Application Note

Is Matching the LNA Input for Γ_{OPT} Always Worth the Effort?

AN008

In receiver applications, optimizing for the very best in LNA noise figure (NF) performance is a logical step for ensuring that the radio can obtain the ultimate in receiver sensitivity. To that end, designers often embark on a quest to find that perfect LNA match which yields the lowest possible NF. One must be careful, however, to assess all of the tradeoffs involved with seeking such perfection; in many situations, the better approach involves making very slight sacrifices in NF performance in exchange for matching simplicity. Understanding these tradeoffs begins with thorough assessment of an LNA's simulated noise circles.

Using Simulated Noise Circles to Assess an LNA's Sensitivity to Matching

The NF impact of an LNA's match can be observed by analyzing the *noise circles* associated with a device's de-embedded S-parameters. The simplest way to create these circles is to import the noise-specific S-parameters into a simulation tool like Keysight's ADS. (Refer to Keysight's documentation which will provide additional guidance on these specific noise simulations. The following are two good places to start: General Overview and Noise Circle command line syntax.)

Using the notation take from Keysight's *General Overview*, we see that the noise factor can be mapped using the following expression:

$$F = F_{MIN} + \frac{4r_n|\Gamma_{SRC} - \Gamma_{OPT}|^2}{(1 - |\Gamma_{SRC}|^2)|1 + \Gamma_{OPT}|^2}$$

Where $\Gamma_{OPT} = S_{OPT}$, and Γ_{SRC} = the reflection coefficient of the source. The remaining variables - r_n (the noise resistance), NF_{MIN} and S_{OPT} - are taken directly from the noisy two-port parameters that are provided as part of the de-embedded S-parameter set. Note that NF_{MIN} is defined as the minimum noise figure that the circuit can produce when the source has the optimum reflection coefficient S_{OPT}.

As NF is mapped as a function of the source impedance (as seen by the LNA), states of constant NF take the form of nearly-concentric circles on the Smith chart. Like ripples in a pond, these simulated noise circles map the degradation of NF as the source impedance moves away from the optimum center point (where the NF is the absolute lowest). Each 'ring' in the sequence of overlapping circles has a constant value, with each successive ring representing a constant, stepped increase in NF.

The example below will illustrate how these noise circles can be used to ascertain the best overall match for an LNA.

GRF2093 Noise Circle Analysis

The following analysis draws upon the de-embedded S-parameters for the GRF2093 – an ultra-low noise amplifier designed to operate within the 1GHz to 6GHz frequency range using band-specific tunes. For this example, we will be looking the ideal match for operating the device at 2332MHz (the center frequency for SDARS applications).

The plots in Figure 1 were taken directly from an ADS Noise Circle simulation. Recall from above that the NF of an LNA is at its absolute lowest value (NF_{MIN}) when the device's input is presented with its *optimal* source reflection coefficient, S_{OPT}. The source impedance for this optimal point on the Smith chart is depicted in the graphic below as m3, with a simulated $S_{OPT} = 0.326 \angle 116.594°$ and a calculated value of $Z_0 * (0.639 + j0.417)\ \Omega$. The absolute lowest achievable NF_{MIN} is an extremely low 0.142 dB.

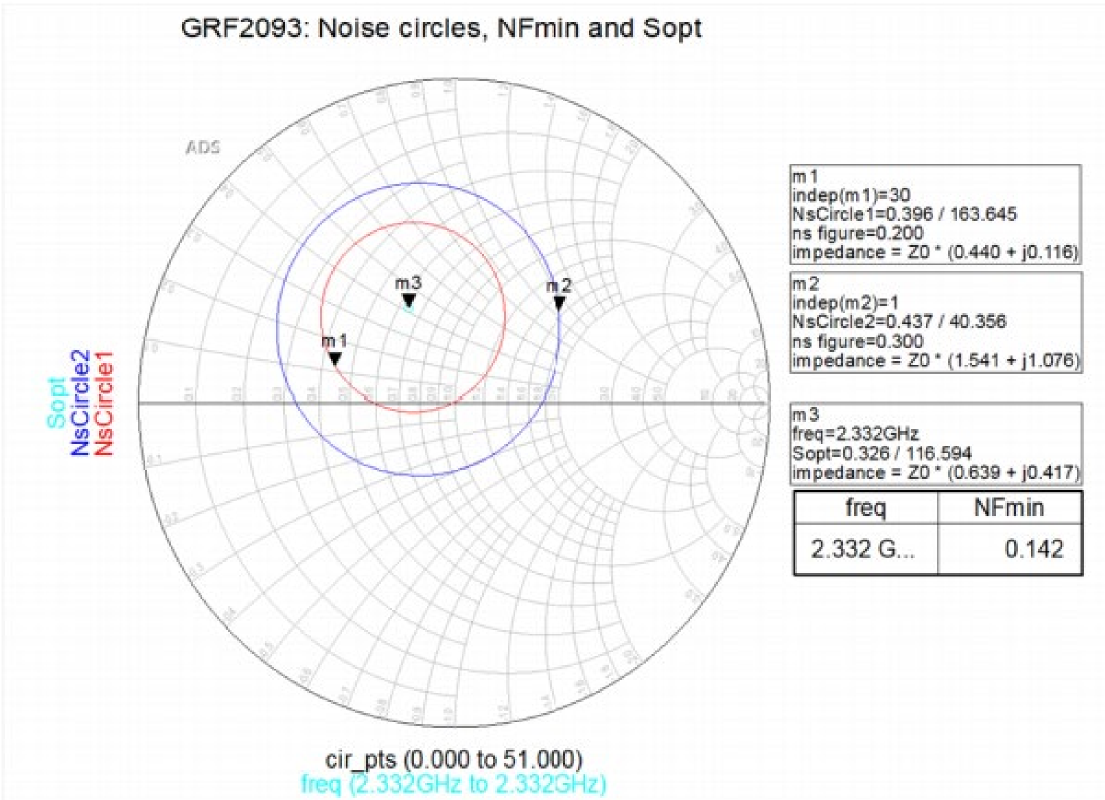

Figure 1. GRF2093 Simulated Noise Circles

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Now that we know the optimal impedance that will yield the absolute lowest NF, the next question is whether it is even worth creating a match that drives the input to the S_{OPT} point. As with most engineering decisions, it all depends upon the tradeoffs being made in the design.

One drawback to consider is the overall impact that an ideal NF match will have on *gain* and *return loss*. Note that while presenting the impedance at M3 to the input of the LNA results in the lowest possible NF, this rarely results in near-optimal S(1,1) and, for this reason, it does not result in the highest possible gain. The highest gain will occur when both S(1,1) and S(2,2) are matched with their conjugate impedances.

A second tradeoff to consider is the complexity of the match itself. Adding shunt and series components may allow us to arrive at the S_{OPT} point, but doing so may require additional board space and cost.

The critical step in making this tradeoff analysis is to *first assess the NF impact of moving away from S_{OPT}*. Refer again to the plot in Figure 1. Shown are two Noise Circles – a red circle yielding a constant NF of 0.2 dB, and a blue circle yielding 0.3 dB. As the noise circles show, the NF penalty from not being exactly at S_{OPT} is small. Notice that the 0.2 dB NF circle (red) appears to cross the 50Ω center of the Smith Chart and that the resulting NF from this 50Ω source impedance is only 0.06 dB higher than the NF_{MIN} value of 0.14 dB! *The net result is that a simple capacitor that is a low-loss RF short will result in near-optimal NF*.

But maybe you're thinking it's still worthwhile to do some additional matching. Based on the position of S_{OPT}, it appears that a shunt inductance on the input would easily translate a 50Ω source impedance to a location very close to this point of lowest possible NF. The problem is that the potential for NF improvement is only 0.06 dB, *and any improvement would be nullified by losses associated with the matching inductor.* This is why we tend to keep our application schematics simple, emphasizing low-loss in the device input match to achieve near-optimal performance at the lowest possible cost.

Summary

Here's the big takeaway: ***In the case of using modern pHEMT LNAs such as the GRF2093, matching to present S_{OPT} to the device input versus simply presenting 50Ω yields little net NF benefit.*** If you were to tune for S_{OPT}, the resistive losses associated with the extra matching components would often nullify any NF improvement. This is because the NF of an LNA application circuit strongly depends on both the device NF and the resistive losses from the input-matching network.

For the vast majority of Guerrilla RF's ultra-low noise amplifiers, *minimal high-Q matching often results in a near optimal NF implementation*. An additional bonus is that you end up with fewer external components and lower cost. The appropriate matching is often just a high-Q series DC blocking capacitor that is an RF short at the band of interest, and thus it essentially presents 50 Ω to the input of the LNA.

Regardless of your design task, the Guerrilla RF applications engineering team is ready to help. Our goal is to make your product successful.

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