Successful LNA design involves performance trade-offs

By Thomas Baker

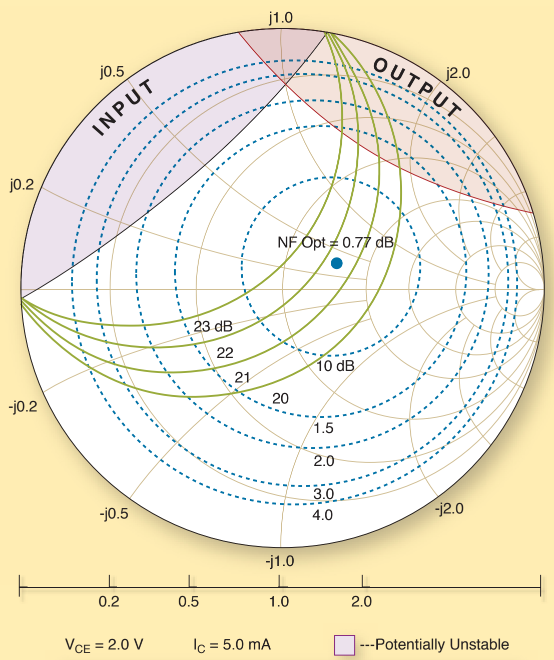
While the low noise amplifier (LNA) is a relatively simple design compared to other RF components in a cellular receiver lineup, the performance trade-offs it presents challenge the LNA application design engineer. LNA design typically involves making choices between directly competing performance parameters. Seldom do design choices afford simultaneous improvements in two or more parameters. Finding the delicate balance in satisfactorily trading off performance variables becomes the challenge more often than simply maximizing a single key parameter.

The most recognizable trade-off is between LNA gain and noise figure (NF). LNA design often begins with the use of gain and NF circles on the Smith chart to visualize the trade-off. Excursions around the Smith chart that cross gain and NF circles leads to a trade-off decision on which impedance to use. Will it be lower gain to achieve improved NF or perhaps an excellent NF with a gain sacrifice?

The optimum NF, NFmin occurs at gamma opt and where this point on the Smith chart meets the gain circles gives one possible solution for the design. But maximum gain rarely occurs at this same impedance state on the Smith chart, so the trade-off begins. To further complicate the trade-off, stability must be considered in the impedance choice. Input and output stability circles are plotted on the same Smith chart to insure that the impedance chosen does not lie in potentially unstable regions.

As an illustration, the Smith chart shown at right, includes the gain and noise circles and the input and output stability circles for 900 MHz. Gamma opt is near the center of the chart, with gain circles crossing the noise circles and the stability circles at the outsides of the chart.

Today's LNA designs also involve trade-offs in linearity and current drain. Third-order intercept point, IP3, has emerged as an important parameter in LNA design. Most of the time the easiest way to improve IP3 performance for a given frequency is to increase the current density or current draw of the LNA. Until the current density reaches relatively high levels, it will continue to improve with increasing current draw. If current draw is less important than IP3 performance, then it can be increased with the usual slight increase in gain and NF. So, in this case, IP3 improves with the trade-off in current draw and NF.



f (GHz)	NF Opt (dB)	Γ_0	Rη	K
0.9	0.77	024 < 252”	8.5	0.48

Input and output return losses, S11 and S22, are also available for trading off to achieve improved gain and NF performance. Maximizing return losses rarely yields optimum gain and NF performance. Typically, the input and output matches are designed to afford good gain and NF performance while maintaining adequate return losses for RF power transfer through the LNA. It is a balance of performance parameters.

Another trade-off is current drain and dynamic range. LNA gain must be adequate so that the noise added by elements in the receiver lineup following the LNA are minimized. Gain, however, must be traded off with linearity concerns in the elements following the LNA.

Emitter degeneration (degen) opens up an entire range of opportunities for trading off performance parameters. The addition of emitter degen can help move gamma opt closer to the complex conjugate gain match, which make the decision on trading off gain and NF easier. Added emitter degen can also bring the match required for good return losses closer to the match for better NF. Adding emitter feedback, however, trades off gain with IP3 and P1dB performance, usually evenly, so output IP3 remains constant.

Emitter degen also trades off linearity and stability, especially at higher frequencies. At the lower frequencies of the cellular bands, stability improves with emitter degen, while at frequencies greater than around 5 GHz, stability decreases as degen increases. So the trade off between linearity and stability must be examined across a full range of frequencies.

Small changes in inductance added to the emitter of a LNA can have large impacts on gain, NF and stability. As inductance increases, stability increases at the expense of gain. NF can also improve. However, continued increases in inductance can soon lead to degraded gain and NF. Simply adding tenths of nHs to the emitter can result in significant movement in the gain and noise circles.

In the LNA transistor, device size can be increased to improve linearity at the expense of current draw. Increasing current density in the LNA device can improve gain and NF, but again it is at the expense of current draw.

Typically, LNAs used in cellular applications must meet competing performance requirements, which becomes increasingly difficult as each specification moves closer to the optimum performance of each individual parameter. The art of LNA design is in exploring the variables available to delicately balance competing parameters. Being cognizant of the performance trade-offs and the variables available to the designer are the first steps in the art of successful LNA design.

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