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GPS LNA Design Made Easy with Enhancement Mode pHEMT MMICs

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New MMIC processes have created solutions for LNAs that approach the noise performance of discrete designs, but with the low parts count, stability, simple biasing and repeatable performance of a MMIC

Many of today's GPS receiver LNA designs are based on discrete transistors rather than MMICs, primarily because designs using discrete transistors result in amplifiers with lower noise figure (NF). However, for today's portable applications, where compact circuits and extremely quick time-to-market are both requirements, circuits with discrete transistors may no longer be the best design choices. While it is true that discrete designs still offer the best NF performance, new MMICs provide noise performance approaching discrete designs, while offering the benefits of integration, such as:

- Unconditional stability across a very wide frequency range.
- Integrated current mirror that simplifies the biasing network design.
- Internal feedback for easier impedance matching across a wider bandwidth.
- Consistent high linearity and low noise.

These benefits translate into a compact circuit with a lower component count and a shorter design cycle compared to the conventional discrete approach. Figure 1 shows a schematic comparison between a typical discrete solution and a MMIC solution—specifically one using an enhancement-mode pseudomorphic high electron mobility transistor (E-pHEMT) MMIC, which offers the additional benefit of requiring only one positive-polarity voltage supply for operation.

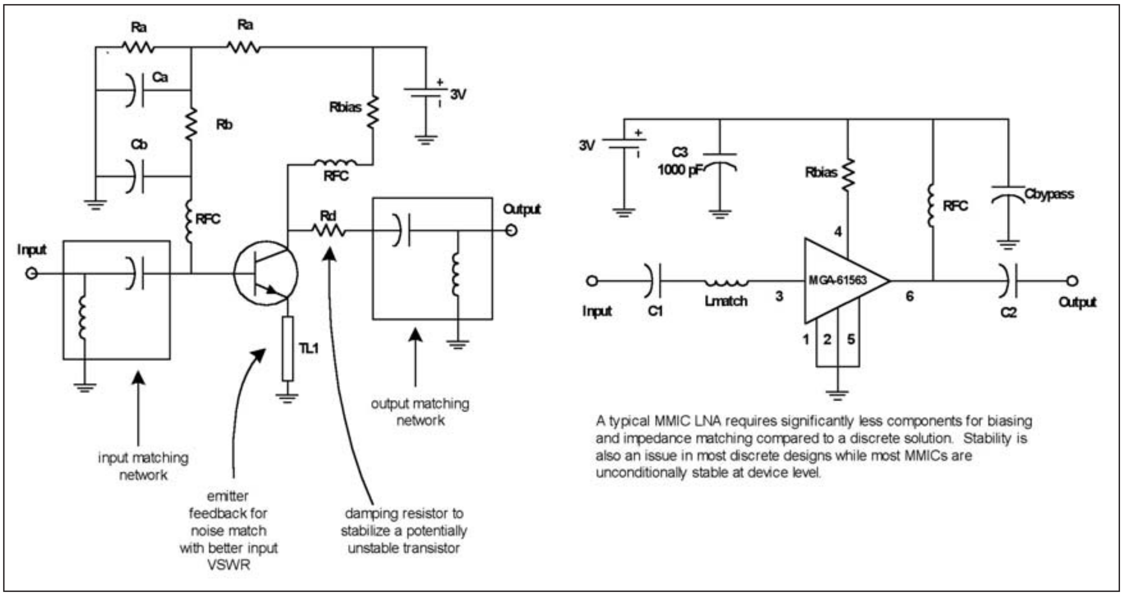

Figure 1 · Comparing a typical discrete LNA (left) and a MMIC LNA (right).

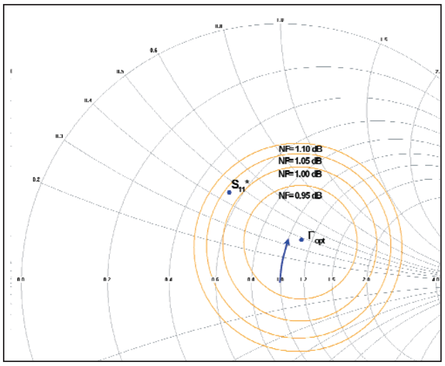

Figure 2 · Positions of S_{11}*, Γ_{opt} and noise circles at 1.575 GHz.

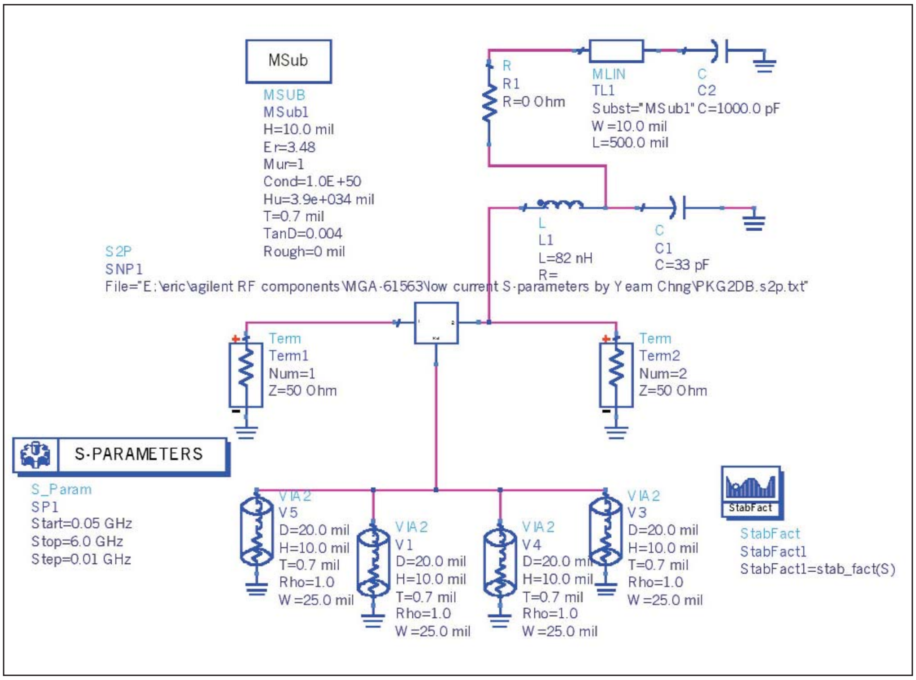

Figure 3 · A simple and quick simulation to predict amplifier performance and validate assumptions used for selecting the MMIC device.

This article demonstrates the specific benefits of using the MMIC approach in a GPS LNA design. The author has chosen the Agilent MGA-61563 E-pHEMT MMIC for this design. First, the S-parameters of the device at low current are analyzed, and unconditional stability is demonstrated. The ease of matching the input for best noise performance while maintaining good input and output VSWR is demonstrated. Due to varying requirements for return loss, noise figure and gain, the author also discusses and demonstrates matching options for the best possible input and output return loss (i.e., conjugate matching), and for compromising the NF for better input return loss. Finally, possible ways of putting such a MMIC-based GPS LNA under software control are also briefly discussed.

Choosing an Active Device

Selecting an LNA device is the first and the most crucial step in designing an LNA once the major performance requirements like NF, gain, return loss and IIP3 (third-order input intercept point) are known. Although device performance parameters are available in a typical device data sheet, very often they are specified at a frequency that is different from the LNA design target so that an accurate set of device S- and noise parameters will be desirable in predicting the final LNA noise figure, gain, return loss and stability. The design target for this GPS LNA was NF <1.1 dB, gain >13.0 dB and current consumption of less than 10 mA from a +3 V supply. Keeping in mind that an LNA with a minimal number of components is also an important requirement, a MMIC with low F_{min} and with S_{22} close to the center of the Smith chart should be considered.

The noise parameters of the MGA-61563 at 10 mA indicate an F_{min} of 0.91 dB at 1.5 GHz. Ignoring the input return loss of the amplifier and considering the losses of the PCB input trace and input matching network, the final amplifier NF should be less than 1.1 dB if the input matching of the LNA is tuned for minimum NF. Besides the $|\Gamma_{opt}|$ at 1.575 GHz of the device being quite close to the center of the Smith chart, the S_{22} at this frequency also shows a low reflection of $|S_{22}|$ = 0.175. This indicates that the output of the final amplifier, having its input tuned for minimum NF, is likely to have an acceptable VSWR either with or without minimal impedance matching. A quick graphical analysis based on the constant NF circles derived from the MGA-61563 noise parameters at 1.575 GHz is shown in the Smith chart of Figure 2. It can be seen that a series inductor at the device input can bring the source impedance sufficiently close to the Γ_{opt} point on the Smith chart.

The S-parameters of the MGA-61563 are then put into Agilent's ADS (Advanced Design System) to perform a simulated check for stability. Here, it is important to consider the effects of PCB vias on the stability of the amplifier. It should be noted that the published S-parameters of devices in datasheets were measured in specialized fixtures that do not take into account the effects of vias on the final LNA PCB. Therefore, even though the device S-parameters show unconditional stability, the stability of the device on the actual PCB with vias may or may not show unconditional stability. Both simulations and measured results indicate that the device is unconditionally stable across a wide frequency range. This makes the resistive damping needed for stability in discrete designs unnecessary in this case, which, in turn, helps to reduce the number of components in the final LNA circuit.

A Simple Simulation to Predict Amplifier Performance

In order to minimize the amplifier NF, the input matching circuit should be tuned to present Γ_{opt} to the input of the MGA-61563. Figure 2 shows the position of Γ_{opt} (0.185∠63.67°) and S_{11}^* at 1.575 GHz on the Smith chart. Figure 3 shows a simulation that can be quickly set up to predict what sort of gain and return loss the final LNA would display when its input is tuned to Γ_{opt}. L2 and C3 in Figure 3 transform the 50 ohm port impedance to a point close to Γ_{opt}.

Note that the purpose of simulating the circuit in Figure 3 is merely to predict the gain and return loss of the LNA and to quickly verify that the device selection makes sense. As such, no board traces and component parasitics need to be considered in the simulation. The LNA is capable of delivering more than 15 dB of gain with good output return loss. This helps to validate the earlier assumption that the low $|S_{22}|$ and $|\Gamma_{opt}|$ helps to maintain a low output return loss and that the amplifier can meet the gain requirement.

Matching Amplifier Input for Minimum Noise

Figure 4 shows a schematic of an LNA using the MGA-61563. R1, which is the resistor connected to the current mirror transistor internal to the MGA-61563, is used to set the device current. For GPS receiver amplifier applications, R1 is selected to be 5.1 kohm to reduce the device current to about 9 mA, which is adequately low for most handheld receiver applications.

It is clear from the Smith chart of Figure 2 that an inductor is sufficient to transform the 50 ohm port impedance to a point close to Γ_{opt}. However, in real circuits with practical inductors, the effects of the microstrip line that connects the inductor and the input pin of the device need to be considered when designing the input matching network. A simple board layout is made and the position of L1 on the board can be varied along a parallel microstrip.

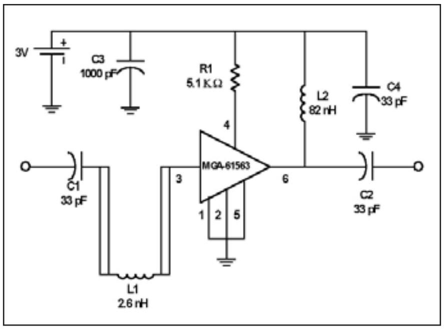

Figure 4 · Schematic of a GPS LNA using the MGA-61563.

The position of L1 affects the source impedance and the effect of the parallel microstrip can be used to tune the source impedance closer to Γ_{opt}. As the position of L1 is varied from the input pin of the MGA-61563 to the other end of the parallel microstrips, the source impedance presented to the input varies from point A to point B on the Smith chart (Figure 5). Since point B is close to the Γ_{opt} of the MGA-61563 at 1.575 GHz, L1 should be placed right at the end of the parallel microstrip lines.

Measured Performance of The Minimum NF Amplifier

As shown in Figures 6 and 7, the completed GPS LNA gives about 15 dB of gain at 1.575 GHz. Measured NF is about 1.07 dB with 8 to 9 dB input return loss. Output return loss of better than 12 dB can be expected from this LNA. Note that input is tuned for the lowest possible noise figure with minimal component count for matching. Measured IIP3 (third-order input intercept point) is around –3 dBm.

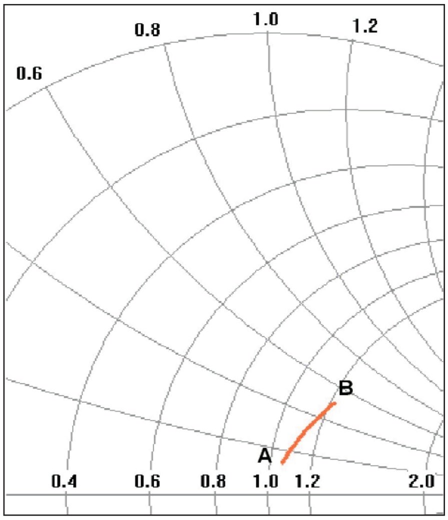

Figure 5 · As L1 is moved away from the MGA-61563 input pin towards the other edge of the parallel microstrips, the source impedance moves from point A to point B.

Matching for Best Possible Gain

As shown in Figure 2, the Γ_{opt} and S_{11}^* are located quite far apart on the Smith chart indicating that the amplifier tuned for the best NF will not have an optimized input return loss. In applications where the amplifier NF is not the most important parameter, a simultaneous conjugate match can be attempted to extract the maximum possible gain out of the MGA-61563, while at the same time providing good input and output return loss.

Simulations using the device S-parameters shows that a shunt inductor of 5.1 nH at the output and a shunt inductor of 3.9 nH at the input will result in matching that is very close to a simultaneous conjugate match. With a conjugate matched LNA, the amplifier measured better than 15 dB return loss at both ports and with a gain of about 16.4 dB. However, the NF increased to about 1.45 dB under these conditions. The Γ_{in}^* at the input of the MGA-61563 with a 5.1 nH output shunt inductor is simulated to be 0.576∠127°. The relative locations of Γ_{opt}, S_{11}^* and Γ_{in}^* on a Smith chart

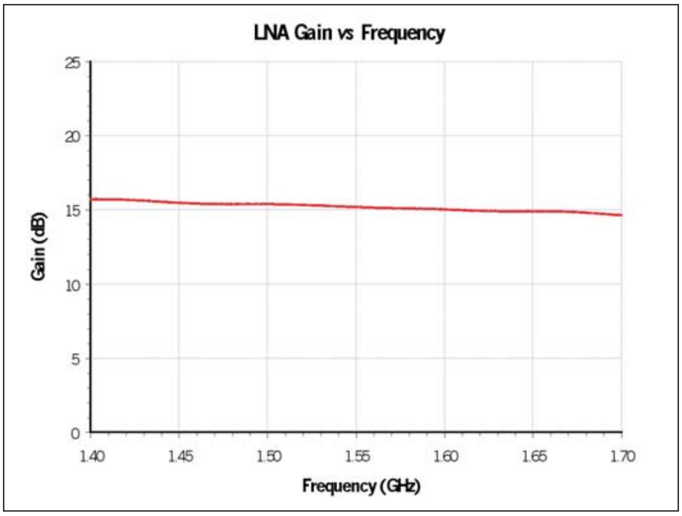

Figure 6 · Measured gain of the MGA-61563 amplifier, with matching optimized for minimum NF.

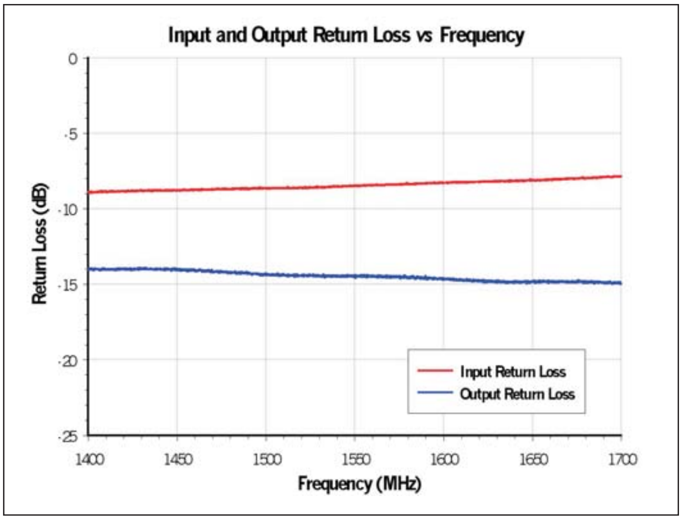

Figure 7 · Measured input return loss and output return loss of the MGA-61563 LNA.

make it clear that the source impedance required for a conjugate match ($\Gamma_s = \Gamma_{in}^*$) is located even further away from Γ_{opt} and thus the resulting NF has now significantly worsened.

The measured gain of this amplifier is about 16 dB and the output return loss is better than 20 dB. As expected, the NF has now degraded to about 1.18 dB, but the input return loss has improved to 11.8 dB.

Striking a Balance Between NF and Gain

Selecting a source impedance point that lies between either Γ_{in}^* or S_{11}^* and Γ_{opt} represents another option available in designing this GPS LNA. Although most amplifiers are not unilateral, the location of S_{11}^* can be approximated to the amplifier input impedance, at least in terms of guiding designers toward better input return loss. It is likely that a source impedance point on the Smith chart that can give a better input return loss (as compared to the minimum NF design) with slightly poorer NF should lie outside the 50 ohm constant-resistance circle. Without resorting to advanced simulators like ADS, it is clear that a shunt inductor should be used at the input to transform the 50 ohm port impedance to a value closer to S_{11}^*. This shunt inductor, Ls connected at the input, is empirically determined to be about 5 nH. A 10 nH shunt inductor is used for L2 to replace the 82 nH RFC.

Implementing Shutdown Control

In portable applications where battery power must be conserved, it is desirable that the receiver LNA can be shutdown and switched on under software control. A P-channel enhancement mode MOSFET connected between the bias source and the junction of C4, R1, L2 and C4 in Figure 4 allows the MMIC to be placed under software control allowing it to be shutdown and turned on via a microcontroller output port. Since P-channel MOSFETs are available with low $R_{DS(on)}$ (<0.5 ohm), the voltage drop across these MOSFETs is negligible and introducing such a switch will not make a significant change to the biasing of the MMIC.

Conclusion

Designing a high performance, low noise figure GPS LNA can be made simple by using a MMIC. Advanced semiconductor processes, like Agilent's enhancement mode pHEMT, produce MMICs that are capable of running from a low voltage supply, consume low current, exhibit low NF and have high linearity. Since most MMICs have internal biasing circuitry and feedback, impedance matching is made easier and the resulting amplifier has a significantly smaller number of components, making it suitable for today's popular portable applications.

Acknowledgements

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About the Author

Eric Chan is a practicing engineer with 12 years of design experience mainly in RF circuits and RF systems. He received a Computer and Communication Engineering degree and M.Sc. Solid State Physics from the University of Science Malaysia. He has worked on RF circuits for CT2 systems, two-way portable radios and development of DSP hardware and algorithms.