Why Fight For That Last Few Tenths of a dB in LNA Noise Figure

By Richard T, Knadle, K2RIW

Some of this information came from the "Do You Need a LNA Line Driver" presentation by K1FO at the 3/17/01 NEWS Meeting at Enfield, CT, USA. In many amplifying devices, there is a considerable difference between tuning for the best gain, and the best Noise Figure (NF). Under certain conditions it is possible to tune a particular amplifier for best gain and realize a NF of 0.9 dB. That same amplifier may deliver 0.3 dB NF, with slightly less gain (maybe 0.5 dB less), when tuned for best NF. At first you might say, gee, a 0.6 dB NF improvement.
Is that small improvement worth fighting for? The answer is YES, YES!
In the paragraphs that follow I'll attempt to show you:

(1) Why it is worth fighting for.

(2) Why it is hard to detect the improvement with typical laboratory equipment.

(3) What else in the system must be working right to get the full benefit.

(4) The Antenna Impedance problem.

(5) You'd better have the correct Gain Distribution.

(1) Why is it Worth Fighting For?

-- You're about to have a demonstration that dB's of NF are not linear, when dealing with a cryogenic communication system; and a small NF improvement can make a big difference in the Signal to Noise Ratio (SNR). A communication system becomes cryogenic when you aim the antenna into cold space.

Two EME System Examples -- Assume I have an excellent EME antenna that is presently aimed at a high elevation angle, and it is aimed at a cold direction in the Universe, where the true Celestial Background is 2.73 degrees Kelvin (the residual of the Big Bang, by Penzias and Wilson, Nobel Laureates, 1968). Under those conditions that excellent EME antenna might have a total Antenna Noise Temperature (Ta) of 30 degrees Kelvin (they [the experts] call it 30 Kelvins).

-- If your Low Noise Amplifier (LNA) had a NF of 0.9 dB, that equals an electronic Noise Temperature (NT) of 66.78 Kelvins. The formula for NT is:

NT = [ALOG(NF/10) - 1] * 290.

Your total possible system NT (Ts) is now the sum of the Ta and the NT.

Ts = Ta + NT. Ts = 30 + 66.78 = 96.78 Kelvins.

-- If I was using that LNA when it is tuned at a NF of 0.3 dB, the LNA's NT would equal 20.74 Kelvins. Now the Ts = 30 + 20.74 = 50.74 Kelvins. The only thing that is always linear about a cryogenic communication system is that the total Noise Power is proportional to the Ts in Kelvins. You have to almost ignore the dB's.

When I compare a system with a Ts of 96.78K (A) to a system with a Ts of 50.74K (B), that ratio is 2.80 dB. In other words, that EME signal will be 2.80 dB further out of the noise when I use the LNA with the better tuning (I'm ignoring Moon Noise). That 2.80 dB of difference can easily make the difference between a QSO and a missed QSO, when I'm listening to a weak EME signal.

A Better EME Antenna -- If I was able to make further improvements to that EME antenna so that the Antenna Temperature (Ta) was 20 Kelvins (and, that is possible), then that ratio would be 86.78 Kelvins versus 40.74 Kelvins, or 3.28 dB of system improvement in Signal to Noise Ratio (SNR). All of this from a 0.6 dB NF improvement (0.9 dB to 0.3 dB NF) in the LNA! A ~ 3 dB SNR improvement for a 0.6 dB NF change, that's a beautiful (apparent) non-linearity! But, it really isn't non-linear, it just looks that way (in dB's).

(2) Why is it Hard to Detect With Typical Lab Equipment

-- When I make measurements with room temperature laboratory equipment, everything (the pads, signal generators, FM Receiver, etc.) is at approximately 290 kelvins. In that 290K environment, a change in the LNA's NF from 0.9 dB to 0.3 dB, can create a change in SNR of 0.6 dB (at best). Here the dB's are linear. Unless you are using some good laboratory equipment (such as WB6KBL's SINAD Meter, or a good NF Meter), you will probably not detect that 0.6 dB SNR improvement. Your ear probably doesn't have enough discrimination to allow you to hear it, when you hit that "Sweet Spot" in NF tuning. And, as section (3), (4), and (5) will show, you will not be able to realize the benefit of that 0.6 dB of NF improvement, unless the rest of the RCVR has a NF of nearly 1.0 dB or so, has the proper antenna impedance, and the proper gain distribution.

(3) What Else in the System Must Be Working Properly to Get the Full benefit?

-- If I was using a RCVR that was Gain Starved, or had a second stage NF of 15 dB, then the tuning of the LNA takes on an entirely different characteristic.

High Transceiver NF -- Many of the currently used Base Station Transceivers have a bare foot NF of 12 to 15 dB. This occurs because Japan favors dynamic range over RCVR sensitivity. Those Transceivers are front end Gain Starved. If you lived in a dense community where there was a Ham Radio Operator living on each street, you might agree with this approach.

Add an LNA -- Therefore, almost every American SSB operator must add a ~ 20 dB gain LNA in front of his Transceiver, if he desires full sensitivity of his communication system. If he doesn't add that LNA, all his SSB friends will eventually call him an Alligator (he is all mouth), instead of a Rabbit (a guy that is all ears). During a terrestrial contest, everybody can hear that Alligator call CQ, and they answer him, but because of his poor hearing aide (RCVR), he only hears the locals and only responds to them. The rest of the contest operators become frustrated, and learn to ignore him. Unless some local explains this to the "Alligator," he will conclude that there wasn't much activity during the contest.

It is well known that the total system's cascaded NF (NFs) is equal to:

NFs = NF1 + (NF2-1)/G1 + (NF3-1)/(G1*G2) + ..., where:

NF1 = NF of the first stage (as a real, anti-LOGed number).

NF2 = NF of the second stage (as a real number), etc.

G1 = Gain of the first stage (as a real number).

G2 = Gain of the second stage (as a real number), etc.

Sometimes Best Gain = Best NF -- If I was tuning a communication system's LNA, while it is connected to that bare foot Transceiver, I would find that the best system NF would be approximately the LNA tuning with the maximum gain. Here is an example:

If you experiment with just the first two terms of that Cascaded NFs formula, and use 15 dB for NF2, 0.3 dB for NF1 and a gain of 10 dB for G1, you will find that the System Noise Figure (NFs) [in dB's] is equal to 6.16 dB. If, now, I use 0.9 dB for NF1 and 10.5 dB for G1, I realize a NFs of 5.98 dB.

Notice, that I worsened the LNAs NF by 0.6 dB, while improving the gain by only 0.5 dB, yet the system NF IMPROVED by 0.18 dB. What this example demonstrates is that when your RCVR system is gain starved, and has a high second stage NF, then the LNAs gain is much more important than it's NF. Even if I was using perfect laboratory instrumentation (such as a perfect NF Meter) while tuning that LNA in that environment, I would end up tuning it for maximum gain, not best NF.

The conclusion is that to get the maximum benefit of a Super Low Noise LNA, you have to put it into the right environment while tuning it, and using it. Otherwise, you may be "casting pearls upon swine," you could be wasting your time and your money.

(4) The Antenna Impedance Problem

-- It is well known that when you are tuning an LNA for the best NF, you are primarily adjusting the impedance that the front end of the LNA is looking into. It would be quite wasteful to carefully adjust an LNA stage while it is connected to perfect 50 ohm resistive laboratory equipment, and then connect it to an antenna with a VSWR of 1.41:1. That 1.41:1 antenna could be an impedance that consists of a capacitive reactance of 50 ohms in series with a resistance of 50 ohms. That antenna would drastically change the LNA's NF.

That uncorrected 1.41:1 VSWR antenna could easily raise your LNA's NF from 0.3 dB to 0.9 db, and hurt your EME RCVR sensitivity by ~ 3 db. But on transmit, the 1.41:1 would only cost you 0.127 dB of transmission loss.

Your corrective choices are either to perfectly impedance match the EME antenna (with a double stub tuner, for instance) to make it look like a 50 ohm resistive load to the LNA, or do the NF tuning of the LNA while it is connected to the antenna -- such as by injecting the NF Meter's Noise Source through a 20 dB Directional Coupler (DC) that is always left in the antenna line.

The DC Line Perturbation -- If, after the NF tuning of the LNA, you made the mistake of removing the Directional Coupler, you would be changing the transmission line length, and that would rotate the antenna impedance to a different place on the Smith Chart. This would disturb the LNA tuning.

Another solution is to add a carefully chosen extra length of line onto the DC's straight through path, so that the DC plus the extra line is an exact multiple of a half wavelength (electronically). Now you could remove that DC plus extra line, and not effect the antenna's impedance.

(5) You'd Better Have the Correct Gain Distribution

-- To realize the system's best possible sensitivity requires that you have enough front end gain, and a low enough second stage NF. But, this requires a compromise of system NF vs Dynamic range. You usually can't have both all at once.

The best possible system NF usually requires a lot of front end gain (sometimes 20 to 30 dB). But, a system with that much front end gain will saturate 20 or 30 dB sooner from strong local signals -- that's the problem that the Japanese equipment manufacturer's discovered.

Noise Power Saturation -- Also, bear in mind that even if you live in the "Out Back," and saturation from local operator's isn't a problem, there can be another subtle detriment from the use of super high front end gains -- Noise Power Saturation. It is possible that the later stages of your RCVR are being subjected to so much Noise Power, from all the front end gain, that they are beginning to saturate on the instantaneous noise peaks. Even if that saturation is only a fraction of a dB, it can lower the SNR of a weak signal.

It is well known that a limiting stage will suppress a weak signal that's surrounded by noise with, what is called, "Signal-Cross-Noise Terms." In other words, it is possible for a super high gain system to suppress that weak EME signal you're trying to hear, in the later stages of your own RCVR. This phenomenon is quite subtle, and not easy to detect. But, if the gain in your system is shoving the S Meter above S7 on basic Noise Power, than be wary, it could be happening to you. The only quantitative test procedure I know of to detect this condition is the "Notched Noise Power Fill-In Test," also called the Noise Power Ratio (NPR) Test.

IF Filter BW -- It is also possible that your system is going into and out of Noise Power Saturation, as you change the bandwidth of the IF filter. At first, you would think that the broader IF filter selection would aggravate the problem. However, it is possible that the more narrow filter selection allows less noise power into the final detection stage, and this in turn causes a smaller AGC voltage, which increases the RCVR's gain, and causes Noise Power Saturation in an earlier stage.

Sun Noise Problems -- As your EME system becomes more refined, and you experience a larger number of dB's of Sun Noise measurements, it is possible that with the added Sun Noise power, your RCVR system could be experiencing Noise Power Saturation. That would give you a pessimistic Sun Noise measurement. One simple method of detecting this problem would be to put a 6 dB pad in various places (after the LNA), and repeat the Sun Noise measurement. If you get a better reading, you may have the problem.

The best system for high dynamic range is one that has a gain distribution that's just enough, at each stage, to override the NF of the next stage. The best system NF requires considerably more front end gain than that. Soon we will all pay more attention to the Noise Power Saturation characteristics of tunable IF RCVRs. Then we will simultaneously have the best system NF and high dynamic range.

I hope this information is helpful. Please feel free to correct the mistakes.

73 es Good VHF/UHF/SHF/EHF/Laser DX,

Dick, K2RIW.