ANALYSE OF PARAMETERS OF TRANSMITTED SIGNALS IN ANALOGUE CATV SYSTEMS

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The paper deals with analyse and simplified optimization of the transmission of analogue television and radio signals in broadband cable distribution networks (CATV). Optimization is realized with a view to obtaining the required parameters of output signals – namely signal level, signal-to-noise ratio and dynamic range. Results of these analyses are valid partially for digital cable distribution too. There is no need to pursue the dynamic range of signal in that case, because digital signals are very resistant to the nonlinear distortions.

Keywords: *CATV, broadband amplifier, dynamic range, noise factor, nonlinear distortion, optimization*

1. INTRODUCTION

Is there any point today in being involved in the analyse of the parameters of analogue signals when the standard for digital cable distribution, DVB-C (Digital Video Broadcasting – Cable), was adopted in Europe a number of years ago, together with standards for digital satellite broadcasting, DVB-S (Satellite), and terrestrial broadcasting, DVB-T (Terrestrial)? While in most countries satellite and terrestrial digital television broadcasting currently predominates, the digitization of television distribution frames proceeds very slowly (with the exception of digital distribution networks for signal transmission from the television studio to the transmitter). This is due to the fact that cables represent a high-quality transmission channel of sufficient transmission capacity, and digitization (unless the picture format is changed, as will happen when HDTV is introduced) would not bring the viewer practically any improvement in picture quality. Thus there is nothing that would induce operators of these networks to adopt this technically and economically demanding change in the technology. The basic parameters of analogue TV and radio signals on the output of subscriber cable distribution to be analysed in the paper are

- signal level V,
- signal-to-noise ratio Φ,
- dynamic range D.

For simplification, it is assumed in the analyse of these parameters that the distribution network is impedance matched and that practically a travelling wave propagates along the line (there is no distortion caused by reflections).

2. BASIC CONCEPTS AND RELATIONS

2.1. Expression of noise relations

a) $\Phi = V_s/V_n$ …signal-to-noise voltage ratio [-],
$\Phi_{dB} = 20 \log (V_s/V_n)$ in logarithmic form [dB],

b) S/N (Signal to Noise)...signal-to-noise power ratio in the basic frequency band [-],
$(S/N)_{dB} = 10 \log (S/N$ in logarithmic form [dB],

c) C/N (Carier to Noise)…signal-to-noise power ratio in the high frequency band [-],
$(C/N)_{dB} = 10 \log (C/N)$..in logarithmic form[dB],

d) $F = (C/N)_1 / (C/N)_2 = 1 + T_{ekv}/T_o$...noise factor [-],
$F_{dB} = 10 \log F$ in the logarithmic form [dB].

e) Resulting noise factor F_{rm} of m transmission blocks (active or passive) with noise factors F_1, F_2, …… F_m and power transmission ratio G_1, G_2,.. G_m (G_i <>1) is defined by the known relation

$$F_{rm} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + ... \quad (1)$$

Output signal-to-noise voltage ratio $\Phi_2 = V_{s2}/V_{n2}$ is expressed (for source of the signal impedance matched to the input resistance R_{in} of the amplifier with noise factor F) by the equation

$$\Phi_2 = V_{s2}/ V_{n2} = V_{s1} (F\, k_B\, T\, B_n\, R_{in})^{-1/2} , \quad (2)$$

where
$k_B = 1{,}37.10^{-23}$ Ws.K^{-1} (Boltzmann′s constant),
T…..absolute temperature of surround [K]
$T = 293 + t$,
B_n…noise frequency bandwidth of the amplifier [Hz],
Rin…input resistance of amplifier [Ω].

Equation (2) is valid providing, that the input noise signal answers to the thermal noise of impedance matched input resistance R_{in} of amplifier only. If an input signal V_{s1} includes other noise components (for example cosmic noise) this fact can be respected by the magnification of the equivalent noise factor F_{ekv} of an amplifier. This account is very simplified and approximate, because it isn′t respected different spectrum density level of this additive noise.

Notice: Noise frequency bandwidth Bn answers to the noise frequency bandwidth of one television channel (Bn ≈ 10MHz), regardless of the total frequency bandwidth of the proposed broadband cable distribution (for example CATV), because the bandpass filter of the IF amplifier in television receiver limits the resulting noise frequency bandwidth. This effect is dominant for rejection of the noise influence in observed picture.

2.2. Expression of dynamic range and noise relations for cascade of broadband amplifiers

a) Output dynamic range D_{2dB} (in logarithmic form) of the **one amplifier**, whose input resistance is impedance matched to the output impedance of the signal source, can be expressed by the equation (3) [1]

$$D_{2dB} = V_{2max} - V_{2min} = V_{2max} - V_{1n} - F_{dB} - G_{dB} - \Phi_{2dB}, \quad (3)$$

where

V_{2max} .....the greatest level of output amplified signal of single amplifier for achievement of the signal to non-linear distortions protection rate which is greater than 60dB [dBμV]. This value must be reduced depending on the number k of independent channels, that are amplified in the whole frequency band of broadband identical amplifier according to the expression $V'_{2max} = V_{2max}$ - C.log (k - 1), Empirical constant C ≈ 7,5 holds for syn-chronnous and C ≈ 15 for non-synchronous TV signals,

V_{2min}......minimal level of the amplified output signal for resolution of the minimal brightness level [dBμV],

V_{1n} ....level of thermal noise of impedance matched input resistance of an amplifier [dBμV],

G_{dB}........gain of used amplifier [dB],

F_{dB} ....noise factor of used amplifier [dB],

Φ_{2dB} ......required output signal-to-noise ratio [dB].

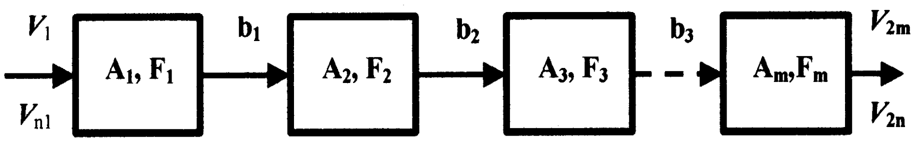

Fig. 1 Simplified block diagram of cascade of broadband amplifiers

b) Output dynamic range D_{2mdB} of the cascade of **m identical** amplifiers

We shall be assuming these simplifying conditions for:

– identical power gains of all amplifiers in cascade $G_{1dB} = G_{2dB} = ... = G_{mdB}$,
– identical noise factors of all amplifiers $F_{1dB} = F_{2dB} = ... = F_{mdB}$,
– impedance matching of the whole cable line.

Then can be written (see [3])

$$D_{2mdB} = V'_{2mmax} - V_{2mmin} = V_{2max} - C.\log(k-1) - 10\log m - (V_{1n} + F_{dB} + \log m + G_{dB} + \Phi_{2mdB}), \quad (4)$$

c) Output signal-to-noise ratio Φ_{2mdB} of cascade of **m** identical amplifiers

Resulting signal-to-noise ratio Φ_{2mdB} on the last amplifier output can be expressed by means of equation (5) (providing the same simplifying condi-ions as in equation (4))

$$\Phi_{2mdB} = V_{2m} - V_{2n} = V_{1min} + m.G_{dB} - b_{tdB} - (V_{1n} + F_{dB} + 10\log m + G_{dB}), \quad (5)$$

where

V_{2m} .... required output signal level [dBμV],

V_{2n} .... output noise signal level [dBμV],

b_{tdB} .... total cable attenuation [dB].

Notice: Providing that the noise figures of the individual amplifiers are not identical, the signal-to-noise ratio Φ^{*}_{2mdB} on the output of the last amplifier can be expressed by means of approximate relation [4]

$$\Phi^{*}_{2mdB} = \Phi_{2mdB} - 10\log(p_1 + p_2 + p_3 .... + p_m), \quad (6)$$

where

$p_m = F_m/F_1$…ratio of noise figures of m and first amplifier.

3. CRITICAL NUMBER OF AMPLIFIERS IN THE CASCADE m_{crit}

Critical number of amplifiers m_{crit} that is possible connected in cascade for achievement of required voltage signal-to-noise ratio Φ_{dB} and dynamic range D_{smindB} for number k of amplified synchronous TV signals (channels) can be expressed in the form

$$m_{crit} = 10^{\frac{V_{2\,max} - 7,5\log(k-1) - V_{2\,min} - D_{smindB}}{20}}, \quad (7)$$

where

V_{2min}......minimum output signal level for achievement of required voltage signal-to-ratio Φ_{dB}

It holds

$$V_{2min} = V_{š1} + F_{zdB} + G_{zdB} + \Phi_{dB}, \quad (8)$$

D_{smindB}.. minimum required dynamic range of the cascade of m identical amplifiers [dB].

4. SIMPLIFIED OPTIMIZATION OF CASCADE OF BROADBAND AMPLIFIERS

Proposal of every part of cable distribution CATV must to ensure sufficient values of the fundamental parameters of **output signals**

- required signal level V_{2m} on the last amplifier output. This value is defined by the relevant recommendation for example on the output of subscriber's socket must be level of signal
  $80\ dB\mu V > V_{2m} > 60\ dB\mu V$,
- required output signal-to-noise ratio -usually
  $\Phi_{2mdB} > 40$ dB.

This value warrants negligible visual perception of noise in the picture practically,

- sufficient dynamic range D_{2mdB} of the output signal – minimum value is $D_{2mmindB} \geq 20$ dB.

Necessary **input specifications** for proposal of the broadband cascade of m identical amplifiers are:

- total cable attenuation b_{tdB} corresponding to the length of cable and to the attenuation coefficient which depends on the frequency. Therefore total cable attenuation b_{tdB} must be determined for several frequencies,
- parameters of used amplifiers: noise factor F_{dB}, gain G_{dB}, input resistance R_{in} (it answers to the characteristic impedance Z_0 of the used cable for the impedance matching),
- number k of carried signals and their mutual synchronisation,
- maximum level of the output signal V_{2max} of the one amplifier for achievement the signal to non-linear distortions protection ratio greater than 60 dB,
- levels of all input signals V_1 or level of the smallest input signal V_{1min}.

Optimization of the cascade of m identical amplifiers can be performed by two ways. Resulting gain of all m amplifiers must to compensate total attenuation b_{tdB} of cable line and it must be achieved required level of output signal V_{2m}. For total gain of m cascade connected amplifiers must to hold

$$\sum_{n=1}^{m} G_{ndB} = m.G_{dB} = V_{2m} - V_{1\min} + b_{tdB} \qquad (9)$$

Optimal number m_{opt} of cascade connected amplifiers for achievement of **maximum value of output signal-to-noise ratio** Φ_{2mdB} can be determined by means of the location of local extreme (maximum) functional dependence $\Phi_{2mdB}(m)$.

Equation (5) can be expressed in the form (for simplifying conditions $G_{1dB} = G_{2dB} = ... = G_{dB}$ and $F_{1dB} = F_{2dB} = ... = F_{dB}$)

$$\Phi_{2mdB} = V_{2m} - V_{2n} = \\ = V_{2m} - (V_{1n} + F_{dB} + 10\log m + m.G_{dB}/m), \qquad (10)$$

where product $m.G_{dB} = V_{2m} - V_{1min} + b_{tdB} = B$ is invariable for required values V_{2m}, V_{1min}, b_{tdB}. Only two last terms in the relation (10) depends on the parameter m. **Maximum** of the function $\Phi_{2mdB}(m)$ shall be achieving for the **minimum** of the function $F(m) = 10\log m + B/m$.

It holds for local extreme (minimum) of this function

$$\frac{\delta F(m)}{\delta m} = \frac{4{,}43}{m} - \frac{B}{m^2} = 0 \quad \text{and from}$$

$$m_{opt} = \frac{B}{4{,}43} = \frac{V_{2m} - V_{1\min} + b_{tdB}}{4{,}43} \qquad (11)$$

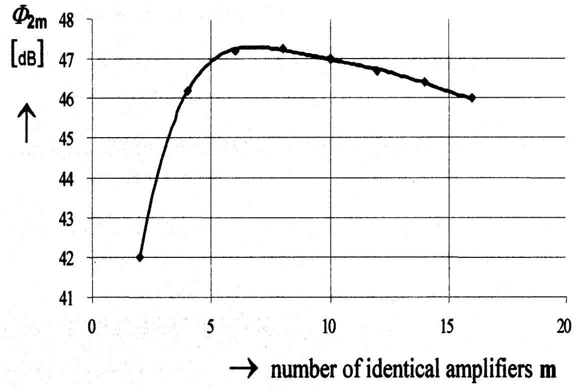

Fig. 2 Example of relation $\boldsymbol{\Phi_{2mdB} = F(m)}$ for $V_{2m} = 80 dB\mu V$, $V_{1n} = 10\ dB\mu V$, $F_{1dB} = F_{2dB} = F_{mdB} = 10$ dB, B = m. $G_{dB} = 30$ dB

Optimal number of amplifiers in this example is (see Fig. 2) $\mathbf{m_{opt1} = B/4{,}43 = 30/4{,}43 \approx 7}$.

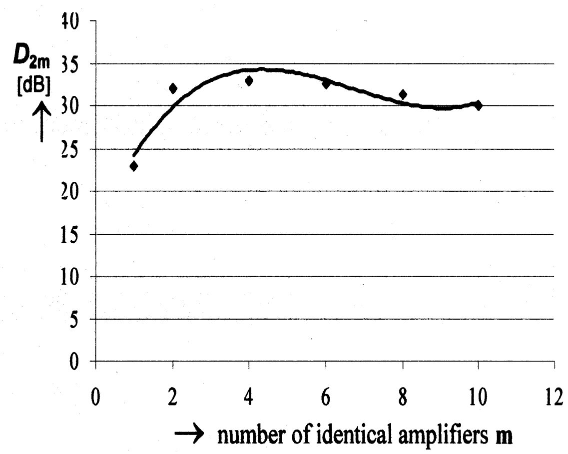

Fig. 3 Example of relation $\boldsymbol{D_{2mdB} = F(m)}$ for $V_{2mmax} = 120 dB\mu V$, $V_{1n} = 10\ dB\mu V$, k = 1, $F_{1dB} = F_{2dB} = F_{mdB} = 10$ dB, B = $m.G_{dB} = 30$ dB, $\Phi_{2mdB} = 47$dB

Second approach of optimization is determination of optimal number m_{opt} of identical amplifiers in cascade for achievement of **maximum value of the dynamic range** D_{2mdB} of output signal can be determined likewise by means of location of local extreme (maximum) of the functional dependence D_{2mdB}(m) expressed in the equation (4). In this case for value m_{opt} it can be derive

$$m_{opt} = \frac{B}{8{,}86} = \frac{V_{2m} - V_{1min} + b_{tdB}}{8{,}86} \qquad (12)$$

Optimal number of amplifiers in this example is (see Fig. 3) $\mathbf{m_{opt2} = B/8{,}86 = 30/8{,}86 \approx 4.}$

Fig. 2 and 3 show, that relations $\Phi_{2mdB} = F(m)$ and $D_{2mdB} = F(m)$ are relatively flat. Calculated values m_{opt} in relations (11) and (12) must be rounded off to the nearest higher integer.

5. CONCLUSION

This article deals with the simplified optimization method for determination of the optimal number m_{opt} of the broadband cascade-connected amplifiers. Numerical analyse shows, that the number m_{opt} in the cascade of m amplifiers, designed for the maximum of dynamic range D_{2mdB} of output signal, is smaller (half) This fact is technically and economically preferable especially whereas the functional dependence of the output signal-to-noise ratio Φ_{2mdB}(m) is very flat.

These analyses are valid partially for **digital cable distribution** too. There is no need pursue the dynamic range of signal in that case, because digital signals are very resistant to the nonlinear distortions. On the contrary there is necessary extra observe and ensure the correct course of phase-frequency characteristics of digital cable network, which significantly influences bit error ratio (BER) of transmitted and amplified digital signals.

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BIOGRAPHY

Václav Říčný was born in 1937 in Brno (Czech Republic). He is professor (since 1990) at the Istitute of Radio Electronics at the Faculty of Electrical Engineering and Communication Technology of Technical University in Brno. His research interests includes television technology and video technology (digital systems and standards especially) and analogue and digital processing of video signals.