Improvement of the CATV Coaxial Distribution System Parameters

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Summary
The paper deals with coaxial part of HFC CATV system. System parameters determinative in obtaining the desired signal level, carrier-to-noise ratio and acceptable nonlinear distortions are considered. Formulae for the gain and the maximum number of RF amplifiers in the longest coaxial link are developed. A mathematical model of the return path channel is suggested with the noise-funneling effect being taken into consideration. Experimental and analytical results are shown that enable the engineer to determine the optimum operating level for a return path laser. A special attention is drawn to the design of the subscribers' distribution network and to the equalization of the downstream and upstream signal levels in particular. Two methods to set and maintain the balance of the return path are described that make it possible for some of the signal characteristics to be monitored.

Key words:
HFC CATV system, coaxial distribution network, forward and return path, noise and distortion, balancing the return path.

1. Introduction

Contemporary CATV networks are of the hybrid fiber-coax (HFC) type. Such a network is comprised of an optical ring which is fed by the hedend, multiple hubs connected to the optical ring, access networks, and home communications terminals (HCTs). The headend supports broadcast services and is the focal point of a wide area network that supports interactive services. In systems that use analog supertrunks to the hub, the headend is the location of all broadcast modulators, both analog and digital. If SONET or other digital interconnects are used to connect to the hub, then all modulators may be located in the hub. Each of the hubs serves an access network, which consists of optical nodes connected via a coax bus network to HCTs.
The systems here considered differ by using RF carriers to transmit the information signals. Two frequency bands are provided for signal transmission from the headend/hub to the subscribers: 112 MHz to 550 MHz (for analog video broadcasting) and 550 MHz to 862 MHz (for narrow casting services – data, voice and digital video). Analog video signals are transmitted by using VSB-AM while QAM methods (usually 256-QAM) are mainly used to transmit digital video programs and data. The system reverse paths make use of the 5 MHz to 65 MHz frequency band and subscribers' signals are transmitted by using QPSK or 16-QAM methods.
Signals transmission over the cable network of a CATV system worsens the quality of service (QoS) due to noise and distortions inherent to the active devices in the HFC system such as laser transmitters, optical receivers, optical and RF amplifiers. The level of both noise and unwanted spurious signals depends on the parameters of the HFC network components, the dynamic range of RF signals, number of channels, optical modulation depth etc. In order to be estimated the QoS the following parameters are usually used: acceptable signal level variations, carrier-to-noise ratio (C/N) and ratios of the carrier to the intermodulation products (C/I), such as composite second order (CSO), composite triple beat (CTB) and composite intermodulation noise (CIN).
The paper aims at providing formulae that can be directly applied in engineering design of coaxial part of HFC CATV network. It also focuses on the ways to reduce the effect of noise-funneling in the return path and the methods for signal level management in the upstream direction.

2. Signal Degradation due to Noise and Distortion in the Coaxial Network

In order to overcome the loss of the distribution cables and to provide power to drive end terminals, RF amplifiers are used throughout the distribution system. These must be designed to add as little signal degradation as possible, particularly noise and distortion, consistent with providing the required gain and total power output [1-3].

2.1 Carrier-to-Noise Ratio

The C/N degradation as a signal passes through a single RF amplifier is given by the formula

$$C/N_{\mathrm{A}} = U_{\mathrm{in}} - \left(10\lg B_{\mathrm{n}} - 5.23\right) - NF \qquad (1)$$

where U_{in} is the amplifier input level in dBμV, NF is the noise figure of the amplifier in dB (typical noise figures

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range from 6 to 8 dB) and B_n is the effective noise bandwidth in MHz. The value ($10\lg B_n - 5.23$) in dBμV represents the thermal noise in bandwidth B_n.

Although the allocated channel bandwidth for analog signals is 7 MHz (in Europe), the effective noise bandwidth of receivers B_n is less (4.75-MHz bandwidth is used as the standard for noise measurements). For QAM signals the noise power is measured over the entire bandwidth of the entire assigned channel (7 MHz for downstream signals and various bandwidths for upstream signals). Therefore, for analog signals the calculated value of ($10\lg B_n - 5.23$) is 1.54 dBμV while for QAM signals the noise floor is $10\lg(7/4.75)$ = 1,68 dB higher.

To ensure uniform degradation of CNR for each channel, it is necessary the amplifier input signals to have approximately the same levels. As is known, the loss of coaxial cable increases as the square root of frequency. Thus, the RF amplifier need not supply the same level for channels at the bottom of the spectrum as at the top to overcome cable loss. Therefore between the preamplifier and output stage, a slope circuit is used to adjust the frequency response so that it uniformly increases across the downstream frequency range (typical gain slopes are 6 to 10 dB). Furthermore the amplifier input circuits are designed to accommodate a variety of equalizers that are optimized to compensate for the residual response variation and pads that are used to set the correct drive level to the preamp input.

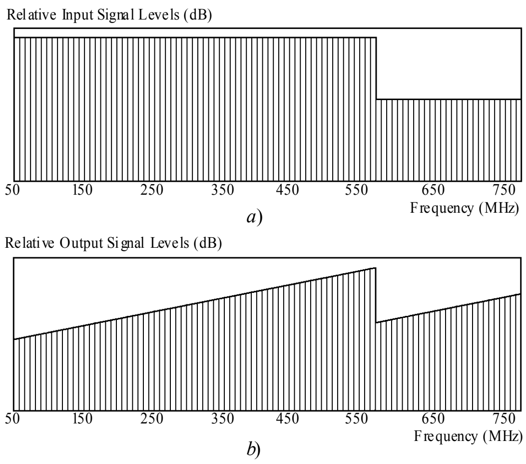

Fig. 1 Amplifier operating dynamic.

Figure 1 shows the nominal preamplifier input (after equalization) and output levels of a 750-MHz amplifier with hybrid analog-digital signal loading. Digitally modulated signals do not require the same C/N and C/distortion as analog video channels, and so are reduced in level to reduce overall amplifier loading. Usually QAM signals are operated 6 to 10 dB lower in level than equivalent analog video signals would be at the same frequencies.

In the downstream direction, coaxial distribution networks with multiple, identical amplifiers in cascade are usually designed and operated so that the gain, measured from amplifier output to amplifier output, is unity. For a cascade of i identical RF amplifiers, each followed by loss equal to the gain of selected amplifier type, end-of-line C/N (in dB) can be easily calculated as follows:

$$C/N_{\mathrm{CL}} = C/N_{\mathrm{A}} - 10\lg i\,. \qquad (2)$$

Therefore, the effective noise figure increases by 3 dB for every doubling of the cascade, so the minimum input level U_{in} (and thus amplifier output level U_{out}) must increase by that amount to provide the same end-of-line C/N. For digitally modulated signals the calculated value of C/N_{CL} is 6 dB lower.

The total C/N on the subscriber outlet (SO) is

$$C/N_{\mathrm{SO}} = -10\lg\left[10^{-0.1(C/N_{\mathrm{CL}})} + 10^{-0.1(C/N_{\mathrm{T}})}\right], \qquad (3)$$

where C/N_T is the C/N of the terminal equipment (e.g., set-top terminal), considered alone.

Typical set-top terminals that handle analog input signals have noise figure specifications ranging from 10 to 13 dB. Since cable operators are only required to deliver analog television signals at levels of 60 dBμV (and typically deliver many channels at close to that level), we can use equation (1) to determine that, with the noisiest terminals $C/N_T = 60 + 1.54 - 13 \approx 48.5$ dB.

For QAM signals the calculated from (3) value of C/N_{SO} must be corrected by the quantity

$$\Delta(C/N_{\mathrm{SO}}) = -S - 10\lg(B_{\mathrm{ch}}/B_{\mathrm{n}}) - 2\,, \qquad (4)$$

where S is the suppression of digital signal levels relative to analog video (in dB), B_{ch} is the channel bandwidth (7 MHz), B_n is the effective noise bandwidth for analog signals (4.75 MHz) and 2-dB margin is the expected variation from design performance. As an example, if $S = 6$ dB, $\Delta(C/N_{SO}) = -9.68$ dB.

Typical design specifications for the supertrunk plus coaxial distribution portion of the plant call for 48 to 49 dB analog video C/N. For QAM signals, 40 dB end-of-line C/(N+CIN) is a typical design spec and is consistent with 49-dB analog signal to noise, with digital signals depressed 6 dB from analog and correction of 1.7 dB for the noise susceptibility bandwidth, provided that the noise floor is similar across the analog and digital spectrum.

2.2 Distortion Introduced by RF Amplifiers

RF amplifier is not perfectly linear and its transfer function can be expressed as a power series

$$u_{\mathrm{out}} = Au_{\mathrm{in}} + Bu_{\mathrm{in}}^2 + Cu_{\mathrm{in}}^3 + Du_{\mathrm{in}}^4 + \ldots \qquad (5)$$

where u_{out} is the output voltage and A, B, C, D, . . . are the gains at the various powers of the input voltage u_{in}. A major cause of this nonlinearity is the compression that takes place as the amplifier nears its saturation voltage. The distortion due to saturation effects can take any of three related forms: even-order distortion (CSO), odd-order distortion (CTB), and cross-modulation. Because of the difficulty in making the test and demonstrated inconsistency in the results, cross-modulation has become less important than CTB as a means of characterizing third-order distortion.

As seen from expression (5), the level of the second-order products rises as the quadrate of the input voltage (e.g., the rise is 2 dB for every 1-dB rise in input level) so that the ratio of carrier to composite second-order beats (C/CSO) at the output decreases by 1 dB for every 1-dB rise in the input level. The ratio of carrier to composite triple beats (C/CTB) at the output degrades by 2 dB for every decibel increase in operating level.

All modern cable RF line amplifiers are “push–pull”, meaning that their output stages contain two transistors in a balanced circuit that ensures symmetrical, or nearly symmetrical, compression. To the extent that any nonlinearities are also symmetrical, they will produce only odd-order distortion products. Analysis has shown that only CTB products at frequencies $f_i \pm f_j \pm f_k$ $(f_i < f_j < f_k)$ must be taken into consideration when determining the nonlinear distortion.

For a contiguous set of N equally spaced carriers, the number of third-order beats falling in any given channel N_{CTB} is approximately [4]

$$N_{CTB} = 0.25\left(N-1\right)^2 + 0.5\left(N-M\right)\left(M-1\right) - 0.25N \quad (6)$$

where M is the number of the RF channel. The frequency distribution of a broadband system for a different number of channels transmitted is shown in Fig. 2.

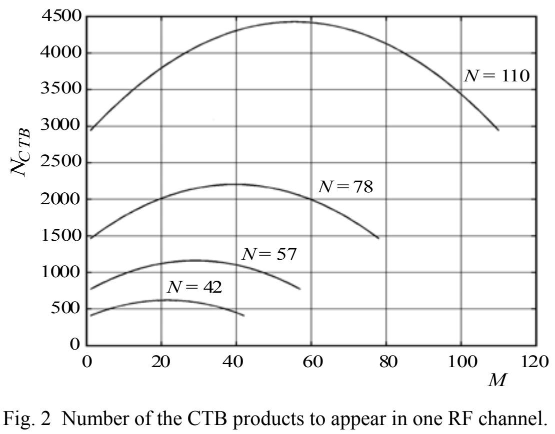

Fig. 2 Number of the CTB products to appear in one RF channel.

By solving equation $dN_{CTB}(M)/dM = 0$ one can show that a maximum number of the CTB products is attained when $M = (N+1)/2$, hence the CTB products number is at its maximum for the central RF channel and can be calculated with the following formula

$$N_{\mathrm{CTB(max)}} = \left(3N^2 - 8N + 2\right)/8 \,. \quad (7)$$

If $N >> 1$, then equation (7) can be written in the form $N_{CTB(\max)} \approx 3N^2/8$.

From Fig. 2 does not follow that the channel with the greatest number of beats is necessarily the channel most affected by third-order interference. As is known, amplifiers are not operated with equal power carriers, but rather with a uniform upward “slope” of levels with frequency (this increasing in level across the operating range is known as tilt), causing some beats to be stronger than others. Reducing the levels of the lower-frequency channels reduces the amplitudes of the intermodulation products to which those channels contribute.

In the specifications issued by broadband equipment manufacturers C/CTB of the amplifiers are given for a reference output level $U_{\mathrm{out\,ref}}$ (the operating output levels of the highest channels are usually +95 to +100 dBμV) and channel loading N_{ref} (e.g. 57, 78 or 110 channels). When the amplifier output level and the number of channels differs from those given in the specifications but the tilt is as specified by the manufacturer, then the following correction of the amplifier performance must be made:

$$C/CTB_{\mathrm{new}} = C/CTB_{\mathrm{ref}} - 20\left(U_{\mathrm{out\ new}} - U_{\mathrm{out}\,ref}\right) - 10\lg(N_{\mathrm{new}}/N_{\mathrm{ref}}) \quad (8)$$

where $U_{\mathrm{out\,new}}$ is the actual amplifier output level in dBμV and N_{new} is the actual channel loading.

When i identical RF amplifiers are included in the coaxial line connecting the subscriber with the optical node, the following expression can be used to determine the end-of-line C/CTB (in dB):

$$C/CTB_{\mathrm{CL}} = C/CTB_{\mathrm{A}} - 20\lg i\,, \quad (9)$$

where C/CTB_{A} is the distortion of a single amplifier. It is evident that CTB distortion increases by 6 dB for every doubling of the cascade, so the maximum allowable output level must decrease by 3 dB to maintain the same end-of-line distortion levels.

Typical RF amplifiers provide a C/CTB of 70 to 90 dB when loaded with unmodulated carriers at recommended operating levels, depending on design. The results of such testing do not match the distortion when systems are loaded with analog television carriers and there are standard assumptions regarding the approximate improvement when loaded with modulated carriers: 6 dB in the case of CSO and 12 dB in the case of CTB.

The total C/CTB on the subscriber outlet (SO) can be calculated by the formula

$$C/CTB_{\mathrm{SO}} = -10\lg\left[10^{-0.1(C/CTB_{\mathrm{CL}})} + 10^{-0.1(C/CTB_{\mathrm{T}})}\right] \quad (10)$$

If typical analog set-top terminal distortion levels (60- to 65-dB C/CTB_T) are taken into account, it is evident that the C/CTB_{SO} is well within standard requirements.
The preceding analysis was based on the carriage of a spectrum of signals, each of which has a carrier that represents most of the energy in the channel. QAM signals, however, have a suppressed carriers and, when viewed on a spectrum analyzer, look like a flat blocks of noise occupying the entire communications channel. When such signals are subject to second- and third-order distortion, they do not produce single-frequency products but rather noiselike bands of energy whose amplitude versus frequency signature depends on the distortion mechanism. The products of this type of distortion are known as composite intermodulation noise (CIN). Generally, CIN is quantified as an equivalent (but output-level-dependent) increase in noise level that must be figured into the C/N calculation.

3. Noise-Distortion Trade-Off

When designing the coaxial part of a HFC CATV system the loss between each pair of amplifiers must be made identical to the gain of selected amplifier for optimum performance (unit gain concept), that is

$$(\alpha/100)\, l_{(i-1),\, i} = G\,, \qquad (11)$$

where α is the cable attenuation in dB per 100 m, $l_{(i-1),\,i}$ is the length of the coaxial cable between the $(i-1)$-th and i-th amplifier in meters. If the loss is less than that value, then each amplifier's input level (and hence output level) will be greater than the previous amplifier, and the distortions will quickly build up to a high level. If the loss is greater than the gain, then the input of each amplifier will be less than the previous amplifier and thus contribute disproportionately to the overall C/N degradation.
The amplifier output level must be kept within certain limits in order to ensure the required signal quality at the subscriber outlet. Those limits are defined by the minimum ($U_{\text{out min}}$) and maximum ($U_{\text{out max}}$) level of the amplifier output signal. The minimum level refers to the required carrier-to-noise ratio and the maximum one refers to the acceptable non-linear distortion. If the equations (1), (2), (8) and (9) are taken into account, the acceptable output levels (in dBμV) of the amplifiers in the longest coaxial link can be defined as follows [5]:

$$U_{\text{out min}} \geq C/N_{CL} + G + (10\lg B_n - 5.23) + NF + 10\lg i \qquad (12)$$

$$U_{\text{out max}} \leq U_{\text{out ref}} - 10\lg(N_{\text{new}}/N_{\text{ref}}) - 20\lg i\,, \qquad (13)$$

where G is the gain of the selected amplifier (typical gains range from 20 to 38 dB).

If we plot the expressions (12) and (13) as a function of cascade, we can see that there is a maximum attainable cascade and a unique operating level that allows that cascade to be realized. Figure 3 illustrates the usable operating range, along with the parameters that define the noise-distortion-cascade relationship. As seen, the values $U_{\text{out max}}$ and $U_{\text{out min}}$ come closer to each other and coincide for a given amplifier when the cannel loading and the number of cascaded amplifiers is increased. If the parameters of the wideband RF 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 7-8 km and the number of amplifiers in the line can not exceed 10-12.

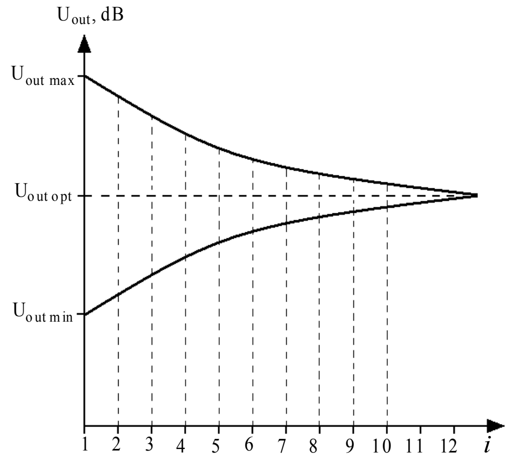

Fig. 3 Acceptable dynamic range of U_{out}

When higher-gain amplifiers are used, then either output levels must be raised or input levels lowered; the former will further increase distortion, whereas the latter will cause a greater C/N degradation in each amplifier station. If amplifiers are spaced more closely together, then more will be required to reach the same physical distance, thereby increasing both noise and distortion.
The dependences given in this paragraph allow the acceptable number of amplifiers in the longest coaxial trunk line and there gain to be determined. For this purpose, the distance S_i between the first and i-th RF amplifier is calculated so that the following condition to be met:

$$S_i = 100(i-1)G_i/\alpha \approx l_{\text{CL}}\,, \qquad (14)$$

where l_{CL} is the maximum length of the coaxial line. If the condition is satisfied for $i = n$, the number of amplifiers that can be included in the coaxial line is n, and their gain is equal to that of the n-th amplifier. Then the distance between two adjacent amplifiers is

$$l_{(i-1),i} = l_{\text{CL}}/(n-1)\,. \qquad (15)$$

4. Return Path Issues

The electronic blocks of the electro-optical transducers, RF amplifiers and subscriber devices (converters and cable modems) are the main source of noise in the CATV return path. Intermodulation distortion appears both in amplifiers and lasers and in passive devices 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 MHz. Loose-contact connectors can also form diode transitions that cause intermodulation products by high levels appearing in the return path. As a rule about 70% of the interference in the return 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 return path 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. 4 the frequency and amplitude distribution of penetrating interference (ingress) in the return path is shown. Ingress in the LF range of the return 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.

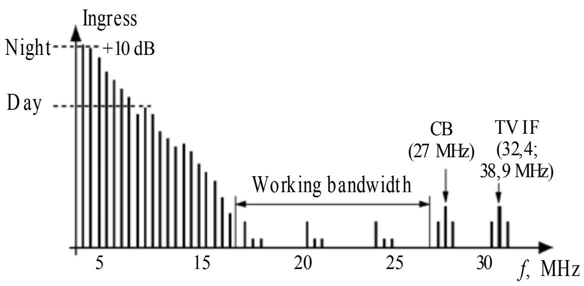

Fig. 4 Distribution of the ingress signals.

One of the main causes to worsen communications over the CATV return path is the noise-funneling effect due to tree-and-branch topology of the cable distribution network. With such an effect the noise, inter-modulation products and interference from all the cable network branches interfere with the signals in the subscribers’ cable modems. In result, the carrier-to-noise ratio and ratios of the carrier to the intermodulation products (C/I) at the receiver input of the cable modem terminal system (CMTS) are reduced to an unacceptable value. Thus, the value of the bit error rate (BER) is increased and communications over the return path get worse or cut-off. Cable modems, telephone, LAN etc. provide services require different BER values varying in the range of 10^{-4} to 10^{-7}.

Analysis has shown that the acceptable level (low enough) of noise, distortion and interference in the return path of a CATV system can be provided in two ways [6, 7]. 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.

Demand for upstream bandwidth is increasing rapidly, driven primarily by the needs of DOCSIS modems. This pressure on upstream bandwidth has generated several technologies for splitting the optical node in the upstream direction, without using more fibers to get data back to the hub or headend. Splitting the upstream path is one technique used to improve the effective upstream bandwidth of, for example, DOCSIS modems. Since the upstream band is so much narrower than the downstream path, much less upstream capability is provided as compared with downstream capability. Splitting the node also helps with noise-funneling issues.

In the downstream direction, distribution networks with multiple, identical amplifiers in cascade are usually designed and operated so that the gain, measured from amplifier output to amplifier output, is unity. When systems carry only one signal type (e.g., analog video signals), their levels are often adjusted so that they increase linearly with frequency, as measured at amplifier output ports. This usually results in amplifier input levels that are approximately the same across the spectrum and creates the optimum balance between noise and distortion. QAM signals are operated 6 to 10 dB lower in level than equivalent analog video signals would be at the same frequencies.

Signal level management in the upstream direction is much more complex and must be treated as an overall system problem rather than as just part of the distribution network design. Signals may originate from anywhere in the system and may be of various types so that the channel loading and levels may vary continuously at any given amplifier.

When balancing the return path some difficulties can be met because of the different level of the signals that come from the subscribers’ cable modems and are passed to the input of the reverse path amplifiers. This is due to the unequal paths passed by the signals, i.e. to the different attenuation along the coaxial cable and the passive devices included (splitters and taps). Though the level of the radio pulse transmitted by the cable modem is automatically controlled in the CMTS (within the limits of 92 dBμV to 112 dBμV) no alignment of the signals’ levels is possible, so variations within 6 dB are quite admissible. Hence, when designing the return path it is of great importance to achieve a level equalization of the subscribers' signals at the input of the drop amplifier.

5. Some Approaches to Improve the Return Path Parameters

5.1 Noise Mitigation

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

$$C/N_{RP} = C/N_A - 10\lg(\sqrt{m.v}), \qquad (16)$$

where C/N_A is the reference value of the carrier-to-noise ratio of the amplifier type applied in the return path, m is the total number of amplifiers and v is the number of branches over the coaxial network.

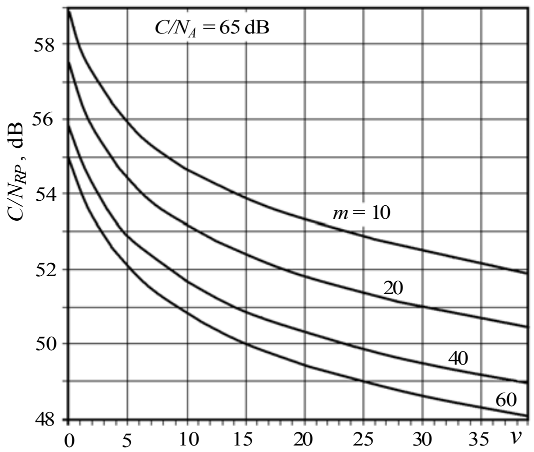

Fig. 5 Diagram to calculate the number of branches over the coaxial network.

Analysis has shown that C/N_{RP} 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 $C/N_{RP} = 52{,}5$ dB. It can be proved that the value of C/N_{RP} 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 v will increase parameter C/N_{RP} until at $v = 40$ it equals that of a network without branches. If C/N_{RP} and the type and total number of amplifiers are known the optimum value of v can be easily calculated by the use of the diagrams (Fig. 5) obtained with (16).

In order to remove return band energy that might be coming out of the house drop filters can be used. These are high-pass filters whose cutoff frequency is about 65 MHz. With typically 25 to 40 dB of attenuation in the return band, such filters do not allow return band signal power in the home to reach the hard-line plant. The high-pass filter is intended for use at homes not taking any services requiring two-way communications. When the home has a video-on-demand set top or a cable modem, both of which must communicate back to the headend, a bypass is added to allow signals in a narrow band to pass. Interference from the home that occurs in the passband obviously appears in the hard-line plant, but interference coming out of the house at other frequencies is blocked.

Another interference mitigation option is to provide, in the tap or externally, two diplex filters, which separate the upstream frequency band (5 to 65 MHz) from the downstream band. An attenuator is inserted into the low side of the diplex filter chain so that the loss is increased in the return direction while not changing the loss in the forward direction. The rationale is that tap values are selected to yield the correct signal level at the highest downstream frequency (70 ± 5 dBμ). Since cable loss is roughly proportional to the square root of the frequency, the loss in the upstream direction is considerably lower than in the downstream direction. Thus, whereas the downstream received level is the same at all houses (within a certain range), the upstream transmit level is significantly different between homes. Compensation for these signal level differences can be achieved by proper selection of attenuators, added in the return direction.

When choosing the value of return attenuation some considerations must be made referring to the subscribers' distribution network, attenuation in the coaxial cable and in passive devices, the level of signals transmitted from home terminals, the reference level at the return amplifier input (75 ± 2 dBμV) etc. The aim is to make all signal levels coming to the drop amplifier from all the subscribers' cable modems equal to the reference value. As shown in the example on Fig. 6, this is achieved when 6-, 12- and 18- dB attenuators are used.

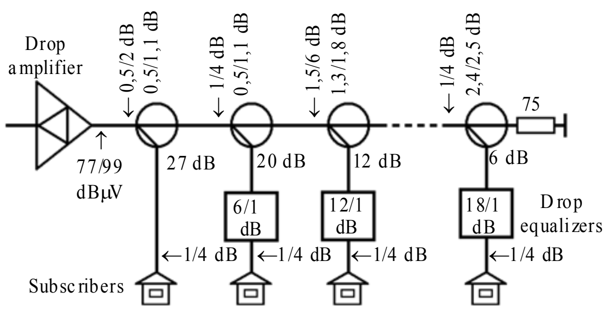

Fig. 6 Level equalization of the upstream signals at the drop amplifier input.

5.2 Optimum Signal Level at the Return Laser Input

One convenient way to establish the level at which to operate the return path laser is to determine the range of input signal levels across which some specified minimum noise power ratio (NPR) is obtained, as indicated in Fig. 7. At low signal levels, the NPR is noise limited. Above the level of peak NPR performance, the drop in performance is precipitous as the laser rapidly enters the region in which the signal is clipped. The initial drop may be due to distortion, primarily second order, and then follows a region in which the primary effect is from laser clipping. Clipping noise tends to be the dominant mechanism by which the NPR is reduced on the right side of the graph.

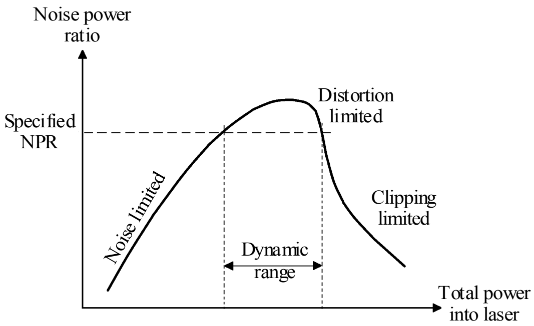

Fig. 7 NPR as a function of total power into the laser.

NPR curves are published by laser manufacturers and it is desirable to set the actual RF operating level (the power sum of all upstream signals) just to the left of the point of maximum NPR without going over the limit where clipping gets to be a significant issue. The operator must take into account temperature effects, errors in level setting, and laser loading due to ingress. Besides, he must also account for future services that may be added; it is not good to go back and readjust operating levels to accommodate a new service.

Once the optimum operating level for a return path laser $P_{L\,\mathrm{opt}}$ is determined, the power to each service P_{Si} using the return path must be apportioned taking into account the following rules: 1) For a given modulation type, allocate signal power proportional to the bandwidth of the signal, since a wider bandwidth signal requires more power than a narrow one. 2) For different modulation types, we adjust the amplitude according to the need of the modulation. 16-QAM modulation, for instance, requires about 4 dB better C/N than does a QPSK signal of the same bandwidth. Thus, a 16-QAM signal will be carried at 4-dB greater amplitude than will a similar-bandwidth QPSK signal.

The signal levels are set such that the total signal power is equal to the total at the operating point of the NPR curve, for example, 75 dBμV, i.e.

$$10\lg\left(10^{P_{s1}/10}+10^{P_{s2}/10}+\dots\right)=P_{L\,\mathrm{opt}}\,. \quad (17)$$

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

$$P_{si}=P_d+10\lg B_i=P_{L\,\mathrm{opt}}-B_{RP}+10\lg B_i, \quad (18)$$

where B_i is the frequency bandwidth for the signal to provide the i-th service (in Hz), P_d is the mean power of the RF signal for a unit frequency band (in dBμV/Hz) and B_{RP} is the return path bandwidth.

5.3 Balancing the Return Path

The preferred approach to upstream level and gain setting is to align the system from headend out so that the input level to each upstream amplifier is consistent; that is, if a level of x dBμV is inserted into the input of any upstream amplifier, the level received at the headend will be the same [8]. Pads (and, if required, equalizers) are placed in the output of the gain modules to set overall system gains properly.

CATV systems are designed to operate at a reference level of 75 ± 2 dBμV. The test signal frequency must correspond to the operation frequency of the cable modems, a frequency of 23 MHz to 25 MHz being the ideal one. In systems that employ a very wide reverse path (5 … 65 MHz) it may be better to utilize two test frequencies, one at 25 MHz and the other at 50 MHz to properly correct for even the reverse path slope.

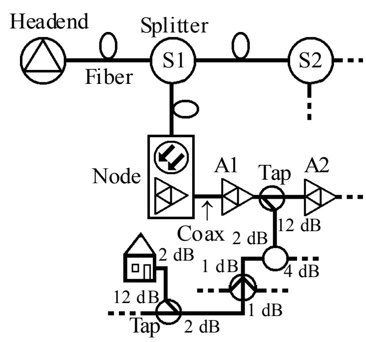

Fig. 8 Algorithm for balancing the return path.

The algorithm for balancing the return path can be explained by means of Fig. 8 where a section of the cable distribution network of a CATV system is shown. Its optical part has a tree-and-branch topology, where signals at some points of the optical trunk line branch out towards optical nodes to feed the local area coaxial distribution networks.

The procedure of balancing starts from the optical node that is closest to the headend. A test signal (75 dBμV and frequency about 25 MHz) is fed to the modulation input of the return laser module. Its gain is adjusted in a way to make the level of the RF signal at the headend input equal to the reference level. A spectrum analyzer or a sweep receiver in the range of 5 MHz to 65 MHz can be used to monitor the test signal in the headend.

Balancing the coaxial sections of the return path can not start before gain of all optical nodes is set to the desirable value. Initially the test signal is fed to the input of amplifier A1 in the first local coaxial network that is closest to the optical node. The test signal level at the headend input is made equal to the reference one, the attenuator and the equalizer connected in its output being properly adjusted. After balancing the section of the first amplifier the test generator is injected into the next amplifier input port A2 and the procedure is repeated, etc.

The above algorithm for balancing the return path requires co-operation of two operators: one to adjust the corresponding optical node or amplifier and the other to monitor the signal level in the headend and to communicate with the first operator. This makes it necessary for more effective methods of balancing to be applied during the whole lifetime of the system.

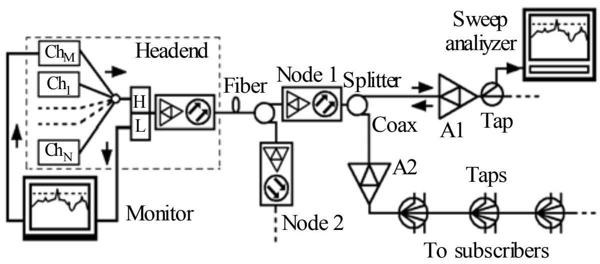

Fig. 9 Method for return path balancing.

The method, presented in this paper (Fig. 9), makes use of a sweep analyzer and a return monitor. The sweep analyzer is connected at the input of the return path amplifier to be adjusted and the return monitor is in the headend, its image being transmitted over a separate forward TV channel. Thus a direct connection is established between the two sets of instruments. This method provides possibilities to monitor the frequency-response curve of the whole return path and to evaluate ingress, reflection and frequency-dependent attenuation in all the units.

6. Conclusion

The relations described in the paper have been applied to design the coaxial path of HFC CATV system. Experiments carried out with operating systems show that the calculated values of the system parameters correspond well enough to those required by the existing technical standards.

Balancing the reverse path of HFC CATV can cause troubles to the operators due to random factors that can not be considered at the design phase. The proposed method for balancing the return path provides facilities to build up a fully automated system for maintaining the desired quality of communications over the CATV systems.

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