WIDE DYNAMIC RANGE CARRIER-TO-NOISE TESTING

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Abstract

An increasing demand for better system carrier-to-noise performance is, in turn, creating demand for better carrier-to-noise measurements. To help take the mystery out of this measurement, five correction factors are introduced to help describe a practical measurement method using a spectrum analyzer.

INTRODUCTION

The increasing use of fiber, new FCC technical standards, and higher quality expectations of operators and subscribers have all focused more attention on the carrier-to-noise measurement. Getting repeatable results when measuring noise at low levels requires a detailed knowledge of how the instrument being used measures noise, its limitations, and corrections necessary.

The carrier-to-noise test requires two measurements, carrier level and its related noise level. Much has already been written on measuring carrier levels. This paper will concentrate on the more difficult noise measurement.

THE NOISE MEASUREMENT

Measuring noise is more difficult than measuring carrier levels mainly due to two reasons:

1) the levels at which noise is measured are very much lower than carrier levels (see Figure 1), and,

2) noise is not really a "signal"; it is a continuously and randomly changing voltage, while a carrier's level is relatively constant.

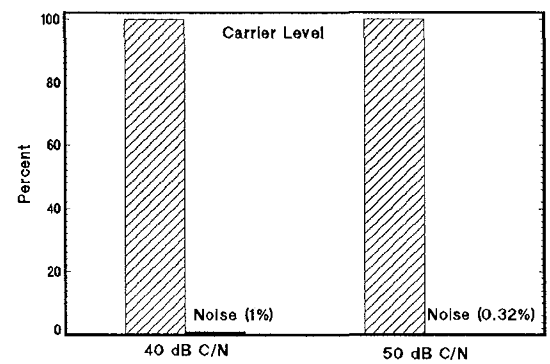

Fig 1 – Carrier vs Noise Levels

In Figure 1, note that for a 40 dB C/N, the voltage level of the noise is 1/100th of the carrier level and for 50 dB C/N it is 1/316th! In this case it doesn't even show up on the chart. One consequence of this is difficulty in getting the same kind of repeatable measurement results we are used to seeing when measuring higher level signals such as carrier levels.

CORRECTION FACTORS

When measuring noise, a number of corrections to the initial instrument readout are usually necessary. To understand what they are and why they are used, let's look at five of the most important of these.

Noise-Equivalent Bandwidth

To measure C/N in an ideal world we would use a perfectly rectangular, 4 MHz wide filter centered at the desired frequency with its output connected to a power meter.

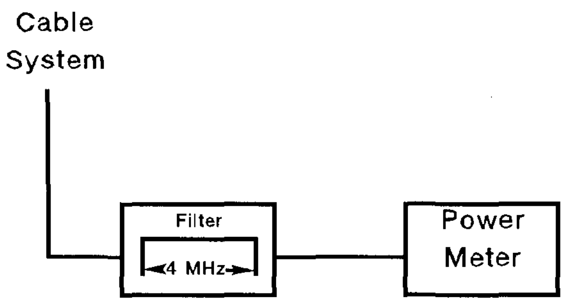

Fig 2 - Ideal World Setup

Unfortunately, our ideal world scenario is not possible for a number of reasons. These reasons give rise to the correction factors that are necessary in practice.

The first problem we encounter is that perfectly rectangular filters do not exist. So we must introduce the concept of "noise-equivalent bandwidth". This is simply the bandwidth that the filter would have if it were perfectly rectangular and letting through the same amount of noise as the imperfect filter. Since filter bandwidths are often specified as their bandwidth 3 dB down on either side of center frequency, our first correction factor is to change the specified bandwidth to a noise-equivalent bandwidth. A typical value is 0.52 dB. This means that, in this case, the noise-equivalent bandwidth is slightly wider than the specified bandwidth.

Correction to 4 MHz Bandwidth

We now know that specifying a filter by its noise-equivalent bandwidth gives us an effectively perfect rectangular filter. However, it still isn't likely to be what we want, i.e. exactly 4 MHz wide. So our second correction factor changes our real world filter bandwidth (whatever it is) to 4 MHz.

Loss

Real world filters have loss. Fortunately, since the carrier-to-noise test is a relative test where both measurements, carrier level and noise, are done through the same loss, we can usually neglect this factor.

Noise Figure

Now that we have dealt with the filter in Figure 2, let's consider the power meter. Again, the ideal world setup doesn't work. This is because power meters cannot directly measure the low levels of noise we need to measure. So we have to add an amplifier to bring the noise level up to what the meter can measure. But the amplifier adds its own noise. How much? What other effects could it have on the measurement?

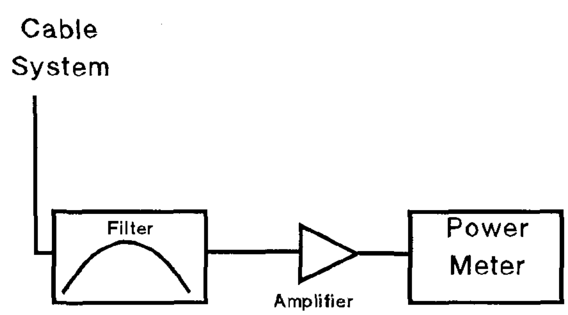

Fig 3 - Real World Setup

In practice, we usually only consider the effect of the amplifier's noise contribution (defined by its noise figure) and assume the other effects it could have on the measurement to be negligible. Thus, noise figure is our third correction factor.

So far, we have introduced three noise measurement correction factors:

1. Filter noise-equivalent bandwidth

2. Filter bandwidth corrected to 4 MHz

3. Amplifier noise figure

Real World Practices

Why don't we normally measure C/N with the Figure 3 setup? There are several reasons:

1. The setup in Figure 3 does not provide for a way to adjust a tunable bandpass filter.

2. Knowing the filter's noise-equivalent bandwidth is critical to the measurement, but the bandwidth of tunable filters varies as a percent of center frequency, so their noise-equivalent bandwidth will also change with tuning. Using calibrated filters is possible, but not very convenient.

3. Measuring in an exactly 4 MHz wide bandwidth has an advantage in that it incorporates any ripple or slope in the noise level over this range. However, it will also include any distortion products, extraneous signals, or the unmodulated carrier, if present. This might lead to an erroneously high result. In practice, noise measurements are done in narrower bandwidths, typically from 30 to 300 kHz, and then corrected to 4 MHz.†

4. Power meters are not commonly available at cable TV shops.

Using a Spectrum Analyzer

Spectrum analyzers are commonly available at cable TV shops and are very convenient to use for this purpose.

When it is not sweeping (zero span), a spectrum analyzer is a fixed tuned, frequency selective voltmeter. When it is sweeping, it is simply displaying the results of a series of measurements made over a range of frequencies. When an analyzer displays power, it is calculated from that measured voltage.

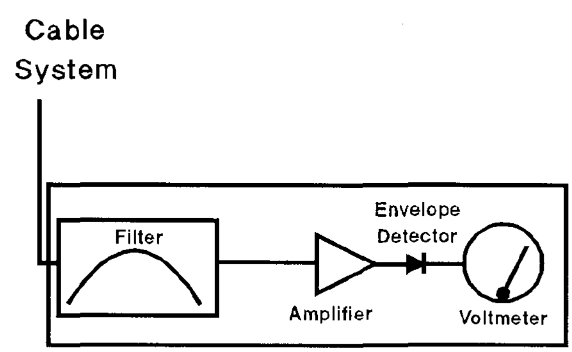

Fig 4 – Spectrum Analyzer

In Figure 4 we have transformed the ideal, but impractical setup of Figure 2 into a real world, practical measurement setup through the use of these three correction factors:

1. Filter noise-equivalent-bandwidth

2. Filter bandwidth corrected to 4 MHz

3. Amplifier noise figure

Logarithmic Detection of Noise

But, we're not done. The fourth correction factor to be introduced is a result of using the measurement unit "dB".

A spectrum analyzer is a voltmeter which, when displaying results in units of dB(m, mV, etc.), is actually measuring a voltage that has been converted into a logarithmic value. This allows very widely differing levels, such as carrier and noise, to be easily viewed on the same display. Otherwise noise, for example, when on screen with a carrier, would be too small to see. For an example of what this would look like, see Figure 1.

However, measuring noise in dB reports a value 2.5 dB too low. This is made up of 1.05 dB from envelope detecting the Gaussian noise distribution and 1.45 dB from logging that result. So our fourth correction factor is to add 2.5 dB to our measured noise level.

Our correction factor list now looks like:

1. Filter noise-equivalent bandwidth

2. Filter bandwidth corrected to 4 MHz

3. Amplifier (spectrum analyzer) noise figure

4. Log detect noise

Preamp Noise Contribution

The setup in Figure 4 performs well when measuring C/N in high level parts of the distribution system, such as at line extender outputs. However, for measuring C/N at lower levels (e.g. +15 to +25 dBmV or less) the amplifier noise figure correction, #3 above, is not adequate.

This is because spectrum analyzer designs put a high priority on amplitude accuracy. This is done at the expense of sensitivity. Thus, noise figure is traded off for best amplitude accuracy. To boost the noise to be measured into the measuring range of the spectrum analyzer, a preamplifier is used. See Figure 5.

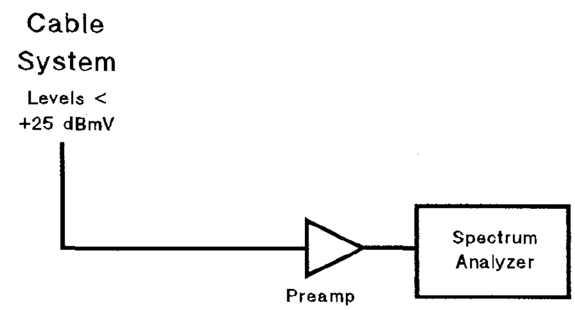

Fig 5 – Spectrum Analyzer w/ Preamp

We have now added yet another uncertainty to the measurement and have to add another noise figure correction factor. Our list of corrections with typical values for a spectrum analyzer now looks like:

1. Noise-eq-BW: 0.52 dB
2. 30 kHz to 4 MHz: 21.25 dB
3. Analyzer noise figure: (use Fig 6)
4. Log detect noise: 2.5 dB
5. Preamp noise figure: (use Fig 7)

An Example

Now that we know the correction factors involved, let's do an example measurement. Here are some typical measurement conditions:

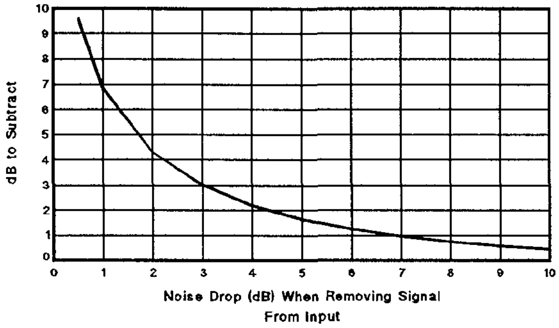

Fig 6 - Noise-near-Noise Correction

Carrier level at preamp output:	+13 dBmV
Uncorrected C/N:	73 dB
Noise drop when disconnecting cable from analyzer input: (use Fig. 6 to get 0.6 dB)	9 dB
Preamp Gain:	10 dB
Preamp Noise Figure:	7 dB

Using the above information we calculate C/N at the output of the preamp:

C/N at preamp output =

73 -	(Uncorrected C/N)
(-0.52	(Filter noise-equivalent bandwidth)
+21.25	(30 kHz to 4 MHz)
+2.5	(Log detect noise)
-0.6) =	(Analyzer noise fig)

50.37 dB C/N at preamp output

Now, to correct for the noise contribution of the preamp, we subtract the C/N just found above from the carrier level at the INPUT of the preamp, which is the output carrier level minus the gain:

+13 - 10 - 50.37 = -47.37

Find -47.37 on the x-axis of Figure 7 to find the noise correction value of 1.3 dB on the curve for a noise figure of 7 dB. This means the preamp is adding 1.3 dB of noise at its output so we should add thus:

50.37 + 1.3 = 51.67 dB C/N

51.67 dB C/N is now the value we would have measured with the ideal Figure 2 setup if it were possible.

Note that equation (1) at the end of this paper can also be used to directly calculate C/N at the preamp input.

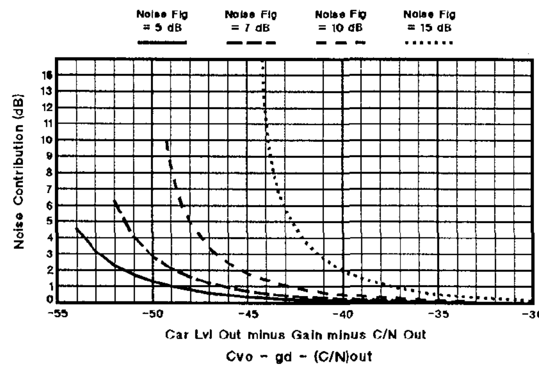

Fig 7 - Preamp Noise Contribution

SMART INSTRUMENTS

Newer spectrum analyzers, such as the HP8591E with cable TV measurement personalities, can automate many of the above tasks.

For example, Figure 8 shows the measurement information screen of the carrier-to-noise test in the HP85711B CATV measurements personality. It shows exactly how the instrument calculated C/N and what values it used for the correction factors.

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      C/N CALCULATION                                   dBmV
Uncorrected 30 kHz mkr on noise              = -47.36
Correct 30 kHz to 4 MHz          (+21.25)    = -26.11
Rayleigh Noise; LOG detect       (+2.50)     = -23.61
IF Noise Equiv. Pwr BW           (-0.52)     = -24.13
Analyzer Noise Correction        (-0.31)     = -24.44
Preamp Noise Correction          (-0.79)     = -25.22

C/N = Carrier Level - Corrected Noise
          22.04     -    (-25.22)    =  47.26

            C/N =  47.2 dB
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Figure 8

CONCLUSION

Getting repeatable results when measuring carrier-to-noise over a wide dynamic range requires attention to a number of details. Modern instrumentation can do a lot of the work while increasing measurement accuracy and reducing errors.

REFERENCES

1. "Spectrum Analysis Basics", Application Note 150, Hewlett-Packard Company, 1989.

2. Lin, Wen Tsung and Tim Homiller, "Noise Measurements For A CATV System-C/N, S/N, Phase Noise", 1989 NCTA Technical Papers, p. 179.

3. Schwartz, Mischa, "Information Transmission, Modulation, and Noise", Second Edition, McGraw-Hill, 1970.

†The noise measurement bandwidth used with a spectrum analyzer is often 30 kHz. Theoretically, any bandwidth can be used as long as the correction to 4 MHz is done properly from the chosen bandwidth. 30 kHz is a good compromise between keeping a reasonable measurement dynamic range and minimizing the effects of distortion products and of the carrier (if present) on the lower end of the noise measurement range.

PREAMP NOISE EQUATION

$$(C/N)_{sig} = C_{vo} - g_d - 10LOG\left[10^{\frac{C_{vo}-g_d-(C/N)_{out}}{10}} + 10^{\frac{-59.2}{10}} - 10^{\frac{-59.2+nf}{10}}\right] \qquad (1)$$

Where:

$(C/N)_{out}$ = Carrier-to-noise at preamp output (dB)
$(C/N)_{sig}$ = Carrier-to-noise of applied signal at preamp input (dB)
C_{vo} = Visual carrier level at preamp output (dBmV)
nf = Preamp noise figure (dB)
g_d = Preamp gain (dB)
-59.2 = Thermal noise in a 4 MHz noise BW @ 17.5 °C (dBmV)