Improving the Quality of Analog TV Signals in Cable TV Networks through Optimization of the Number and Parameters of Amplifiers in the Network

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Abstract – **We study a transmission line by performing experiments varying the signal/noise ratio (S/N), non-linear distortions (CSO, CTB), amplification coefficient (K_U) and the number of transmitted TV channels.**
We exhibit graphical relationships, which allow easy determination of the required number of amplifiers in order to compensate for transmission line losses, given the signal/noise ratio. We optimise a structure with the smallest amplification coefficient, maximum signal level at the output that results in high signal quality.

Keywords – **Signal/noise (S/N), non-linear distortions (CSO, CTB), amplification coefficient (K_U)**

I. Introduction

Each CATV is designed to supply its subscribers with quality signal. Application reveals that there are a number of difficulties encountered in the translation of many channels. The passing of a signal along the whole line, through active and passive elements, causes its modification. Distortions, degrading and noises appear whose norms are given in detail in the standards [2, 3].

Basically, they are divided into linear and nonlinear [1, 2]. Nonlinear include the irregularity of group delay time (channel distortions) and the amplitude frequency response of the individual channel and as a whole [4, 6].

II. Nonlinear distortions analysis

Nonlinear distortions re caused by active devices (amplifiers). In practice we have multifrequency impact at their input – these are the carriers of the individual channels – ω_1, ω_2,… ω_n [1, 2]. CATV amplifier can be regarded as an active four pole piece whose input signal is "*x*" and the output signal is "*y*".

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By approximating by power order of Taylor's function we get $y = f(x)$, where f stands for the translation characteristic at point

$$y = f(x_0) + \sum_{n-1}^{\infty} f^{(n)}(x_0).(x - x_0)^n \quad . \tag{1}$$

Where $f^{(n)}(x_0)$ is the derivative of translational characteristic at operating point x_0.

If we are confined to two signals

$$x = x_0 + a_1 \cos\omega_1 t + a_2 \cos\omega_2 t \quad . \tag{2}$$

Actually only the distortion products of the first two orders are evaluated: IMA2 (second order) and IMA3 (third order – Inter Modulation Amplitude).

2.1. Inter Modulation products analysis

One of the consequences of the linear irregularity is the decrease of the amplification coefficient when the level of the input signal is boosted (Fig. 1).

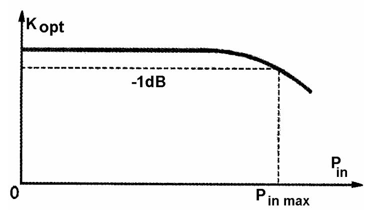

Fig. 1

In fact, if an input signal $x = \alpha_1 \cos\omega_1 t$; output signal $y = f'\alpha_1 + \frac{1}{8} f'''\alpha_1^2$ and the coefficient of amplification is $f' + \frac{1}{8} f'''\alpha_1^2$. Accordingly, by entering amplification coefficient of relatively weak signal function f', equal to $1 + \frac{1}{8}\frac{f'''}{f'}\alpha_1^2$ then it will increase in proportion to the square value of the input signal amplitude $(f' > 0,\ f''' < 0)$.

As much as the output power in the reference frequency of the second and third harmonic increments with the increase of the input power, the dependencies $P_{out}=f(P_{in\omega1})$ intersect at some values of input power P_{ip} (Fig. 2). The values of these intersection points allow finding the levels of the harmonic at the amplifier input with a certain level of input signal. The ratio which combines output power with basic power ($P_{1\omega1}$), the double frequency ($P_{2\omega1}$) and the output power of the third order with the output power in the basic frequency at the point of intersection P_{ip} (Intercept Point), is of two kinds:

$$P_{2\omega 1} = 2P_{1\omega 1} - P_{ip}(dBm);$$
$$P_{3\omega 1} = 3P_{1\omega 1} - 2P_1. \quad (3)$$

Thus, on the ground of the discussed subject (3) it is possible to draw the following conclusion: when boosting (decreasing) the output level of the amplifier signal ΔdB the intermodulation components of second order (IMA2) will rise (decrease) also to ΔdB whereas the intermodulation components of the third order (IMA3) will rise (decrease) to $2\Delta dB$.

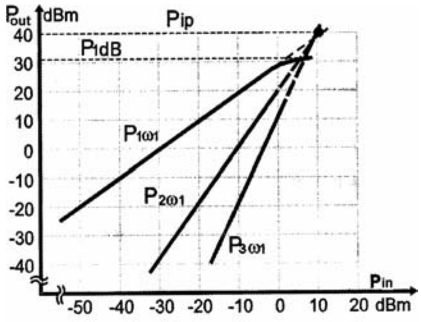

Fig. 2

2.2.Calculation of nonlinear distortions

To determine the maximum level of the output signal during translation of a large number of channels according to [5, 7] the usual procedure is to estimate intermodulation components by the composite beat of second CSO (Composite Second Order) and third CTB (Composite Triple Beat). In addition, it is known that for amplifiers having upper frequency of *606MHz* test trials are conducted with *29* channels whereas for amplifiers with upper frequency *862MHz* the number of channels is *42*. Estimations of CSO and CTB are carried out along the worst performing channel with predetermined frequency disposition of the channel.

Calculation of maximum output level of the amplifier U_{maxN} (*CTB = 60dB*) for distortions of the third order during translation of *N* number of channels is done by the formula:

$$U_{\max N3} = U_{\max 3} - 10\lg(N/2) \quad (4)$$

Formula (4) shows that with the increase in the number of channels we get the maximum level of the output channel U_{maxN3} drop to (see Table 1) the value of $\Delta U_{1(3)}$. By virtue of this when studying the instruction manuals of the selected type of amplifier special note should be taken concerning the assigned values U_{max3}(*IMA = -60dB, 2* channels) and U_{maxN3} (*CTB = -60dB, 42* channels). The difference between them should be about $13 \div 14$ *dB*. If that difference is higher or less than the assigned value, check carefully the parameters in the manuals.

A similar dependence can be derived for a product of the second order (*CSO = -60dB*) by the empirical expression:

$$U_{\max N2} = U_{\max 2} - (3{,}5...4{,}3)\lg(N/2) \quad .(5)$$

Table 1 contains the results from calculations concerning the decrease of the maximum output level U_{max2} (for average cases) with increased number of translated channels (*CSO = -60dB*). When conducting real calculations with a large number of channels (*N* >20) it is preferable to use values close to that recommended by the manuals U_{maxN2} and U_{maxN3} (i.e, according to criterion *CSO = 60dB* and CTB=60*dB*).

$$U_{\max N2} = U_{\max SCO} + (3{,}5...4{,}3)\lg(42/N) \quad (6)$$

TABLE1

N	$DU_{1(3)}$, *dB*	$DU_{1(2)}$, *dB*
1	+3,0	+1,1
2	0	0
4	-3,0	-1,1
6	-4,8	-1,8
8	-6,0	-2,3
10	-7,0	-2,7
20	-10,0	-3,8
40	-13,0	-4,9
60	-14,8	-5,6
80	-16,0	-6,1

$$U_{\max N3} = U_{\max CTB} + 10\lg(42/N) \quad . (7)$$

Example 1. Determination of maximum output level of amplifier GPV 841 U_{maxN3} for *29* channels with reference value $U_{maxCTB} = 108dB\mu V$ (*42* channels, *CTB = 60dB*).

Solution: By using formula (7) we get:

$$U_{\max N3} = 108 + 10\lg(42/29) = 109 dB\mu V$$

which is similar to the reference value $110dB\mu V$.

Distortions with random output level of the amplifier. By way of analogy with distortions IMA2 and IMA3 with the increase (decrease) of output level of the amplifier signal *DdB*, the intermodulation components of the second order (CSO) are boosted (drop down) to same *DdB* whereas intermodulation components of third order IMA3 are boosted to *2DdB*, i.e.:

$$CSO = 60 + (U_{\max CSO} - U_{out}),$$
$$CTB = 60 + 2(U_{\max CTB} - U_{out}). \quad (8{,}9)$$

Example 2. Determination of values and CTB when GHV 835 (Hirschmann) amplifier is used with reference parameters $U_{maxCSO} = 104dB\mu V$ and $U_{maxCTB} = 102dB\mu V$ (*42* channels, *CTB = CSO = 60dB*) at $U_{out} = 95dB\mu V$.

Solution: By using formulae (8) and (9) we get:

$$CSO = 60 + (104 - 95) = 69dB,$$

$$CTB = 60 + 2(102 - 95) = 74dB.$$

General case. In this way by using formulae ($6 \div 9$) we get expessions for calculation of CTB including a random number of channels and random output operating level:

$$CSO = 60 + (U_{\max CSO} - U_{out}) + 4{,}3\lg(42/N), \quad (10)$$

$$CTB = 60 + 2[U_{\max CTB} - U_{out} + 10\lg(42/N)]. \quad (11)$$

Example 3. We find the values for CSO and CTB for amplifier YCM-800-2737 (Standard telecom) of U_{maxCTB} = 114$dB\mu V$ and U_{maxCSO} = 110$dB\mu V$ (*42* channels *CTB = CSO = 60dB* and balance between channels of *9dB*) for translation of *50* channels at $U_{out} = 105dB\mu V$.

Solution: By altering the numeric values in (10) and (11) we get:

$$CSO = 60 + 110 - 105 + 4{,}3\lg(42/50) = 64{,}7dB,$$

$$CTB = 60 + 2[114 - 105 \ + 10\lg(42/50)] = 77{,}8dB.$$

Accumulation of distortions along the lines is effected by formulae:

$$CSO_{\Sigma} = -10\lg(10^{-CSO1/10} + 10^{-CSO2/10} + ... + 10^{-CSOi/10}), \quad (12)$$

$$CTB_{\Sigma} = -10\lg(10^{-CTB1/20} + 10^{-CTB2/20} + ... + 10^{-CTBi/20}), \quad (13)$$

Formulae (12) and (13) indicate that distortions of third order (CTB) are generated quite easily as compared to distortions of the second order (CSO). For *n* amplifiers switched on in cascade with equal values of CTB and CSO the total number of distortions is determined by the formula

$$CSO_{\Sigma} = CSO10\lg n, \quad (14)$$

$$CTB_{\Sigma} = CTB - 20\lg n. \quad (15)$$

Thus for *5* amplifiers in a series (example 3) CSO_{Σ} = *57,7dB* (decrease to *7dB*) and CTB_{Σ} = *63,8dB* (decrease to *14dB*).

Lets consider another example.

Example 4. We find the extreme values CTB_{Σ} and CSO_{Σ} provided that the inherent values of CSO and CTB are known at the output of each active device. Main station *CSO = 72dB*, *CTB = 84dB* optic system: *CSO = CTB = 65dB*; highway amplifiers: *CSO = 74dB*, *CTB = 82dB*; subscriber amplifiers: *CSO = 72dB*, *CTB = 66dB*

Solution: By substituting numeric values in (12) and (13) we get:

CSO_{Σ} = *62,5dB*, CTB_{Σ} = *57,3dB.*

Example 5. How many amplifiers of one type can be switched on in a series if their individual CTB_i = *84dB* (conducted system calculation) with CTB_{out} = *-57dB*. Total CTB of all other devices is CTB_{Σ} = *64dB.*

Solution: We calculate the permissible value of distortion *ΔCTB* entering the highway amplifiers from (11):

$$\Delta CTB = -20\lg(10^{-CTB_{изх}/20} - 10^{-CTB_{\Sigma}/20}) = $$
$$= -20\lg(10^{-57/20} - 10^{-64/20}) = 62{,}1dB.$$

This means that such CTB are permissible for all highways for storing of final CTB_{out} = *57dB*

2. We find the maximum number of highway amplifiers (15):

$$n \le 10^{(CTB_i - \Delta CTB)/20} = 10^{(84 - 62{,}1)/20} = 12{,}4,$$

i.e., we found 12 equal amplifiers each of which has *CTB=84dB*. This guarantee final CTB_{out} > *57dB*. For requirement (*CTB > 57dB*). Up to 21 amplifiers can be switched on at any equal terms.

Measuring CTB and CSO by [3] are different in the methods they employ, however, all sets of methods boil down to the following:

1. *At the amplifier input or the main station we enter* N_{test}*. unmodulated carrying signal whilst at the output of the tested object we switch on a spectrum analyzer*

2. *The spectrum analyzer helps fix the levels of useful signal in the tested channel.*

3. *The spectrum analyzed is set to a maximum sensitivity mode. Combination components are observed, video carriers (by rule they are divided by frequencies which withstand from the carrier by 0, 0.25 and 0,5 MHz) and then their levels are fixed The difference in levels is expressed in dB and make up the CSOs and CTBs*

III. Optimization of Amplifier Output Level

By analyzing the above formulae we draw the following conclusion: the lower the output level of the amplifier the lesser its nonlinear distortion. From this follows that it is enough to transmit TV signals at lower input/output levels to solve the problems. In fact it is just the opposite. Apart from the observed nonlinear distortions ther is the requirement which states that the signal to noise (S/N) ratio should not be lower than 44dB [3]. S/N at the output depends on the noise parameters of the source itself, the noise parameters of the main station, the optic system, amplifiers, operational modes and their values.

This dynamic range is a convenient value for conducting system calculations and shows the magnitude of S/N ratio, which is generated at the amplifier output when “ideal” “quiet” signal is entered at its input. [5]

$$S/N_{[dB]} = U_{out[dB\mu V]} - K_{[dB]} - F_{[dB]} - 2{,}4 \quad (16)$$

It is evident that U_{out} *-K* indicates the level of input signal that is entered directly through the first amplifier (no account is taken for the losses of the input device – attenuator and equalizer). From (16) it is evident that the larger the amplifying coefficient the lower its *S/N* ratio. We discussed the means of selecting proper amplifier in [4]. Here will note that for most highways which employ *7 ÷ 10* amplifiers, when it is necessary to keep maximum possible output *S/N* ratio amplifiers with smaller amplifying coefficients should be selected. This, however, is very expensive due to the large number of amplifiers switched in series.

Noise accumulation along highways. When amplifiers are connected in series with individual S/N_i ratios, the sum total of output S/N_{Σ} ratio will be :

$$S/N_{\Sigma} = -10\lg(10^{-(S/N_1)/10} + 10^{-(S/N_2)/10} + ... + 10^{-(S/N_n)/10}). \quad (17)$$

In this way it is possible to calculate for a cable TV if at its antenna system *S/N = 54dB* at the main station : *S/N = 54dB* at the optic line *S/N = 52,2dB* for the three highway amplifiers *S/N = 58,6dB* then the output S/N_{Σ} = *45,5dB*

From (17) it follows that if the highway contains *n* number of switched on devices with similar mode of operation then S/N_{Σ} will be determined by:

$$S/N_{\Sigma} = S/N - 10\lg(n) \quad (18)$$

So when two similar highway amplifiers are on then the output S/N_a will drop with 3*dB.*

Subscribers amplifiers should be able to ensure the required level of the signal. In reality it turns out that subscribers’ amplifiers are the cause for the maximum number of distortions CSO and CTB, To ensure less nonlinear products it is necessary to keep lower signal levels = *92÷100dBμV*. The number of channels should also be taken into account as well as the dynamic range of the amplifier plus the number of amplifiers, which are connected in series. Fig. 3 shows the dependence of permissible levels of output signal on the number of amplifiers which are connected in series.

Graphics are draw by formulae (15,18). *CTB= 60÷70 dBμV* is selected as criterion whereas the preventive interval *S/N=46dB*. From the analyzed result it is evident that the output level is within the range *91÷102dBμV* (for *CTB=70dB*) or *91÷107dBμV* (for *CTB=60dB*). For the lowest point at *91dB*, *S/N≥46dB* and peak value *102dBμV* (*CTB≥70dB*) by taking into account the reserve we get: *S/N=46+11+57 dB*.

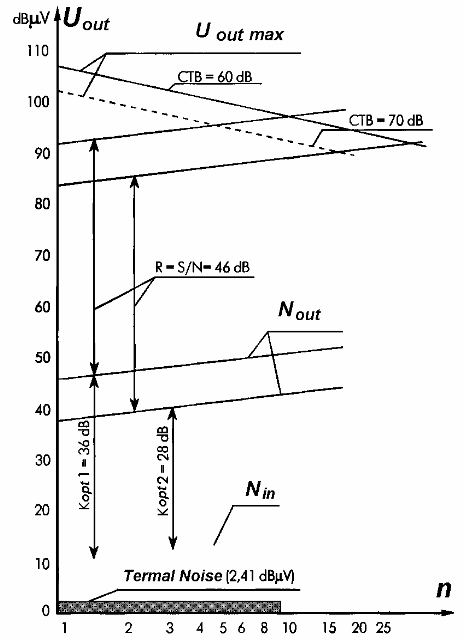

Fig. 3

In cases of increased number of amplifiers it is evident that the difference between permissible levels is being reduced due to the fact that a lot of noises and distortions have been accumulated. For example, amplifiers of the type GPV 839, having coefficient of amplification 36 dB, is possible it be connected up it 10 units in series (*CTB = 60dB*) thus we can recover line losses to approximately 360*dB*. If the amplification coefficient is reduced to 28 then the maximum number of amplifiers connected in series grow to *25dB* which is equivalent of line losses recovery of approximately 700*dB* (Fig. 4).

With *CTB*=70*dB* we observe an opposite trend since the maximum number of amplifiers is only 5 (with k_0=36*dB*). These graphic result are indicative of the importance of parameters such as maximum output level of the signal and amplification coefficient.

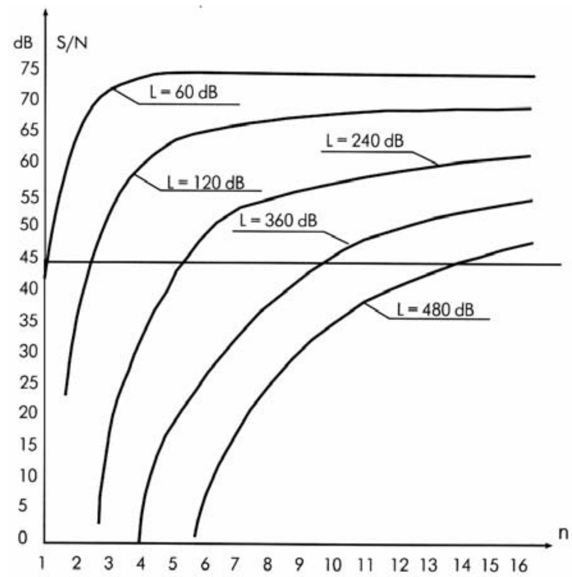

Fig. 4

IV. Conclusion

The optimum level is that output level, which allows for technological reserves (for example, climate conditions when effecting overhead laying of cables) as well as of intermodulational distortions *CTB* and *CSO*. Another important factor is the proper *S/N* ratio when designing and laying CATV networks. Then optimum operating output level for amplifiers could be found by the formula:

$$U_{outopt} = \frac{U_{\max} + 2U_{\min}}{3} \quad , \qquad (19)$$

where U_{max} is the maximum permissible value of the amplifier output level provided *CTB* and *CSO* were carefully considered while designing the network. U_{min} is the minimum permissible value at the amplifier output, which is effected if the *S/N* ratio is protective. Thus for our example we get $U_{out\ opt}$= 95 *dBμV*

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