STANDARD METHODS FOR CALCULATION OF
CARRIER TO NOISE
RATIO IN MODERN CATV EQUIPMENT

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I. INTRODUCTION

Carrier to noise ratio is a universally accepted figure of merit used to indicate performance of a cascade of CATV amplifiers. However, the calculation of system C/N has become somewhat confusing due to the lack of an industry wide method for specifying individual amplifier noise performance and calculating cascase noise performance.

This application note describes the individual amplifier parameters necessary for making cascade noise calculations. It also explains how those calculations should be made.

Section VII is a summary of noise calculations intended for quick reference when making performance computations.

II. BASIC DESCRIPTION OF NOISE

The textbook definition of noise states that noise is anything that corrupts or interferes with a desired signal. For the sake of this discussion we shall limit ourselves to random thermal noise. We shall not consider distortion products generated by the amplifiers as a result of passing the desired signals. We shall also exclude noise from ingress of signals generated outside of the CATV network.

Calculation of system carrier to noise is based upon a theoretical minimum noise floor. The noise floor is a result of thermal or Johnson noise associated with the characteristic impedance of the system, Zs.

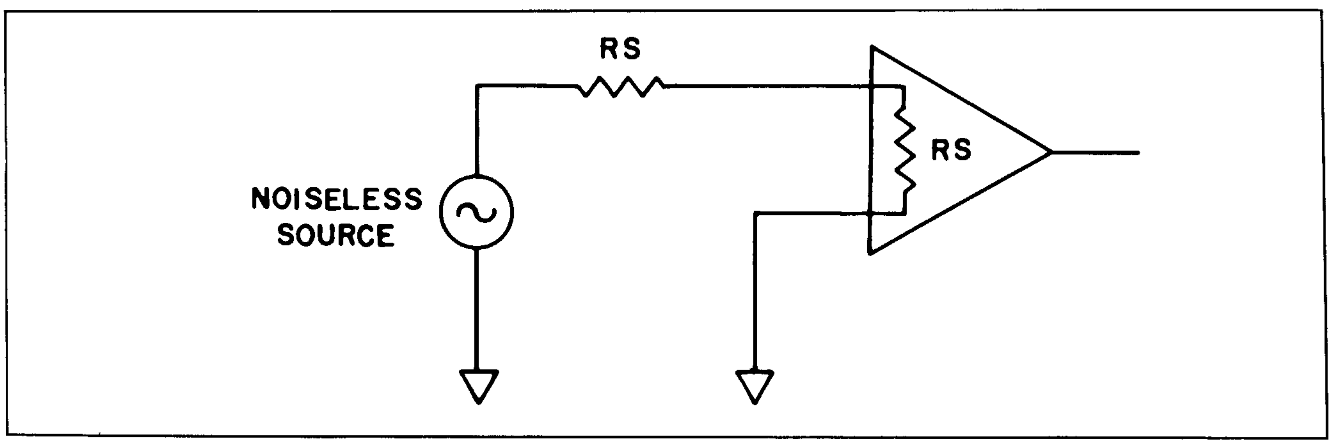

Figure 1.

The calculation of this theoretical thermal noise floor is done by assuming that an ideal noiseless signal source is connected to the input of an amplifier through a source resistance of Rs Ohms. It is also assumed that the amplifier has an input impedance of Rs consisting of an ideal noiseless resistor. See Figure 1.

The rms noise voltage associated with the source resistance is given by:

$$V^2_{rms} = 2(kTRs)\,B \qquad (V^2 rms) \qquad \textbf{(2.1)}$$

where

K = Boltzmann Constant, $(1.381\times10^{-23}\ J/^{o}K)$.
T = Resistor Temperature, $(290^{o}K)$

R_s = Source Impedance (75 Ohms)
B = Bandwidth, ($4X10^6$Hz)

For our system Vrms = $2.2X10^{-6}$ Vrms
The noise power coupled into the input of the amplifier is given by

N = Input Noise Power =

$$V^2_{rms} \left(\frac{Rs}{2Rs}\right)^2 \frac{1}{Rs} = k\ T\ B \qquad (2.2)$$

$= 1.6X10^{-14}$ Watts or -59dBmV

Two useful parameters for determining amplifier noise performance are noise factor and noise figure.

Noise factor is defined as:

Noise Factor nf =

$$\frac{\text{Total Noise Power Output}}{\text{Noise Power Output Due to Rs}} \qquad (2.3)$$

$$\frac{Npo}{ApNpi} = \frac{Npo\ Spi}{SpoNpi} = \frac{Spi/Npi}{Spo/Npo}$$

Where Rs = Source Resistance

Npi = Noise Power at Input (due only to thermal noise in Rs)
Npo = Noise Power at Output
Spi = Signal Power at Input
Spo = Signal Power at Output
Ap = Power Gain of Device Under Test

Thus noise factor is a measure of the noise added by a device over and above that due to random electron motion in the source resistance.

Noise Figure = NF = (2.4)
$10 \log_{10}$ (nf) (dB)

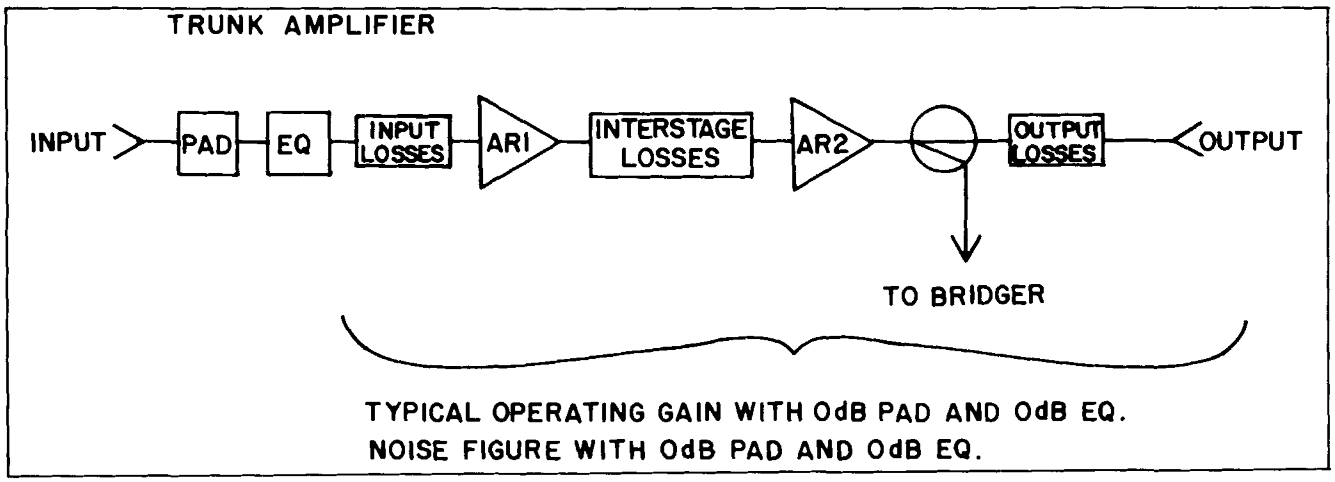

Figure 2.

III. INDIVIDUAL TRUNK CARRIER TO NOISE

The block diagram shown in Figure 2 is a simplified model of a trunk amplifier. This model can be used to calculate total trunk noise figure, total trunk operating gain and carrier to noise.

Step 1: Calculate Total Trunk Noise Figure.

Most CATV equipment manufacturers specify a trunk noise figure with 0dB pad and 0dB equalizer. To this number must be added the loss of the input pad and input equalizer. Additionally, some manufacturers fail to include any input losses before the first hybrid (AR1) and specify noise figure at this point. In this case the input losses (loss of seizure, diplex filter, input test point, AC bypass, etc.) must be added to obtain accurate results.

Total trunk noise figure = NF_{tt} (3.1)
= NF (0dB pad, 0dB EQ)
+Pad loss
+EQ loss
+Input loss (if not included in manufacturer's Spec)

Step 2: Calculate Total Trunk Operating Gain.

The equipment manufacturer should also specify a typical operating gain with 0dB pad and 0dB equalizer. This gain specification must not be confused with recommended station operational gain (usually 22dB) or the station minimum full gain (which places the variable cable equalizer outside its normal operating condition). It must also be determined if this gain specification includes all input losses before the first hybrid

To obtain the total trunk operating gain one must subtract the input pad losses, the equalizer losses and the input losses (if any) from the typical operating gain.

Total Trunk Operating Gain = **(3.2)**

G_{tt} = Typical Operating gain
- Pad loss
- EQ loss
- Input loss (if not included in manufacturer's Spec)

Step 3: Calculate Carrier to Noise Ratio.

C/N for a single trunk station is given by the equation

$$C/N_{single} = Lo - (N_t + NF_{tt} + G_{tt}) \quad \textbf{(3.3)}$$

Where

Lo = Carrier output level
N_t = Thermal noise floor (-59dBmV)
Nf_{tt} = Total trunk noise figure
G_{tt} = Total trunk operating gain

Example 1: Calculate the carrier to noise ratio of a 22dB 450MHz trunk amplifier with the following parameters.

a. Trunk noise figure with 0dB pad and 0dB equalizer and including input losses = 8.0dB
b. Typical operating gain with 0dB pad and 0dB equalizer including all input losses = 24.5dB
c. 1dB input pad
d. 22dB 450MHz equalizer with 1dB of insertion loss at 450MHz
e. Output level at 450MHz = 33dBmV

Solution:

Carrier to noise is usually assumed to be worst case at the highest frequency of operation. This is a consequence of: 1) the dice characteristics of the transistors used in the amplifiers and 2) maximum loss in the cable occurring at high frequencies.

Step 1 (from equation 3.1)

NF_{tt} = 8dB + 1dB + 1dB = 10dB

Step 2 (from equation 3.2)

G_{tt} = 24.5dB - (1dB + 1dB) = 22.5dB

Step 3 (from equation 3.3)

C/N Single = 33dBmV - (-59dBmV + 10dB +22.5dB) = 59.5dB

IV. <u>TRUNK AMPLIFIER CASCADE</u>

A rigorous calculation of cascade carrier to noise becomes quite complicated. However, if it is assumed that the cascade is composed of identical amplifiers with identical pad and equalizer losses the solution reduces to a simple form.

Noise is a random process. Consequently noise sources combine on a power basis. The noise at the end of a cascade of n amplifiers is equal to the sum of the noise contributions from each of the individual amplifiers, i.e.;

Total noise for n amps = n(noise of single amp). (watts) **(4.1)**

or equivalently for dB

Total noise for n amps = noise of single amp + 10 Log_{10} (n) **(4.2)**

It is assumed that a CATV trunk amplifier cascade is unity gain. Consequently, the carrier level after n amplifiers is the same as after a single amplifier.

$C/N_{cascade}$ = **(4.3)**

$$\frac{\text{carrier level at end of cascade.}}{\text{n x noise level of single amp}} =$$

or for C/N in dB

C/N cascade = C/N single amp - 10 Log_{10} (n)

Where n is the number of amplifiers in cascade.

Example 2: Calculate the C/N of a cascade of 20 amplifiers of the type in Example 1.

Solution: (From equation 4.4)

C/N cascade = 59.5 -10 Log_{10} (20) = 46.5dB

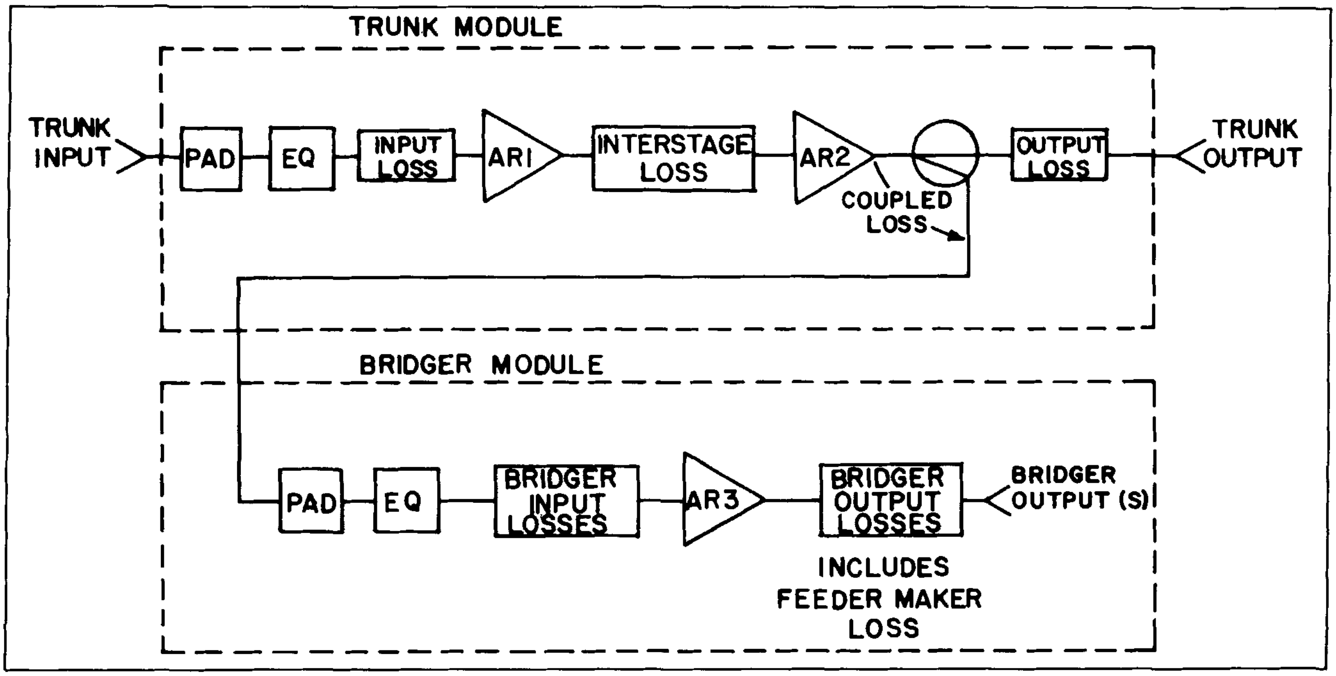

Figure 3.

V. TRUNK + BRIDGER C/N

Trunk and bridger C/N can be calculated by first calculating the C/N at the output of the trunk amplifier and then computing the additional degradation associated with the bridger module. (See Figure 3.)

Step 1: Calculate the Total Bridger Noise Figure.

As is the case with the trunk module the CATV equipment manufacturer will specify a bridger noise figure with 0dB pad and 0dB equalizer (this noise figure may or may not include input losses associated with the bridger). It is assumed that the bridger is cascaded with the trunk amplifier. Therefore, total bridger NF can be calculated by:

$NF_{brt} = NF_{br}$ (0dB pad, 0dBEQ) + input losses (if any) **(5.1)**
+pad loss + EQ loss + coupled loss
- trunk output loss

It can be assumed that the high gain of the bridger will make noise contributions from the output losses associated with the feeder makers negligible.

Step 2: Calculate the Total Bridger Operating Gain.

The total bridger operating gain can also be computed from the manufacturer's specified typical operating gain with 0dB pad and 0dB equalizer. It is again important to add in any input losses occuring before the first bridger hybrid if they are not already included in the manufacturer's gain specification.

Total Bridger Operating Gain = G_{brt} =

Bridger typical **(5.2)**
operating gain (0dB pad, 0dBEQ) - (pad loss + EQ loss + coupled loss - trunk output loss + feeder maker loss + bridger input loss (if not included by manufacturer))

Step 3: Calculate the Noise at the Bridger Output Due to the Previous Cascade.

Noise at the bridger output comes from two sources: 1) noise from the previous cascade and 2) noise produced in the bridger itself.

Noise at the bridger output due to the trunk cascade is related to the excess noise (noise in excess of the thermal noise floor) at the bridger input. However, for practical system conditions the difference between the excess noise and the total noise at the bridger input is negligible. This error can be ignored for the sake of simplicity with no ill effects on the final result.
Noise level bridger output due to trunk cascade = N_{b1} = **(5.3)**

carrier level at bridger output - trunk cascade output C/N

Step 4. Calculate Noise at the Bridger Output Due to the Bridger Itself.

N_{b2} = Level of noise at the bridger output due to the bridger itself = $Nt + NF_{brt} + Gbrt$ **(5.4)**

Where N_t = thermal noise floor (-59dBmV for 75 Ohm system)

Step 5. Calculate the Total Bridger Output Noise

The total bridger output noise can be calculated by combining the two noise soures on a power basis.

N_{bt} = total bridger output noise level = **(5.5)**

$$10 \ \mathrm{Log}_{10} \left(10^{\left(\frac{Nb1}{10}\right)} + 10^{\left(\frac{Nb2}{10}\right)} \right)$$

Step 6: Calculate the Trunk + Bridger C/N

C/N_{tk+br} = trunk bridger carrier to noise = carrier level at bridger output - N_{bt}

Note that in these expressions all losses associated with the bridger input (coupled loss, trunk output loss, pad loss, equalizer loss, bridger input loss) all cancel out. It is therefore possible to ignore these losses so long as the bridger noise figure and bridger gain are specified with the amplifier in exactly the same configuration. This will not work if, for example, bridger input losses are not included in the bridger noise figure but are included in the bridger typical operating gain.

Example 3: Assume that at the end of the cascade of example 2 there is added a bridger with the following parameters.

a. NF of bridger with 0dB pad, 0dB equalizer, 1 way feeder maker including all input losses and ignoring coupled losses and ignoring trunk output losses = 7.0dB
b. bridger typical operating gain with 0dB pad, 0dB equalizer, 1 way feeder maker including all input losses and ignoring coupled losses and ignoring trunk output losses = 33dB
c. desired bridger output level = +42dBmV
d. 2 way feedermaker loss = 3.5dB at 450MHz)
e. equalizer loss = 1dB at 450MHz
f. pad value = 7dB
g. trunk output loss = 1.5dB
h. coupled loss = 14dB

Solution:

Step 1 (from equation 5.1)

NF_{brt} = 7.0dB + 7dB +1dB +14dB - 1.5dB = 27.5dB

Step 2 (from equation 5.2)

G_{brt} = 33dB - (7dB + 1dB + 14dB + 3.5dB - 1.5dB) = 9dB

Step 3 (from equation 5.3)

N_{b1} = 42dBmV - 46.5dB = -4.5dBmV

Step 4 (from equation 5.4)

N_{b2} = -59dBmV + 27.5dB + 9dB = 22.5dBmV

Step 5 (from equation 5.6)

$$N_{bt} = 10 \ \mathrm{Log}_{10} \left(10^{\left(\frac{-4.5}{10}\right)} + 10^{\left(\frac{-22.5}{10}\right)} \right)$$

Step 6 (from equation 5.6)

C/N_{tk+br} = 42dBmV - (-4.5dBmV) = 46.5dB

Note: Notice that the bridger has only a slight effect on the end of cascade noise performance.

Alternate Solution:

Since the noise figure and gain are specified under the same amplifier configurations (0dB pad, 0dB equalizer, etc.) the losses associated with the bridger input can be ignored.

Step 1

NF_{br} = 7.0dB

Step 2

G_{bt} = 33dB - 3.5dB = 29.5dB Note:

The 3.5dB is feeder maker loss

Step 3

N_{b1} = 42dBmV - 46.5dB = -4.5dB

Step 4

N_{b2} = -59dBmV + 7.0dB + 29.5dB = -22.5dB

Step 5

$$N_{bt} = 10 \text{ Log}_{10}\left(10^{\left(\frac{-4.5}{10}\right)} + 10^{\left(\frac{-22.5}{10}\right)}\right)$$

Step 6

C/N_{tk+br} = 42dBmV - (4.5 dBmV) = 46.5dB

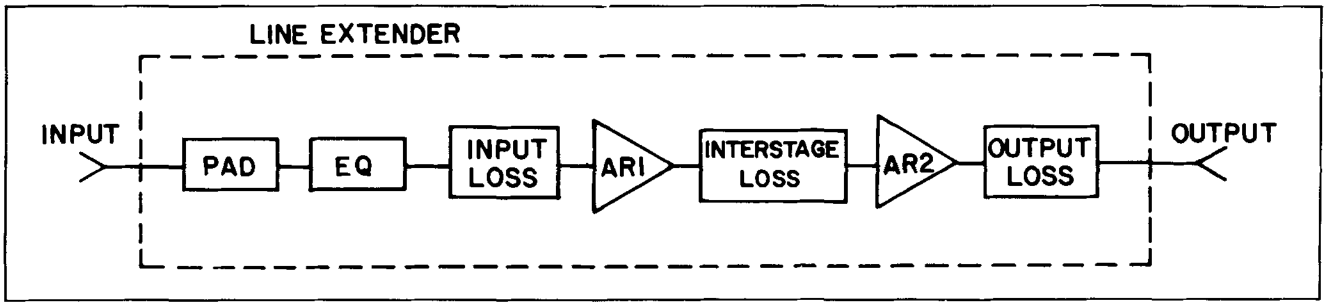

Figure 4

VI. TRUNK + BRIDGER + LINE EXTENDER

The line extender is handled in a similar manner to the bridger. There are two noise sources associated with the line extender 1) noise due to the previous cascade and 2) noise generated in the line extender itself. See Figure 4.

The equipment manufacturer should specify noise figure with 0dB pad and 0dB equalizer as well as typical operating gain with 0dB pad and 0dB equalizer. It is important that these specifications include all input losses to the amplifier.

Step 1: Calculate the Total Line Extender Noise Figure.

NF_{let} = Noise Figure (0dBpad, 0dBEQ) + input losses **(6.1)**
(if not included by the manufacturer)

Step 2: Calculate Total Line Extender Operating Gain.

G_{let} = Gain (0dBpad, 0dBEQ) - (input losses (if not included by manufacturer) + pad loss + EQ loss) **(6.2)**

Step 3: Calculate Noise at Line Extended Output Due to Previous Cascade.

N_{le1} = Noise at L.E. output due to previous cascade = carrier level at L.E. output - previous amp C/N **(6.3)**

Step 4: Calculate the Noise at the Line Extender Output Generated by the Line Extender Itself.

N_{Le2} = Noise level at the line extender output due to noise generated by the line extender itself $= N_t + NF_{let} + G_{let}$ **(6.4)**

Where N_t = thermal noise floor

(-59dBmV in 75 Ohm system)

Step 5: Calculate Total Noise Level at Line Extender Output.

N_{let} = Total noise level at line extender output = **(6.5)**

$$10 \text{ Log}_{10}\left(10^{\left(\frac{N_{le1}}{10}\right)} + 10^{\left(\frac{N_{le2}}{10}\right)}\right)$$

Step 6: Calculate Total Trunk + Bridger + L.E. C/N

$C/N_{tk+br+le}$ = total trunk+bridger+L.E. C/N = **(6.6)**

carrier level at line extender output $- N_{let}$

Example 4: **Assume that the trunk cascade + bridger of example 3 is followed by a line extender with the following specifications:**

a. typical operating gain with 0dB pad and 0dB equalizer = 27dB (includes all input losses)
b. noise figure with 0dB pad and 0dB equalizer = 8dB (includes all input losses)
c. 6dB pad
d. equalizer with 1dB insertion loss at 450MHz
e. desired output level = +46dBmV

Solution:

Step 1 (from equation 6.1)

$NF_{let} = (8dB + 6dB + 1dB) = 15dB$

Step 2 (from equation 6.2)

$G_{let} = 27dB - (6dB+1dB) = 20dB$

Step 3 (from equation 6.3)

$N_{le1} = 46dBmV\ 46.5dB = -0.5dBmV$

Step 4 (from equation 6.4)

$Nle2 = -59dBmV+15dB+20dB - 24dBmV$

Step 5 (from equation 6.5)

$$N_{let} = 10\ Log_{10}\left(10^{\left(\frac{-0.5}{10}\right)} + 10^{\left(\frac{-24}{10}\right)}\right)$$
$= -0.48dBmV=-0.5dBmV$

Step 6 (from equation 6.6)

$C/N_{\ tk+br+le} = 46dBmV - (-0.5dBmV) = 46.5dB$

VII. SUMMARY

A. Calculation of C/N for single trunk

1. Calculate total trunk noise figure

NF_{tt} = NF (0dB pad, 0dB EQ) + pad loss + equalizer loss + input loss (if not included by manufacturer)

2. Calculate total trunk operating gain

G_{tt} = trunk typical operating gain (0dB pad, 0dBEQ) - pad loss + equalizer loss + input loss (if not included by manufacturer)

3. Calculate C/N for single amplifier

$C/N = Lo - (N_t + NF_{tt} + G_{tt})$

where Lo = carrier output level
N_t = thermal noise floor (-59dBmV in 75 Ohm system)

B. Calculation of C/N for trunk amplifier cascade.

If the cascade is assumed to be composed of identical amplifiers and cable spans then the cascade C/N is given by:

C/N cascade = C/N single $-10\ Log_{10}\ (n)$

Where n is the number of amplifiers in cascade

C. Trunk Cascade + Bridger C/N

1. Calculate the total bridger noise figure
$NF_{brt} = NF_{br}$ (0dBpad, 0dBEQ) + pad loss + equalizer loss + coupled loss - trunk output loss + bridger input losses (if not included by manufacturer)

2. Calculate total bridger operating gain

G_{brt} = bridger typical operating gain (0dB pad, 0dBEQ) - (pad loss + EQ loss + coupled loss - trunk output loss + feeder maker loss + bridger input loss (if not included by manufacturer)

3. Calculate noise level at bridger output due to previous cascade.

N_{b1} = carrier level at bridger output - trunk output C/N

4. Calculate noise level at bridger output due to noise generated in bridger

$N_{b2} = N_t + NF_{brt} = G_{brt}$

Where N_t = thermal noise floor (-59dBmV in 75 Ohm system)

5. Calculate total bridger output noise level

$$N_{bt} = 10\ Log_{10}\left(10^{\left(\frac{N_{b1}}{10}\right)} + 10^{\left(\frac{N_{b2}}{10}\right)}\right)$$

6. Calculate trunk cascade + bridger C/N

C/N_{tk+br} = carrier level at bridger output - N_{bt}

D. Trunk Cascade + Bridger + L.E. C/N

1. Calculate the total line extender noise figure

NF_{let} = L.E. Noise Figure (0dB pad 0dB EQ) + pad loss + equalizer loss + input losses (if not already included by manufacturer)

2. Calculate the total line extender operating gain

G_{let} = Gain (0dB pad, 0dB EQ) - (input losses (if not included by manufacturer) + pad loss + equalizer loss)

3. Calculate noise at line extender output due to previous cascade

N_{le1} = carrier level at L.E. output - previous amp C/N

4. Calculate noise at line extender output generated by the L.E. itself

$$N_{le2} = N_t + NF_{let} + G_{let}$$

Where N_f = thermal noise floor (-59dBmV in 75Ohm system)

5. Calculate total line extender output noise level

$$N_{let} = 10 \operatorname{Log}_{10} \left(10^{\left(\frac{N_{le1}}{10}\right)} + 10^{\left(\frac{N_{le2}}{10}\right)} \right)$$

6. Calculate total trunk + bridger + line extender C/N

$C/N_{tk+br+le}$ = level at L.E. output - N_{let}

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