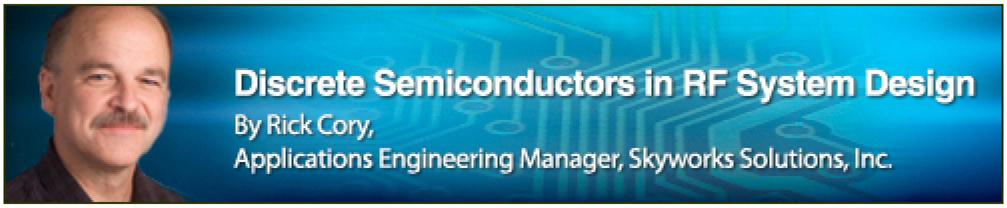


# Hearing Despite The Din:
# The Proliferation Of Low Noise Amplifiers

*By Rick Cory, Skyworks Solutions, Inc.*

In 1888, Heinrich Hertz demonstrated that Maxwell's equations correctly described that electromagnetic energy could propagate through free space. After he showed that he could produce a spark across a small gap in a loop antenna when he generated a radiated signal in equipment located at the distant end of a classroom at the Technische Hochschule in Karlsruhe, he was asked about practical uses for his findings. His response:

> "It's of no use whatsoever," he replied. "This is just an experiment that proves Maestro Maxwell was right, we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there."
>
> "So, what next?" asked one of his students.
>
> Hertz shrugged. He was a modest man, of no pretensions and, apparently, little ambition.
>
> "Nothing, I guess." (**http://www.acmi.net.au/AIC/HERTZ_BIO.html**)

Today, radio communications are interwoven into almost every facet of modern life: increasingly our telephonic communications are wireless, whether by cellular telephone networks, by ISM-band portable phones or by systems such as the Digital European Cordless Telephone (DECT); we lock and unlock our cars and our garages using wireless remote controls; automatic door openers in commercial buildings utilize Doppler sensors to detect our approach; television and radio programs are delivered via satellite links. The advent and adoption of smart energy systems — which utilize radio links to enable two-way communications between customers and suppliers and also to give consumers real-time information on their energy consumption — will increase our use of radio technology. (For more on this topic, read my **previous column**.) The popularity of mobile Internet services is growing geometrically. Man-made radio energy is increasing rapidly.

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This situation delights those who provide the communications equipment and the components they comprise. However, it also poses severe challenges to those who design these systems: how to produce a sensitive receiver that can process the desired signal in the presence of so much interference.

As inescapable as death and taxes, path loss adds to this challenge. Mother Nature mandates that signal power decreases at least as the square of distance (for the purposes of this discussion, we can ignore atmospheric absorption, multipath fading, etc. — all phenomena that the system designer cannot ignore), so most often the signal strength incident upon a receiver is tiny. We can mitigate path loss for a fixed distance in two ways: we can increase transmitted power, which is not always practical or permitted, and we can improve the receiver's sensitivity.

Radio link system designers must provide ample gain at the front end of receivers to mitigate this loss while adding the absolute minimum of locally generated noise, in order to produce signal-to-noise ratios (SNRs) sufficiently large to provide reliable communications. Mother Nature also mandates that molecular motion in all matter (including the materials in our radio receiver and transmitter), solar thermonuclear reactions, and even remnants of energy from the Big Bang all produce electrical noise that can mask these very small received signals.

Low noise amplifiers (LNAs) directly address the challenge of improved receiver sensitivity. They are typically placed as close to a receiver's antenna as possible, in order to provide significant gain while adding very little additional noise. This aspect of performance is quantified by the noise figure of the LNA, which is defined as the ratio of the SNR at the amplifier's input (when the noise level at the input is equal to kTB) to the SNR at the amplifier's output, stated in terms of decibels. No active amplifier can provide a larger SNR at its output than is present at its input, so the asymptotic goal to which circuit designers aspire is analogous to the physician's oath to do no harm: the circuit designer strives to minimize degradation in SNR. Stated another way, they wish to produce an amplifier with a noise figure of 0 dB, knowing that is impossible.

As recently as a few decades ago, LNAs with noise figures below 1 dB consisted of exotic circuit components, some of which required cryogenic cooling to produce their remarkable performance. Needless to say, such amplifiers did not come cheap: unit prices in the hundreds or even in the thousands of dollars were commonplace for such devices.

Advances in semiconductor processing, integration capabilities, and LNA circuit design have fortunately produced radical improvements in terms of LNA size, performance, and cost. Pseudomorphic high electron mobility transistor (pHEMT) semiconductor processes enable integrated circuit designers to produce LNAs with minimum noise figures approaching the theoretical limit of 0 dB at room temperature, packaged in tiny surface-mount plastic packages at prices that are orders of magnitude lower than that of their predecessors. Today, LNAs are everywhere — multiband smart phones may contain several LNAs. LNAs are in many smart energy receivers. Satellite earth station receivers require LNAs. Cellular telephone base station receivers typically contain one or more LNA stages. The radio systems in tablet computers, such as 802.11 Wi-Fi and 3G or 4G cellular telephone interfaces, also often have LNAs in their receiver front ends.

Good LNA design exists in a "Goldilocks zone" — many aspects of LNA performance must be "just right." Clearly, very low noise figure is required. Gain must be large, but not too large. Distortion must also be held to a minimum, and for LNAs intended for use in portable, battery-powered systems, operating current must be minimized. All of these performance aspects are interactive with each other. Lower noise figure and lower distortion may often be accomplished at the expense of greater power supply current. The source impedance that produces optimal gain is rarely the same as that which produces minimum noise figure. The LNA designer must be a master of the art of evaluating and making trade-offs.

One such trade-off that the designer can exercise is LNA circuit topology. An LNA can be a single stage, which is relatively simple to design but not terribly easy to tune: Its reverse isolation is finite, so efforts to tune the output circuit affect the conditions at the input of the device, which can interfere with optimal noise figure impedance matching.

An LNA can also comprise multiple transistors. For example, the cascode circuit topology offers some benefit over the single-stage approach, due to its higher reverse isolation. This benefit comes at the cost of larger amplifier die size, slightly more complicated die-level circuit design, and possibly higher distortion.

While LNA die circuit designers might appear to play the role of Sisyphus in the electronics community, they are exercising all their options to approach the unattainable goal of 0 dB noise figure.

Hertz was a true visionary in the branch of applied physics we know as electronics, but fortunately he could not have been more wrong about what was to come next.

For more information, please visit **www.skyworksinc.com**.

## About the Author

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