Application Note

Anritsu

Using markers to estimate noise figure

Noise figure is a value that shows how much additional noise is added to a signal as the signal passes through a device. Pre-amplifiers are the devices that most commonly have specified values for noise figure. The noise added by a device permanently degrades the signal to noise ratio of a signal.

The measurement of noise figure has long been thought of as a difficult, esoteric measurement. Conceptually it is quite simple. When a signal with a certain signal to noise ratio goes through an amplifier, the amplifier adds an amount of noise to both the signal and the noise as they go through the amplifier. Since the same value is added to both the numerator and denominator of the signal to noise ratio, the ratio drops. By measuring the amount that the ratio decreases, the noise contribution of the amplifier can be determined, and from that the noise figure of the amplifier can be calculated.

Noise Factor in a system is defined as $F = SNR_{in}/SNR_{out}$ where SNR means input and output power signal to noise ratio.

To calculate noise figure from signal to noise measurement data use the equation

$NF = 10 \log (SNR_{in}/SNR_{out}) = SNR_{in,}\ dB – SNR_{out,}\ dB$

Noise figure is noise factor given in dB. So it can calculated as NF = 10 log(F)

There are many fine details that make precise noise figure measurements challenging. The temperature at which the measurement is made makes a difference. The measurement bandwidth makes a difference, although that factor drops out when measuring with a spectrum analyzer because the same bandwidth is used for both halves of the measurement. Spectrum analyzer input match is important since a poor match causes variations that will be different for the terminated input and the input with the amplifier connected. The estimation method presented here assumes that the amplifier being measured has enough gain to make the noise contribution of the spectrum analyzer small.

Make the measurement by using a 50 Ω termination, first at the spectrum analyzer input and second at the amplifier input. The input signal is thermal noise from the termination, kTB, which is –174 dBm/Hz at room temperature.

What is kTB?

The letter k stands for Boltzmann's constant in joules per Kelvin. k = 1.38 x $10^{–23}$ J/K

T stands for the temperature at which the noise is generated in Kelvin. Zero Kelvin is absolute zero and 290 K is approximately room temperature.

B stands for the measurement bandwidth in Hertz.

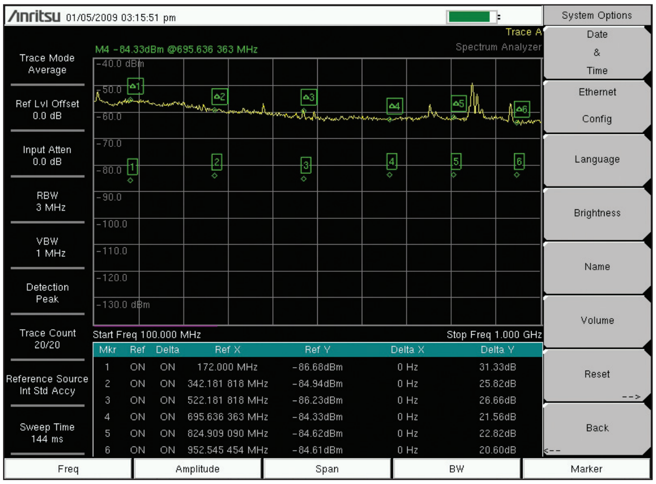

Figure 1. Noise figure measurements of a power amplifier with ~22 dB NF

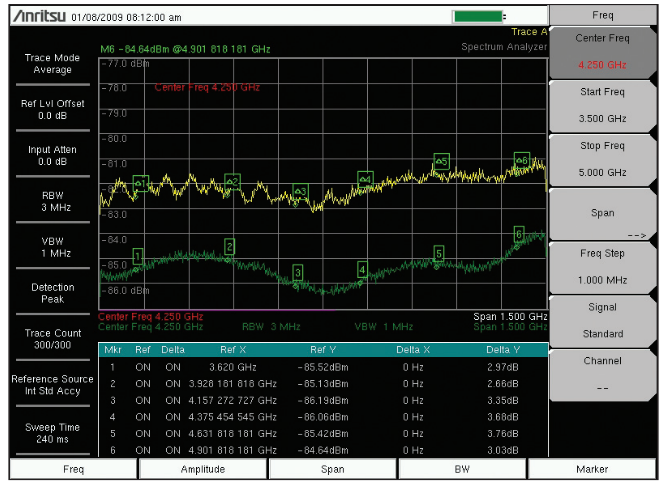

Figure 2. Noise figure measurement of a preamplifier with approximately 3.7 dB NF

You will notice that there are two traces shown in figure 2, while only one is shown in figure 1. The bottom trace in figure 2 is simply a stored trace showing the noise floor and technically isn't needed to make the measurement. However it does give a sanity check since the fixed reference markers should be on top of that trace. The ripple in the upper trace in figure 2 is caused by using 0 dB of input attenuation to get higher sensitivity and the resulting decreased source match.

To get measurements such as those shown in figures 1 and 2 follow this procedure:

1. Terminate spectrum analyzer input using a 50 ohm load.
2. Set reference markers at the frequencies where you want noise figure measurements.
3. For each marker turn on a delta marker and set the reference markers to be tracking markers. Here you have set the spectrum analyzer noise floor as the reference.
4. Turn on the marker table so you can see the values of all markers simultaneously.
5. Select a narrow VBW value to smooth out the noise variations.
6. If using a narrow VBW doesn't smooth the noise enough, the turn on trace averaging on Trace A. An averaging value of 10 to 20 should be sufficient unless a very low noise figure amplifier is being measured.
7. Set each reference marker to be a fixed marker after the averaging has completed and the delta marker value is small. If the value isn't small (say, less then 0.1 dB) increase the averaging value to make it so. Each reference marker is independently set to be a fixed marker giving you a spectrum analyzer noise floor reference.
8. After all the markers are set up, disconnect the 50 ohm load from the spectrum analyzer and attach the amplifier output to the spectrum analyzer input and terminate the amplifier input with a 50 ohm load.
9. Under the sweep menu press Reset Sweep to restart averaging.
10. Wait for the measurement average to stabilize at the new level.
11. The delta marker value is a measurement of noise contributed by the amplifier for each frequency.

You can get more accurate results by following this procedure, although it does take doing some mathematics in steps 8 and 9:

1. Turn a marker on and set it to be a noise marker.
2. Terminate the spectrum analyzer input with a 50 Ω load.
3. Note the marker reading in dBm/Hz and write down the value as "SPA dBm/Hz."
4. Move the 50 Ω load to the amplifier input.
5. Connect the amplifier output to the spectrum analyzer input.
6. Note the marker reading and write it down as "total dBm/Hz."
7. If "total dBm/Hz" is greater than "SPA dBm/Hz" by at least 3 dB, go to the next step. If not reduce spectrum analyzer input attenuation, turn on the spectrum analyzer's preamplifier or, if possible, increase the gain of the amplifier and start again at step 2.
8. Calculate amplifier output noise as 10 * log ($10^{(\text{total dBm/Hz}/10)}$) – 10 * log($10^{(\text{spa dBm/Hz}/10)}$)
9. Calculate amplifier noise figure = (amp output noise, dBm/Hz from step 10) – amplifier gain, dB) – (kTB)
   kTB = –174 dBm/Hz

The accuracy of this method depends on:

- Spectrum analyzer absolute measurement accuracy
- Amplitude jitter in the noise measurements. Use a large ratio of RBW/VBW for best results.
- Relative accuracy of measurements in steps 3 and 6 if total noise is not much greater than spectrum analyzer noise
- Accurate knowledge of amplifier gain

There are limitations to these methods. For example, when measuring a very low noise amplifier, the amount of averaging necessary to smooth-out normal thermal noise variations makes the measurement rather long. Averaging of 300 traces was used for the low noise amplifier measurement in figure 2.

Also, the contribution of the spectrum analyzer's noise figure is part of the measured result. For amplifiers with gain values of 20 dB or more, the contribution of the spectrum analyzer's noise figure will be small, typically less than 0.3 dB. You can calculate the contribution of the second stage using this equation. An important thing to notice in this equation is that the noise contribution of the second stage is divided by the gain of the first stage amplifier – the $(F_2 – 1)/G_1$ part.

$$N_0 = kT_0BG_1G_2[F_1 + (F_2 - 1)/G_1]$$

Where N_0 is the total noise, G_1 and F_1 are the gain and noise factor of the amplifier being measured while G_2 and F_2 are the gain and noise factor of the second stage of gain, the spectrum analyzer in this case.

By following one or both of the procedures in this note, you can get a reasonable idea of the noise figure of an amplifier.

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