GPS low-noise amplifier design made easy with MMIC

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Many GPS receiver low-noise amplifier (LNA) designs are based on discrete solutions. LNA designers prefer this solution over a monolithic microwave IC (MMIC)-based approach because discrete solutions using transistors result in amplifiers with lower noise figures (NFs). However, discrete solutions have their own disadvantages, especially in modern portable applications with compact circuitry and quick time-to-market requirements. While it is true that discrete designs offer the best NF performance, new MMICs give comparable noise performance and benefits such as:

- High linearity and low noise;
- Integrated current mirror, simplifying the biasing network design;
- Internal feedback, making impedance matching easier across a wider bandwidth;
- Unconditional stability across a wide frequency range;
- Enhancement-mode FET requires only a single positive supply.

These benefits translate into a compact circuit with a smaller component count and shorter design cycle compared to the discrete approach. **Figure 1** shows a schematic comparison between a typical discrete solution and an MMIC solution. The MMIC yields a more compact solution that is suitable for portable applications with space constraints.

Choosing an active device

Selecting an LNA device will be the first and most crucial step in designing an LNA after major performance requirements such as NF, gain, return loss and IIP3 are determined. Although these performance parameters are available in a typical datasheet, they are often specified at a frequency that is different from that of the LNA design target. As such, an accurate set of device S and noise parameters will be needed to predict the final LNA NF, gain, return loss and stability. The design target for this GPS LNA was NF < 1.1dB, gain > 13dB and to draw less than 10mA from a 3V supply. Keeping in mind that an LNA with a minimal number of components is also an important requirement, an MMIC with low F_{min} and with S_{ss} close to the center of the Smith Chart should be considered.

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

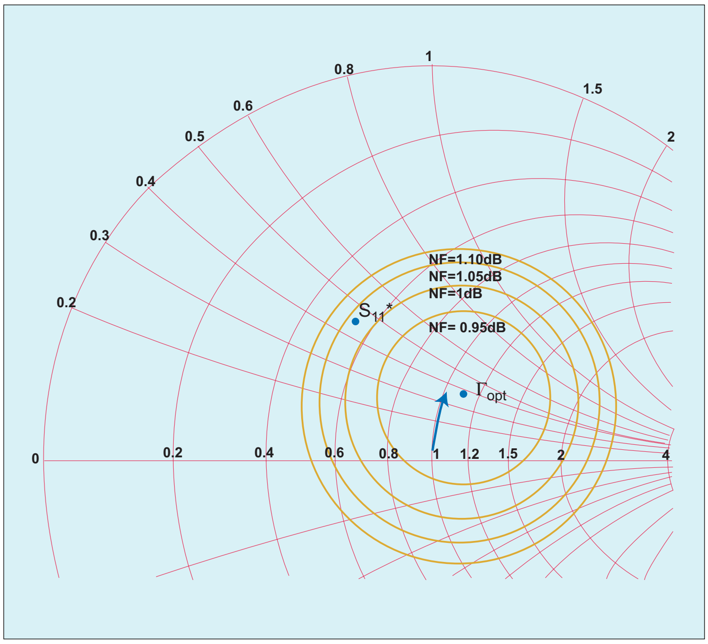

Figure 2: Inductor transforms the 50Ω port impedance to a point close to Γ_{opt}.

The S-parameters of the MGA-61563 are then put into Agilent 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 the datasheet were measured in specialized fixtures that did not consider the effects of vias on the final LNA PCB. Therefore, even if the device S-parameters show unconditional stability, the stability of the device on the actual LNA PCB with vias may or may not show unconditional stability. Resistive damping needed for stability in discrete designs is unnecessary in this case, which in turn helps reduce the number of components in the final LNA.

Predicting performance

To minimize the amplifier NF, the input-matching circuit should be tuned to present Γ_{opt} to the input of the MGA-61563.

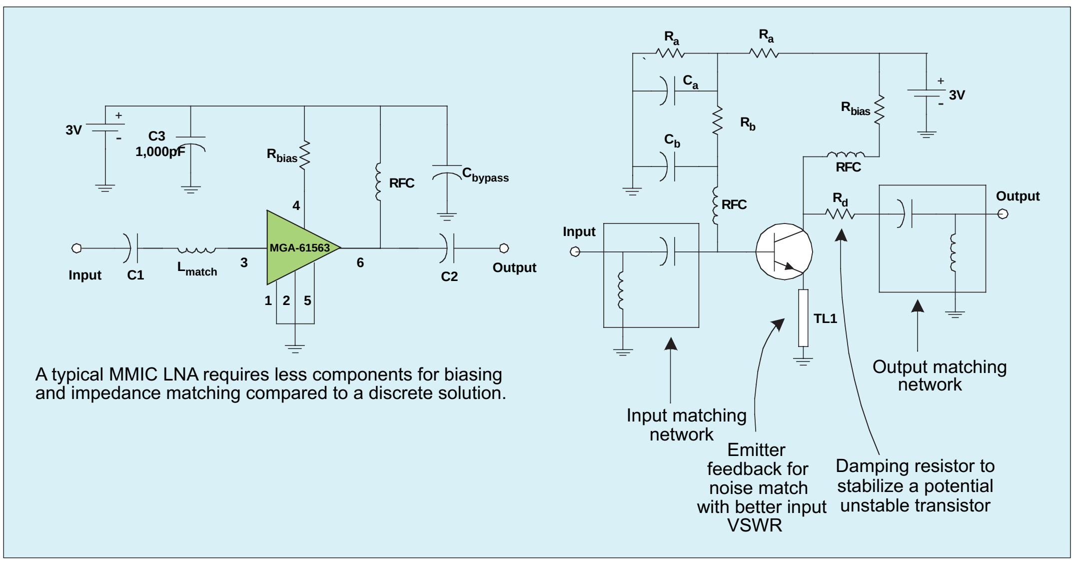

Figure 1: MMIC solution yields a more compact solution that is suitable for applications with space constraints.

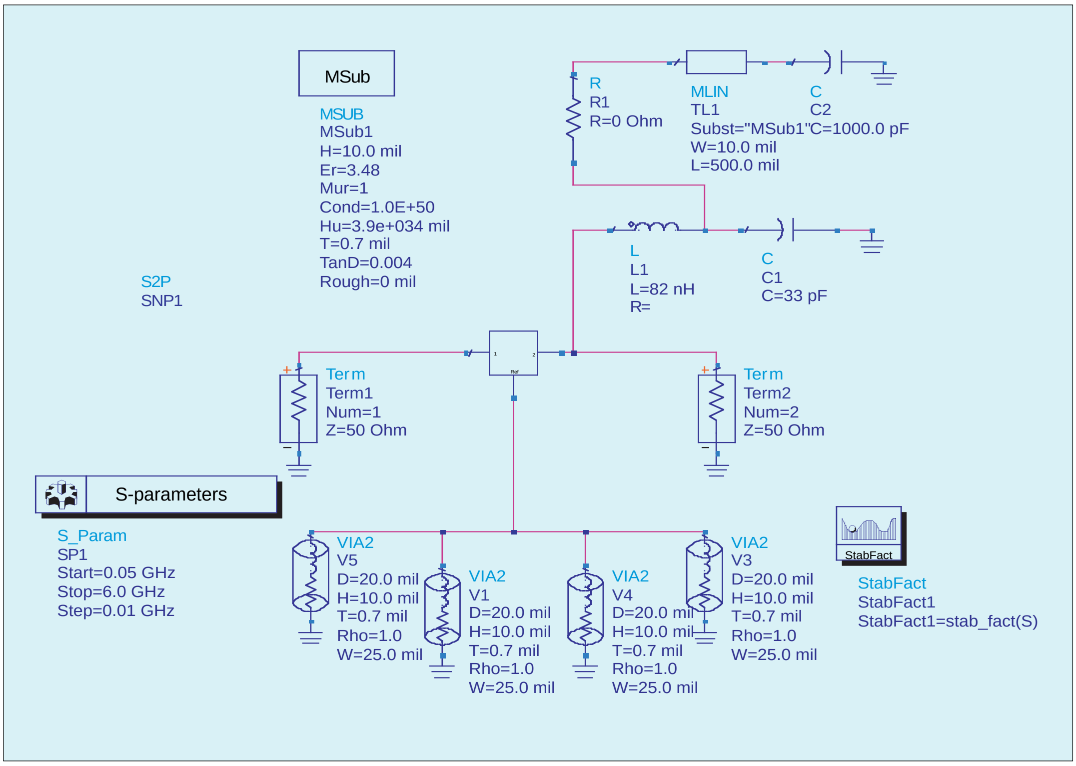

Figure 3: L2 and C3 transform the 50Ω port impedance to a point close to Γ_{opt}.

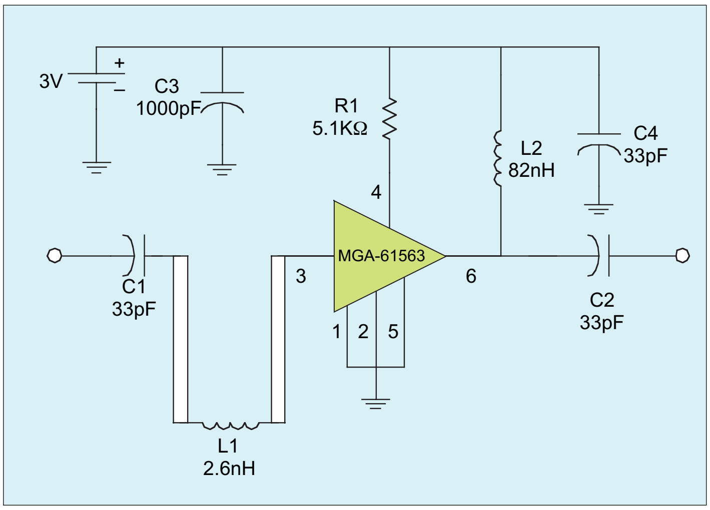

Figure 4: R1, the resistor connected to the current mirror transistor internal to the MGA-61563, is used to set the device current.

Figure 2 shows the position of Γ_{opt} (0.185-63.67°) and S_{11}* at 1.575GHz on the Smith Chart. **Figure 3** shows a simulation that can be quickly set up to predict what would be the sort of gain and return loss of the final LNA when input is tuned to Γ_{opt}. L2 and C3 transform the 50Ω port impedance to a point close to Γ_{opt}.

The purpose of simulating the circuit 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.

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

It is clear from **Figure 2** that an inductor is sufficient to transform the 50Ω 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 input pin of the device need to be considered in 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. 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}.

The completed GPS LNA gives about 15dB of gain at 1.575GHz. Measured NF is about 1.07dB with 8-9dB of input return loss. Output return loss of better than 12dB can be expected from this LNA. Note that this LNA input is tuned for the lowest possible NF with minimal component count for matching. IIP3 is measured to be about -3dBm.

As shown in **Figure 2**, the G_{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 a very good 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 and, at the same time, give good input and output return loss.

Simulations using device S-parameters show that a shunt inductor of 5.1nH at the output and a shunt inductor of 3.9nH at the input will result in matching that is very close to a simultaneous conjugate match. The amplifier measured better than 15dB return loss at both ports and with a gain of about 16.4dB. However, the NF has now increased to about 1.45dB. The Γ_{in}* at the input of the MGA-61563 with a 5.1nH output shunt inductor is simulated to be 0.576∠127°.

Striking a balance

Selecting a source impedance point that lies between either Γ_{in}* or S_{11}* and Γ_{opt} represents another option available in designing a GPS LNA. Although most amplifiers are not unila-

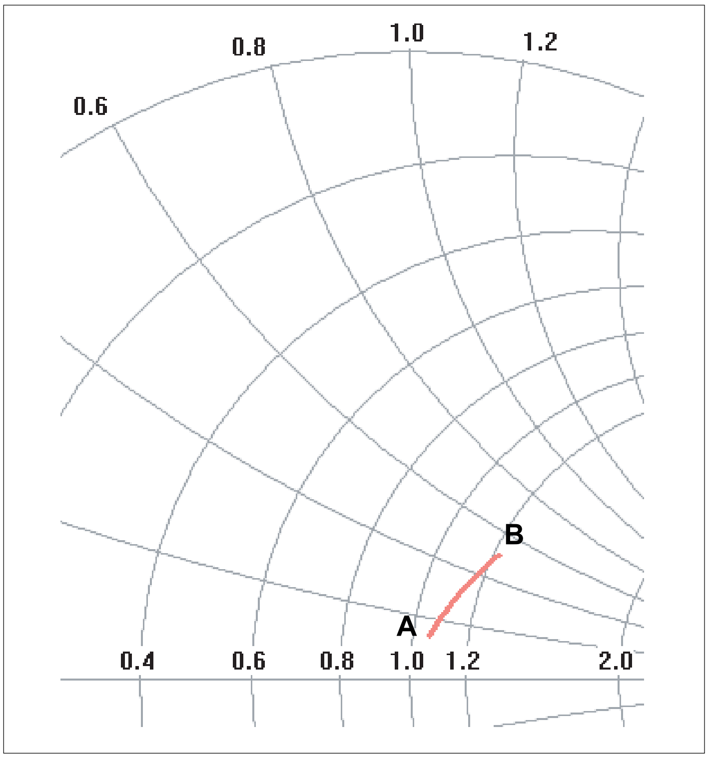

Figure 5: As L1 moves away from the input pin to the other edge of the parallel microstrip, the source impedance moves from point A to point B.

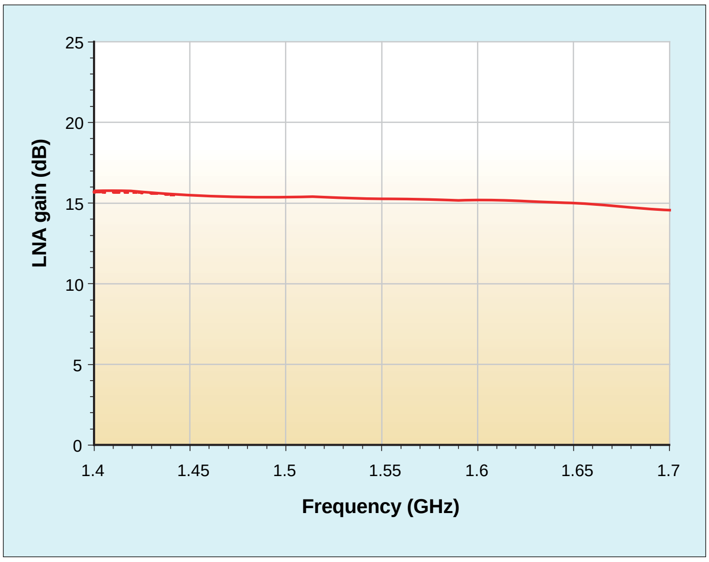

Figure 6: The completed GPS LNA gives about 15dB of gain at 1.575GHz.

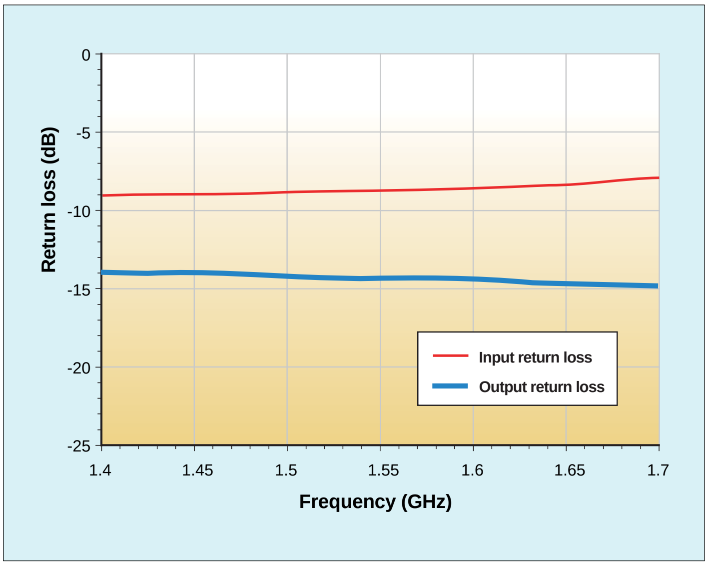

Figure 7: Measured NF is about 1.07dB with 8-9dB of input return loss. Output return loss of better than 12dB can be expected from this LNA.

teral, the location of S_{11}^* can be approximated to the amplifier input impedance, at least in terms of guiding designers toward a better input return loss. It is likely that a source impedance point on the Smith Chart that can give a better input return loss (compared to the minimum NF design) with slightly poorer NF should lie outside the 50Ω constant-resistance circle. Without resorting to advanced simulators like the ADS, it is clear that a shunt inductor should be used at the input to transform the 50Ω port impedance to somewhere closer to S_{11}^*. This shunt inductor, L_s, connected at the input is empirically determined to be about 5nH. A 10nH shunt inductor is used for L2 to replace the 82nH RF choke.

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

Designing a high-performance, low-NF GPS LNA can be done using an MMIC. Advanced semiconductor processes like Agilent's enhancement-mode pHEMT produces MMICs that can run on low-voltage supply, consume low current and exhibit low NF and high linearity. Since most MMICs have internal biasing circuitry and feedback, impedance matching on these devices is made easier and the resulting amplifier has less components, making it suitable for portable applications. □