Improving Radar Performance by Optimizing Overall Signal-to-Noise Ratio

Better noise-figure measurements enhance characterization of excess noise in receivers

Application Note
Radar Measurement Series

Overview

In radar system design, optimizing the overall signal-to-noise ratio (SNR) of the system will improve the overall performance of the system. This is typically done in one of two ways: by increasing the signal or by reducing noise. Because a radar is a transmit/receive system, improved SNR can be achieved by increasing the transmitted power by using bigger, more-powerful amplifiers, by using larger or higher gain antennas, or a combination of these changes.

SNR can also be increased by decreasing receiver-contributed noise, which is usually determined by the quality of the low-noise amplifier (LNA) at the front end of the receiver. In general, it is easier and less expensive to decrease receiver noise—and achieve a better noise figure (NF)—than to increase transmitter power.

In the pursuit of a better SNR, NF is a figure-of-merit that describes the amount of excess noise present in a system. The definition of noise figure is very straightforward. The noise factor (F) of a network is defined as the input SNR divided by the output SNR:

$F = (S_i/N_i)/(S_o/N_o)$, where

S_i = input signal power

S_o = output signal power

N_i = input noise power

N_o = output noise power

Noise figure is simply the noise factor expressed in decibels: NF = 10*log (F). This definition is true for any electrical network, including those that shift the frequency of the input signal to a different output frequency, such as up- and downconverters.

Problem

Radars need to extract very small signals—those coming from targets of interest—in an environment that may include artifacts such as clutter, jamming signals and spurious noise (e.g., signals from other radars). Any internally generated noise in the radar receiver circuit reduces the ability of the radar to discern the targets of interest. Noise generated within a receiver component is indistinguishable from any legitimate signal within the signal frequency band and will be amplified equally along with expected signals in any subsequent gain stages.

Measuring noise properties is an essential step in the process of minimizing the noise generated within a receiving system. The following equation determines the minimum signal level required to overcome system noise at the maximum range of the radar:

$$S_{min} = kT_oB_nF_n(S_o/N_o)_{min}$$

Where:

S_{min} =	the minimum signal level
k =	Boltzman's constant
T_o =	room temperature
B_n =	receiver noise bandwidth
F_n =	noise factor
$(S_o/N_o)_{min}$ =	the minimum SNR required by the receiver processor to detect the signal

A close inspection of this equation illustrates the importance of receiver NF. For example, k and T_o are effectively constants, B_n is dictated by the radar design, and the SNR cannot be improved once the signal arrives at the receiver. Thus, receiver NF becomes the key term for receiver optimization. In reality, this is a somewhat simplistic model of performance, as other items such as system losses and pulse integration will also affect performance. However, the NF performance of the receive circuit is a key performance factor.

The above equation might lead you to believe that improvements in noise figure will enable great improvement in system performance at modest cost. Today's low-noise amplifiers can deliver very low NF values. When properly engineered into the receiver architecture, the system NF penalty can be minimal. As a result, it may seem more economical to reduce receiver noise figure by 3 dB than to increase transmitter power by the same amount. However, reality is not quite that simple. Instead, the receiver must also provide adequate gain, phase stability, amplitude stability, dynamic range, and fast recovery from overload and jamming. In addition, protection must be provided against overload or saturation and burnout from nearby transmitters. As a final point, the receiver design must also be highly reliable.

With these considerations in mind, some designers choose to make the first stage of the radar receiver a mixer rather than a low-noise RF amplifier. Even in these cases, NF is a critical metric that must be optimized within other given constraints.

Solution : Making noise figure measurements

Two techniques are commonly used to make NF measurements. These are the Y-factor method, which is sometimes called the hot/cold source method, and the other is the cold-source or direct-noise method. The Y-factor method uses a signal or spectrum analyzer and a noise source. The cold-source method uses a vector network analyzer, which leads to a higher equipment cost than the Y-factor method but enables measurements such as S-parameters, compression and intermodulation distortion with a single set of connections to the DUT.

This note explains the Y-factor method and describes when you should consider using the cold-source method. As a starting point, the procedures outlined here assume you know the frequency of interest of your radar and understand the gain characteristics of the receiver. This latter point is important because the choice of noise source is dependent on the gain.

You will also need to determine how you will access the device under test (DUT). In an ideal situation, the DUT would have impedance-matched connectors on its input and output. Because this is seldom the case, you will need to determine how to best connect the test equipment. For example, it may be most convenient to connect through an ATE test fixture. Please refer to the "Tips" section below for additional considerations.

One more note: The procedure below includes steps to calibrate the instrument. This removes the major sources of error generated by the measuring instrument, ensuring that you are measuring the DUT and not the noise figure of the instrument.

Solution : Y-factor noise figure measurement

The Y-factor or hot/cold-source method is the most common way to measure noise figure. This technique is relatively easy to implement and provides good measurement accuracy in most situations, especially when the noise source has a good source match and can be directly connected to the DUT. In addition to the DUT, two pieces of test equipment are needed:

- A noise-figure, signal or spectrum analyzer that covers a suitable frequency range and has an NF measurement application installed.
- A noise source (see sidebar on page 3).

The following procedure describes how to perform the Y-factor measurement using an Agilent X-series signal analyzer (typically an N9020A MXA or N9030A PXA), the N9069A NF application (runs in the analyzer) and an N4000A Series smart noise source (SNS). The NF application and the SNS are designed to simplify the measurement process and ensure useful results.

Making the measurement

This procedure assumes the N9069A NF application is installed in a signal analyzer that supports your chosen noise source at the appropriate frequency range. The initial setup has five steps:

1. Select the appropriate frequency range for the device being tested.
2. Select an internal amplifier option for the frequency range.
3. Enter the ENR table for the SNS Series noise source into the signal analyzer: [Meas Setup] key, then {ENR} softkey, {SNS setup} softkey, {Noise Source} softkey, set to SNS (Auto) {Auto Load ENR}.
4. Use a cable to connect the noise source to the signal analyzer; the SNS Series sources use the 11730A cable. Verify that the ENR data has been transferred to the signal analyzer
5. Save the ENR table: [Save] key, then {Data}, {ENR Table}, {Meas} Table, {Save As} name [Enter].

Next, calibrate the NF application and analyzer:

1. Connect the input to the noise source to the rear of the analyzer via the 11730A cable. Connect the output of the source to the input of the analyzer.
2. Set the start frequency: [Freq Channel] key, {Start Freq softkey, [10] keys, {GHz} softkey (enter your choice of frequency).
3. Set the stop frequency: {Stop Freq} softkey, [3] keys, {GHz softkey (enter your choice of frequency).
4. Set the number of points: {Points} softkey, [30] keys, {Enter} (enter the number of points).
5. Set the averaging function: [Meas Setup] key, {Average Num} softkey, toggle to ON, [15] keys, {Enter} softkey.
6. Calibrate the N9069A: [Meas Setup] key, {Calibrate Now} softkey, [Enter].

Make the NF measurement:

1. Select the NF application in the signal analyzer. This is typically completed on the front panel: [Mode] key, then press {More} softkey until {Noise Figure} softkey is available.
2. Use the visual setup guide to get started: [Mode Setup] key, {DUT Setup...} softkey, {Amplifier} softkey, or select your DUT from the drop down menu with a mouse.
3. Disconnect the noise source from the input of the analyzer and connect it to the input of the DUT. Connect the output of the DUT to the RF input of the analyzer (Figure 1). Using fewer adapters will provide better measurement results.

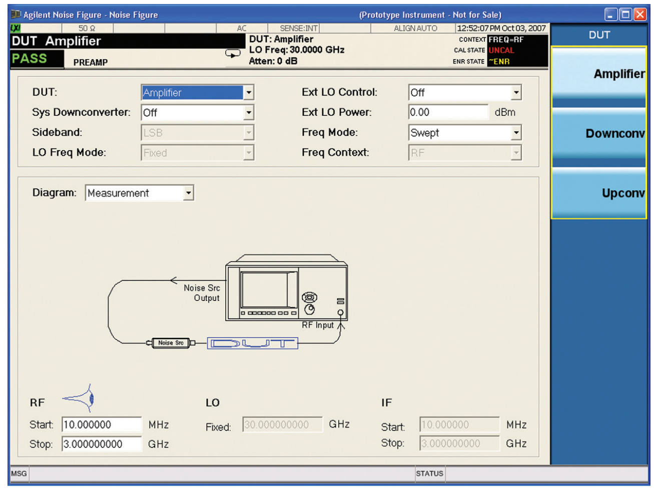

Figure 1. Measurement setup with analyzer, noise source and DUT.

4. Input the appropriate values for your DUT into the setup menu and run the measurement.

Selecting a noise source

The quality of the noise source affects the accuracy and repeatability of your measurements. The excess noise ratios (ENR) of Agilent noise sources are calibrated with traceability to national standards institutes. Nominal ENR values of 6 dB and 15 dB are commonly available.

We recommend a 15 dB noise source for most cases in which NF is expected to be 15 dB or more. A 6 dB noise source is recommended in two cases:

- When measuring a device with gain that is especially sensitive to changes in the source impedance.
- When the DUT has a very low noise figure (e.g., it does not exceed 15 dB).

Agilent offers three families of noise sources. The N4000A Series smart noise sources (SNS) are the simplest to use for frequencies up to 26 GHz because they simplify measurement set up by automatically downloading calibration data to the instrument. The 346 Series extends the frequency range to 50 GHz, and the 347 Series sources have waveguide interfaces for higher frequencies.

Alternative solution : Cold-source measurements

The cold-source or direct-noise method uses a vector network analyzer and requires only a known input termination, which is usually 50 Ω at room temperature. The cold-source method also requires an independent measurement of DUT gain. The procedure requires a single noise-power measurement as well as a gain measurement (both completed by the network analyzer). The network analyzer will require a noise source for instrument calibration as well as an ECal module to be used as an impedance tuner.

When high precision is required, the cold-source method can provide the most-accurate measurements. Additionally, it is better able to compensate for the source-mismatch situations that may occur when testing transmit/receive (T/R) modules that use microstrip input and output lines, or when switching separates the instrument from the module in an ATE system. Because a vector network analyzer is used, measurements can be made across low-gain, multi-stage devices and mixers (these measurements are particularly problematic using the Y-factor technique).

The variables involved are too complex to cover in this application brief. If your testing involves one or more of the situations described here and it is critical to obtain an NF measurement with a high level of accuracy (e.g., a few tenths of a dB), we recommend using the cold-source method with the Agilent PNA-X vector network analyzer, which can make appropriate corrections for common error sources. Figure 2 shows example results from cold-source and Y-factor measurements of a DUT in an ATE environment.

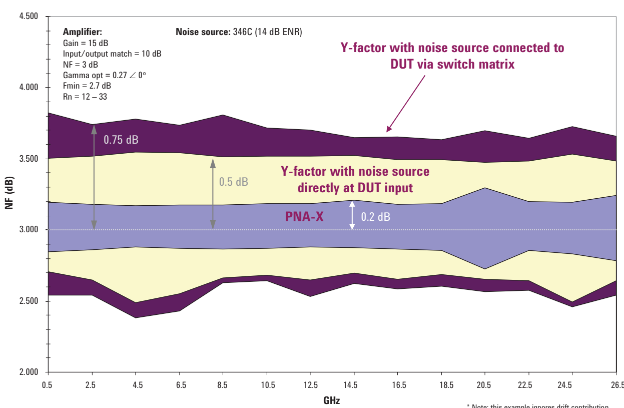

Figure 2. Example of NF uncertainty in an ATE environment

Tips: Avoiding common difficulties

A number of factors can affect the results of an NF measurement. Below are some of the more common issues along with techniques that will help you minimize or avoid problems when using the Y-factor method. In most cases, these items can be managed; however, if any are difficult to control—or if measurements must be made across a frequency-conversion or low-gain device- the cold-source method may be a better choice.

Prevent interfering signals

Any form of RF interference, whether radiated or conducted, will manifest itself as noise power and affect measurement accuracy. Therefore it is imperative to eliminate these sources of interference. Fluorescent lights, cellular telephones, wireless routers and local radio transmitters can all interfere with the accuracy of noise measurements. Additionally, nearby heavy equipment or poorly shielded equipment cables (signal or power) can all affect measurements. Suggestion: Always consider the operating frequency range(s) of the DUT and look for possible sources of in-band interference that will affect your measurements.

Avoid adapters

Corrections must be applied, especially for adapters at the input of the DUT. Wherever possible, use a noise source equipped with a connector that is compatible with the input of the DUT.

Minimize mismatch uncertainties

Any impedance mismatches will create reflections of noise power in the measurement and calibration path. The most likely problem areas are in connections to the DUT. In some cases, an isolator can be used to absorb reflected power—but be aware that isolators work over a limited frequency range.

Use averaging

This will increase measurement times but it reduces display jitter and provides a more consistent measurement. Jitter is reduced by the square root of the number of readings.

Avoid nonlinearities

NF measurements assume the entire system is operating in a linear and stable region. Ensure that both the DUT and instrument are being operated in the linear region.

Calibrate, then measure

The best measurements will be made immediately after calibration.

Conclusion

The process of reducing noise figure starts with a solid understanding of the uncertainties in your components, subsystems, systems and test setups. Quantifying those uncertainties depends on flexible tools that provide accurate reliable results. Whether you use the Y-factor or cold-source method, Agilent's NF solution set—instruments, applications and accessories—helps you optimize test setups, identify unwanted sources of noise and, ultimately, decrease the receiver-contributed noise in your radar system.

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Additional resources

Agilent has published a number of application notes that cover the fine details of noise figure measurements. If you are interested in learning more, please consider the following resources:

- Application Note 57-1: *Fundamentals of RF and Microwave Noise Figure Measurements,* publication 5952-8255EN
- *Noise Figure Measurement Accuracy: The Y-factor method*, publication 5952-3706EN
- *10 Hints for Making Successful Noise Figure Measurements*, publication 5980-0288EN
- *High-Accuracy Noise Figure Measurements Using the PNA-X Series Network Analyzer* (uses the cold-source method), publication 5990-5800EN

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