Application Note AN-002: *Noise Figure Improvements using the µHILNA™ Low Noise Amplifier*

What is Noise Figure and How to Improve it with a Low Noise Amplifier

Noise Figure (NF) describes the amount of noise a component, amplifier, or an entire radio receive chain contributes to the RF signal being received. It can also be defined as the logarithmic unit (dB) derived from the ratio of the signal to noise ratio (SNR) into the device or circuit versus the SNR out of the device. High NF reduces receive clarity and intelligibility.

Although passive components contribute some noise to a signal path, this document will only deal with the NF of amplifiers and chains of amplifiers. This understanding will then be used to demonstrate the improvement in receive quality from adding a low noise amplifier (LNA) to the antenna input (i.e., front end) of a receiver, such as the NuWaves µHILNA™ LNA described in this Application Note.

Figure 1. NuWaves' µHILNA™ Low Noise Amplifier (LNA) operates from 50 to 1500 MHz, delivers 20 dB of gain, with less than 1 dB of Noise Figure (NF) and a Third-Order Intermodulation Product (IP3) of +31 dBm.

Noise Figure Theory

Electrical noise is combined with the RF signal as it is generated by the RF transmitter and propagated through space. This signal is then captured by the receiving antenna and guided to the receiver input via a transmission line (i.e., coaxial cable or waveguide). In an ideal receiver, each amplifier stage would increase the desired signal and the surrounding noise floor by the same amount, or in other words, the amplifiers would not add any additional noise to the signal. This would mean that the signal to noise ratio (SNR) would remain constant throughout the stages of the receive circuit.

In reality, amplifier stages add additional noise to the signals passing through them. In the worst case scenario, this means that through several gain stages the noise floor rises at a greater rate than the desired signal level, which and can eventually envelop the desired signal and prevent reception of the signal altogether. In an effort to reduce cost, the radio designer may select inexpensive transistors or amplifier ICs for the receiver gain stages. Unfortunately, these devices may not be designed for low noise applications, and will have poor NF performance. Selection of these parts leads to a poorly performing receiver as a tradeoff to keeping production costs low.

For a high performance receiver, all gain stages should have the lowest possible NF values. However, because this may be cost prohibitive, significant improvement in system NF is achieved by simply insuring that the first gain stage is a quality LNA device. There are two option for implementation of the LNA in existing equipment: (1) the first gain stage in the receiver is replaced with a low NF device by the original equipment manufacturer (OEM), or (2) an external LNA is placed between the antenna and the receiver. This application note will demonstrate that the first gain stage after the antenna has far more effect on the system NF than any other section of the receive circuit, whether by modification of the existing equipment or adding an external LNA. This will be demonstrated by adding a NuWaves µHILNA™ to the input of a notional high NF receiver to show the improvement achieved by inserting a high quality LNA between the receive antenna and the radio.

Receiver Noise Figure Calculation

Data sheets for amplifier devices typically provide NF characteristics for one or more frequency bands and different operating conditions. Although NF ratings cannot be simply summed or multiplied, the individual NF values can be used to estimate the NF of the entire cascaded amplifier section. The NF numbers must first be converted to Noise Factor (F) values. Noise Factor is the ratio of the input signal to noise ratio (ratio of signal level versus channel noise level, or signal to noise ratio (SNR)) versus the output SNR of the component or circuit. Noise Factor is found using the following equation:

$$NF = 10 * LOG_{10}(F), \text{ or } F = 10^{(NF/10)}$$

The first two stages of the example receiver circuit shown in Figure 2 has a NF = 3 dB and Gain = 17 dB. The third stage has a NF = 5 dB and Gain = 14 dB.

First, the NF values will now be converted to F values:

$$\text{Stage 1 and 2 NF} = 3 \text{ dB}, F = 10^{(3/10)} = 1.995$$

$$\text{Stage 3 NF} = 5 \text{ dB}, F = 10^{(5/10)} = 3.162$$

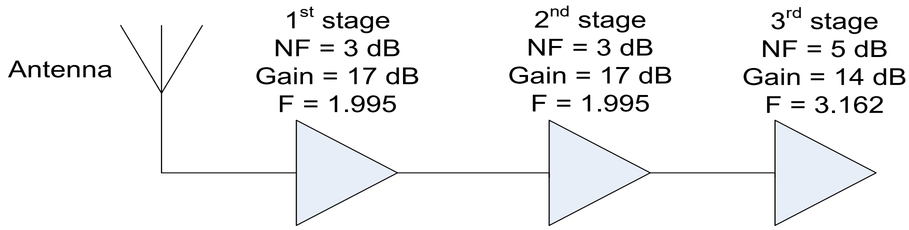

Figure 2. The notional receiver used as an example in this application note has a first stage NF of 3 dB.

Next, the Friis Formula is used to cascade noise factors into one Noise Factor for the entire circuit:

$F_{circuit} = F_1 + ((F_2 – 1) / A_1) + ((F_3 - 1) / (A_1 * A_2)) \ldots$, where A_n is the gain of the stage

$$F_{circuit} = 1.995 + ((1.995 – 1) / 17)) + ((3.162 – 1) / (17 * 17))$$

$$= 1.995 + (.995 / 17) + (2.162 / 289)$$

$$=1.995 + 58.53x10^{-3} + 7.481x10^{-3}$$

$F_{circuit} = 2.061$ (This equates to an SNR of the output signal that is approximately half the SNR of the input signal)

Finally, $F_{circuit}$ for the receiver is calculated and converted to $NF_{circuit}$:

$$NF_{circuit} = 10 * LOG_{10}(2.061) = \mathbf{3.14\ dB}$$

A circuit Noise Figure of 3.14 dB may not give the receive sensitivity required for the intended use. Note in the example above that the Noise Factor of the second and third gain stages are significantly lower than that of the first stage. Thus, it is clear that *the NF of the first gain stage has the greatest effect of all the gain stages on the total NF of the circuit.*

Noise Figure Improvement through the Application of NuWaves µHILNA™

It will now be demonstrated the improvement which will be had by adding the µHILNA™ to the front end of the receiver as shown in Figure 3. The µHILNA™ has a gain of 20 dB and NF = 1dB. From NF, the Noise Factor is calculated:

$$F_{LNA} = 10^{1/10} = 1.259$$

Next, the Noise Factor of the μHILNA™ cascaded with the three gain stages of the receiver is calculated, and converted to a NF value.

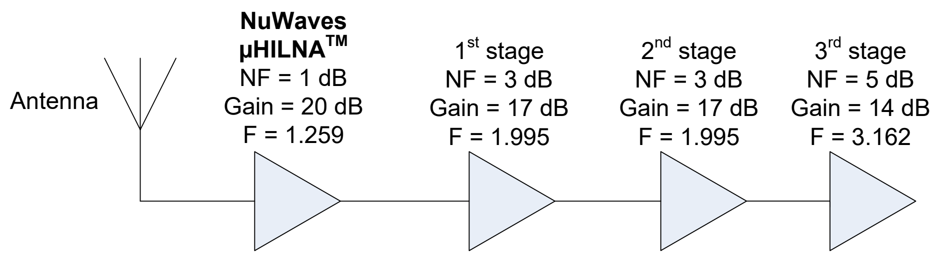

Figure 3. The μHILNA™ is inserted between the antenna and the notional receiver, improving the NF of the system by approximately 2 dB.

$$F_{circuit + LNA} = 1.259 + (.995 / 20) + (.995 / 340) + (2.162 / 5750) = 1.312$$

$$NF_{circuit + LNA} = 10 * LOG_{10}(1.312) = \mathbf{1.18\ dB}$$

$$\text{Improvement due to the μHILNA}^{TM} = NF_{circuit} - NF_{circuit + LNA} = 3.14 - 1.18 = \mathbf{1.96\ dB}$$

The addition of the NuWaves μHILNA™ to the front end of a receiver with a high NF has improved the receiver noise figure by *approximately 2 dB*.

Summary

Noise figure is a key measurement of the performance of an RF receiver. While the peak performance is gained by selecting LNA devices with the lowest possible noise figures, good performance is achieved by using a high quality, low noise figure device as the first gain stage in the receiver. Further, the noise figure of a receiver can be improved through the addition of an external LNA placed between the receive antenna and the receiver. NuWaves offers several LNA modules in the NuWaves product line, including the μHILNA™, providing low noise gain solutions from 2 MHz to 10 GHz.

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Contact Ryan Foster, Director of Product Solutions, at (513) 360-0800 ext. 154, or visit www.nuwaves.com for more information.