 90019, receiver 90060, courtesy ARCODAN company.)**

$$\frac{C}{N_r} = -10\log\left(10^{-\frac{\left(\frac{C}{N_1}\right)}{10}} + 10^{-\frac{\left(\frac{C}{N_2}\right)}{10}}\right) \qquad (4)$$

In practice, exact determination of the C/N_{HE} is complicated. The problem can be distinguished according to signal sources used:

TV studio signals — their noise parameters are determined mainly by the quality of the signal processing (usually top quality) and by C/N ratio of HE modulator and upconverter (usually above 60 dB).

Terrestrial TV signals — the dominant parameter influencing C/N_{HE} is, in this case, the signal level S_a at the receiving antenna output:

$$\frac{C}{N_{HE}} = S_a - F_a - N_a \quad [dB] \qquad (5)$$

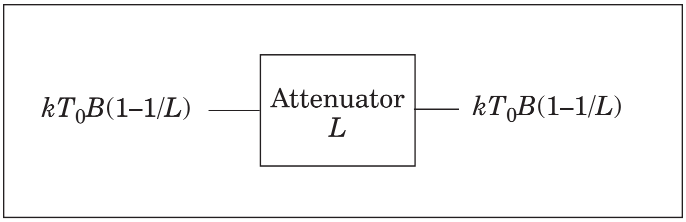
where S_a is a signal level in dBµV at the receiving antenna output, F_a is a noise figure of used antenna preamplifier in dB, and N_a is the basic antenna noise voltage in dBµV depending on a channel bandwidth. The

B (MHz)	N_a (dBµV)
4.75	1.54
5.58	2.24
6.5	2.9

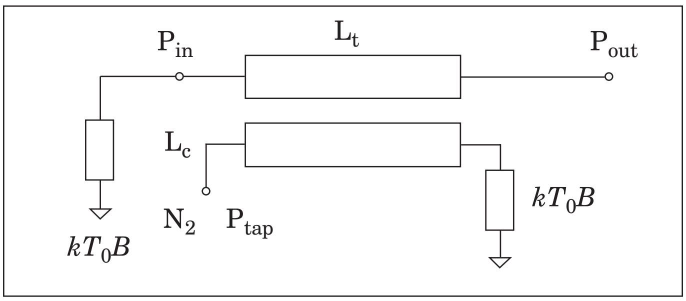
Equation 4 shows that it is necessary to increase the the receiving antenna gain or to lower the preamplifier noise figure for increasing the C/N_{HE} ratio. Since both parameters have practical limits, in the head-end location, there always will be a number of weak terrestrial programs that cannot be used for the distribution in CATV networks. The C/N_{HE} value (Equation 5) does not include the influences both of a finite TV transmitter C/N value and of HE signal processing. Resulting HE output C/N_{HE} values can be calculated with the help of Equation 4.

Satellite TV signals — their transmission chain is very complicated and includes changes in the type of modulation (FM/AM). The determination of C/N_{HE} values is influenced mainly by following parameters:

1. TV studio S/N values
2. Noise parameters of the satellite uplink and downlink



■ **Figure 2. Attenuator thermal noise radiation.**



■ **Figure 3. Lossless directional coupler model.**

3. Head-end location, diameter and noise parameters of a receiving antenna and
4. Noise parameters of HE signal processing.

Only rarely are all four known. Practical C/N_{HE} values lie between 50 dB (with average HE equipment and average reception conditions) and 56 dB (with top HE equipment and very good reception conditions).

Noise in optical networks

Each optical link consists of an optical transmitter (OTX), optical fibers and splitters and optical receivers (ORX). Optical transmitter noise contributions are usually rather small (C/N_{OTX} ≥60dB), optical passive elements are noise-free. Optical link C/N_{OL} ratio is, therefore, mostly influenced by optical receiver input circuits. For practical purposes, the optical link C/N_{OL} ratio is presented in a form of C/N_{ORX} versus optical receiver input power plots. See Figure 1.

When using any C/N_{ORX} plot for optical link noise calculations it is necessary to take into account the following plot parameters:

1. Number of channels.
2. Input wavelength — influences both ORX sensitivity and also C/N_{ORX} (at 1550nm, the C/N_{ORX} is usually approximately 1 dB better with respect to 1310 values).
3. A transmitter optical modulation index (OMI) — also influences ORX output signal level and noise parameters. OMI changes often are used to improve optical link IM parameters. The corresponding dC/N_{OL} change (dB) can be calculated with the help of Equation 6:

$$\frac{dC}{N_{OL}} = 20\log\left(\frac{OMI}{OMI_{ref}}\right) \tag{6}$$

where OMI is an actual OMI value (%) and OMI_{ref} is a reference OMI value (%).

4. TV channel bandwidth — when using catalog C/N_{ORX} plots for different TV channel bandwidth it is necessary to add the following correction constant (dB):

$$\frac{dC}{N_{ORX}} = -10\log\left(\frac{B}{B_{ref}}\right) \tag{7}$$

where B is an actual TV channel bandwidth in Hz, and B_{ref} is an reference channel TV channel bandwidth, also in Hz.

Noise parameters of CATV distribution components

Noise parameters of distribution elements usually are defined with the help of their noise figures F (See Equation 2). Based on knowledge of all network element noise figures, it is possible to calculate the $(C/N)_2$ ratio at the output of an arbitrary network element.

The higher the noise figure of given element, the lower the output $(C/N)_2$ value, compared to the input $(C/N)_1$ value. The calculation of the noise figure of more complex CATV components formed by a cascade of several noisy elements is given by the well-known Friis' formula:

$$F_V = F_1 + \frac{(F_2 - 1)}{G_1} + \frac{(F_3 - 1)}{G_1 G_2} + \ldots.. \tag{8}$$

where,

F_v is the resulting noise figure of the cascade (–)
F_1 is the noise figure of the first element (–)
G_1 is the power gain of the first element (–)
F_2 is the noise figure of the second element (–)
G_2 is the power gain of the second element (–), and
F_3 is the noise figure of the third element (–).

Passive lossy CATV components

All passive lossy distribution elements are the sources of thermal noise. In CATV networks these elements are typically:

- cables
- attenuators
- equalizers.

All these lossy components radiate thermal noise power both to input and output ports (see Figure 1).

The corresponding noise figure of passive lossy elements can be calculated according to Equation 2:

$$F = \frac{kT_0 \frac{B}{L} + kT_0 B(L-1)/L}{kT_0 \frac{B}{L}} = L \quad (9)$$

The noise figure in [dB] of all passive lossy components is equal to their attenuation in dB.

CATV taps

The calculation of the noise figures of CATV taps (directional couplers) is slightly more complicated, since their attenuation is caused primarily by a transformer coupling, which is nearly noiseless (see Figure 3, the model of the ideal loss-less coupled lines).

With P_{in} representing the tap input power and L_c equal to the coupling attenuation (input-tap), it is possible to derive P_{tap} and P_{out} output powers:

$$P_{tap} = \frac{P_{in}}{L_c} \quad (10)$$

$$P_{out} = P_{in} - \frac{P_{in}}{L_c} = \frac{P_{in}(L_c - 1)}{L_c} \quad (11)$$

The total noise power N_2 at the tap output is given by the sum of input termination noise power attenuated by L_c, and inner directional coupler termination attenuated by $(L_c–1)/L_c$:

$$N_2 = \frac{kT_0 B}{L_c} + \frac{kT_{0B}(L_c - 1)}{L_c} = kT_0 B \quad (12)$$

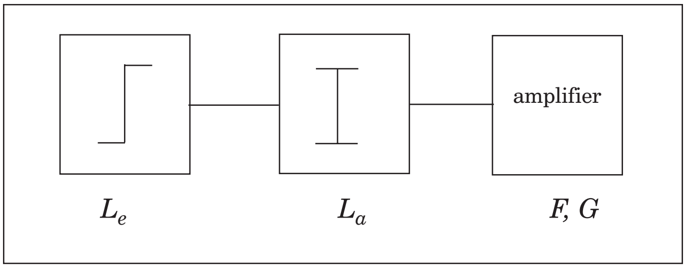
$$F = \frac{N_2}{\frac{N_1}{L_c}} = \frac{kT_0 B}{kT_0 \frac{B}{L_c}} = L_c \quad (13)$$

Noise figures of directional couplers, therefore, are equal to their coupling and through attenuations.

CATV splitters

In a simplified form, the total noise power N_2 at one of the CATV splitter outputs consists of one half of the input noise power N_1 and one half of the noise power generated by an inner splitter resistor (which is interconnected between splitter outputs and ensures sufficient outputs isolation):

$$N_2 = \frac{kT_0 B}{2} + \frac{kT_0 B}{2} = kT_0 B \quad (14)$$



■ **Figure 4. CATV amplifier model.**

$$F = \frac{N_2}{\frac{N_1}{2}} = 2 \quad (15)$$

The minimum two-way splitter noise figure (without additional inner losses) is equal to its input-output attenuation. Practical splitter noise figures (with inner losses) are also equal to corresponding splitting attenuations.

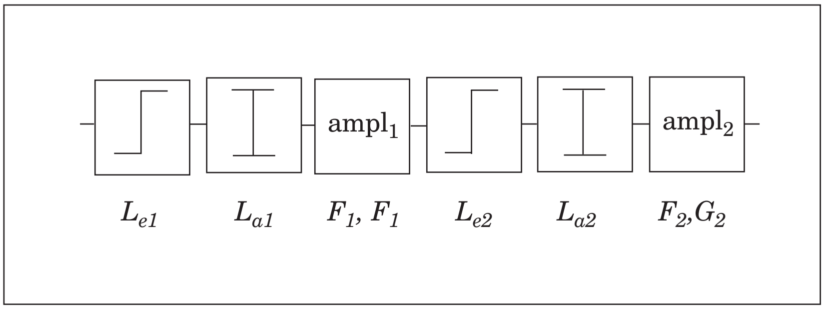
CATV amplifiers

The noise figures of CATV amplifiers can be found in manufacturers' catalogues. When creating the amplifier noise model the fact that the stated noise figures are measured with a zero input attenuator and equalizers must be considered. Practical amplifier noise figures are shown in Figure 4.

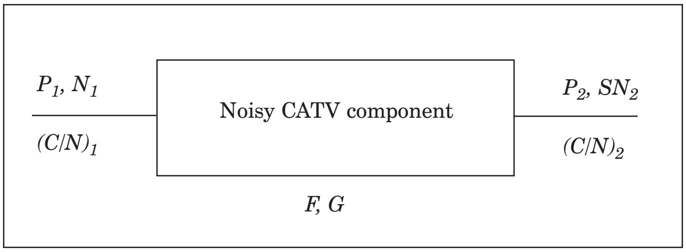
$$F_r = L_e + \frac{(L_a - 1)}{L_e} + (F-1)L_a L_e = L_e L_a F \quad (16)$$

The resulting amplifier noise figure F_r in dB is given by the sum of the equalizer and attenuator attenuation L_a and L_e in dB and the amplifier noise figure F in dB. A different noise model can be obtained in case of two-hybrid amplifiers (preamplifier and output power stage), see Figure 5.

The resulting noise figure F_r of the above stated cascade is given by the equation:



■ **Figure 5. Two-Hybrid CATV amplifier model.**



■ **Figure 6. Noisy component at a general position in the CATV cascade.**

S_2 (dBµV)	C/2 (dB)
30	22.9
40	37.8
50	47.0
60	52.5
70	53.8
80	54.0
90	54.0
100	54.0

■ **Table 1. C/N_2 versus S_2 dependence.**

$$F_r = L_{a1}L_{e1} + (F_1 - 1)L_{e1}L_{a1} + \frac{(L_{e2}L_{a2} - 1)L_{e1}L_{a1}}{G_1} + \frac{(F_2 - 1)L_{e1}L_{a1}L_{e2}L_{a2}}{G_1} \qquad (17)$$

In this case it is possible to shift all the attenuators and equalizers between amplifier stages ($L_{a1} = L_{e1} = 1$) and $F_1 = F_2$, the total amplifier noise figure F_{r2h} (–) drops to the value:

$$F_{r2h} = F_1 + \frac{(L_{e2}L_{a2} - 1)}{G_1} + \frac{(F_1 - 1)L_{e2}L_{a2}}{G_1} \qquad (18)$$

In the case of $G_1 > L_{e2}L_{a2}$, the F_{r2h} value is usually slightly higher than the amplifier noise figure F_1. The influence of two-hybrid amplifiers on the network C/N ratio are described in a more detailed way in the section on using two-hybrid amplifiers.

Calculation of the C/N ratio in the CATV cascade

Each CATV network represents a general cascade with a big number of active and passive components. The C/N ratio in any node of such a cascade can be calculated with the help of Friis' formula, Equation 8, or based on the inherent C/N ratios and Equation 4. But for the computer network analysis another approach can be recommended (see Figure 6).

Figure 6 represents a general task of the calculating output $(C/N)_2$ ratio with known input, $(C/N)_1$ ratio and noise figure F of the CATV component in a general position in the CATV cascade. The derivation of a suitable analysis procedure is based on Equation 2 (It is necessary to take into account the noise input power N_1 being different from the basic termination noise power kT_0B):

$$F = \frac{kT_0BG + N_a}{kT_0BG} = 1 + \frac{N_a}{kT_0BG} \qquad (19)$$

From Equation 19, it is possible to derive the output noise power N_a added by the component:

$$N_a = (F - 1)kT_0BG \qquad (20)$$

The total output noise power, N_2 consists of the amplified input noise power and added noise power N_a:

$$N_2 = N_1G + (F - 1)kT_0BG \qquad (21)$$

From that the output $(C/N)_2$ ratio can be derived (P_1, P_2 represent input and output signal power in watts):

$$\left(\frac{C}{N}\right)_2 = \frac{P_2}{N_2} = \frac{P_1G}{N_1G + (F - 1)kT_0BG} = \frac{P_1}{\dfrac{P}{\left(\dfrac{C}{N}\right)_1} + (F - 1)kT_0B} \qquad (22)$$

The equation above corresponds to the common network signal and IM analysis procedures. Together with all the above stated noise models it has been implemented, for example, into the TOPNET 4.0 program, which is the CATV CAD simulator developed by our company.

CATV network optimization with respect to the C/N ratio

The CATV network design technically is a sensitive matter (influencing not only signal quality, but also network economy).

The initial C/N_{HE} values at the head-end output are usually no more than 50-55 dB; the minimum C/N value at the subscriber outlet is 44-45 dB. Therefore, no more than 5-10 dB for the C/N drop alongside the entire cascade (often many kilometers long) are available. All active and passive distribution elements are the sources of noise.

An erroneous network design with regard to noise can cause a significant reduction of TV picture quality (mainly for the most distanced subscribers).

For an optimum CATV network noise design —

Amplifier max gain [dB]	20	30	40
Input attenuator value [dB]	0	10	20
Output CN	53.13	48.59	39.98
Preamplifier gain	-	15	20
C/N with preamplifier	53.13	52.81	52.30

■ **Table 2. C/N_2 versus amplifier input attenuator value**

ensuring sufficient values of the *C/N* ratio at every network node — it is possible to recommend the following technical solutions:

Optical networks

When designing CATV networks with one or two optical link levels, start with an entire network system design. This design must, above all, ensure the optimum distribution of the *C/N* decrease between the optical and coaxial parts of the network. For example, in systems with short coaxial distribution networks (one or two coaxial amplifiers in the cascade), the *C/N* decline, less than 1 dB, can be reached in the coaxial part of the network. The remaining *C/N* decline can be realized in the optical part of the system. It is possible to go further or use more optical branching.

As has been already stated, the optical link C/N_{OL} ratio depends mainly on the optical receiver input power P_{in} and optical transmitter and optical modulation index OMI. It should be considered that any OMI changes also inversely influence optical links CSO, CTB and CXM. That is why an optimum balance between the C/N_{OL} ratio and IM ratios should be found. A good optical link noise performance can be positively influenced by the proper choice of the optical receivers used. Differences in the C/N_{ORX} values (for the identical optical input levels P_{in}) can be 1-2 dB.

Optimum coaxial amplifier spacing

The decrease of the C/N_2 ratio with an increasing attenuation of any passive distribution element (e.g. with an increasing cable length) is quite non-linear. Table 1 shows the C/N_2 values at the output of a CATV component as a function of output signal level S_2 (dBμV) (simulation using TOPNET 4.0).

The table shows that the output C/N_2 ratio does not essentially change with the attenuation signal level down to S_2 = 70 dBμV; for S_2 <60 dBμV the *C/N* ratio fall is dramatic. From this dependence the following recommendations can be derived:

The common value of a trunk-line amplifier output level is about 95 dBμV. In order that the signal levels at their input should not drop under 70 dBμV, the optimum value of the amplifier gain should be no more than 25 dB. This ensures a very slow trunk-line *C/N* decrease. The cable sections (steps) between the trunk amplifiers should be at maximum, so long that their attenuation, including equalizers and recommended 3 dB input variable attenuator (for fine amplifier output level adjustment), correspond to the above stated gain value.

The employment of the 35 dB gain amplifiers in coaxial trunk lines is inadmissible, but even in the case of using these amplifiers in the distribution networks, the *C/N* ratio should be carefully calculated and checked. Because of the substantial *C/N* dependence, non-linearity using a precise computer simulation can be recommended.

Minimum number/values of attenuators

In CATV networks it is necessary to use an absolute minimum number and minimum values of attenuators, which refers especially to attenuators (both variable or plug-in types) connected to the inputs of CATV amplifiers. Table 2 shows a TOPNET 4.0 simulation of the C/N_2 values at outputs of the amplifiers with a different maximum gain, adjusted as amplifiers with a 20 dB operational gain:

Amplifier noise figure (max. gain)	7 dB
Input level	70 dBμV
Output level	90 dBμV
Input *C/N* ratio	53.83 dB
Operational gain	20 dB

The table shows that the attenuator at the input of an incorrectly selected amplifier (with too high maximum gain) can cause the *C/N* decrease by many dB at a single network stage. In practice, it is recommended to always use the amplifier with a maximum gain only 3-5 dB higher than required operational gain (3-5 dB can represent a reserve for the fine output level adjustment due to the design uncertainties).

Use of two-hybrid amplifiers

The noise parameters of CATV networks can be substantially improved by using amplifiers with the so called “two-hybrid” structure (see Figure 5). By shifting the input attenuator L_{a1} from amplifier input between its stages, it is possible to improve its *C/N* ratio substantially. The degradation of IM ratios caused by the higher preamplifier input signal level is in most cases negligible. In a lower part of Table 2, the output C/N_2 values of the whole amplifier in the case of shifting the input attenuator behind the preamplifier is presented (The preamplifier gain value was taken as one half of the maximum amplifier gain value., using the TOPNET 4.0 simulation).

The bottom line values show that the output *C/N* improvement is significant. In the case of the 40 dB amplifier, the *C/N* enhancement is more than 12 dB. It is hardly comprehensible that, in spite of the fact that the majority of amplifier manufacturers use a two-hybrid structure, the presence of an interstage attenuator is more or less exceptional. Between the stages, in most cases, ALC and ASC circuits, variable equalizers or sloping circuits can be connected only. Nevertheless, some manufacturers enable this way of noise reduction and implement interstage variable or fixed plug-in attenuators in their amplifiers. When choosing amplifiers for your new CATV network, take this possibility into account.

Conclusion

Ensuring sufficiently high *C/N* ratios is among the most important conditions for obtaining the best TV picture and sound quality in all CATV networks. Despite its importance, it is a complicated and often underestimated problem. In common cases, allowance is made for no more than a 5-10 dB decrease of the *C/N* ratio in the whole network, while it can be shown that in the case of an incorrect design, the *C/N* ratio can often drop by more than several dB at a single coaxial cable/amplifier step.

This article presents exact noise models of all CATV distribution elements and defines suitable procedures for the system noise analysis. In the end, it recommends a series of basic rules, by means of which influence of the noise in CATV networks can be kept on an acceptable level, even for large networks. For exact calculations of the *C/N* ratio and optimum noise design, the computer simulation is recommended. Practical results show very good agreement between computer simulated and measured network *C/N* values (usually within the ±0.5 dB range). ■

Author information

Premysl Hudec has received MS and PhD degrees in microwave technics from the Technical University, Prague. He is a founder of the WAVE company that works in the fields of design and manufacturing of microwave communications antennas and CATV CAD and network design. He has developed a software package for the complex design and optimization of both optical and coaxial CATV networks. This currently is being used for projecting large CATV networks (30,000 to 60,000 connections) based on optical ring structure and two levels of E/O - O/E conversion. He can be reached by telephone at 420 2 602 357336 or by FAX/phone at 420 2 301 3858.