

Design and Development of a Low-Noise Amplifier Using Measured Models of Transistors

Simulation is more accurate with real-world models

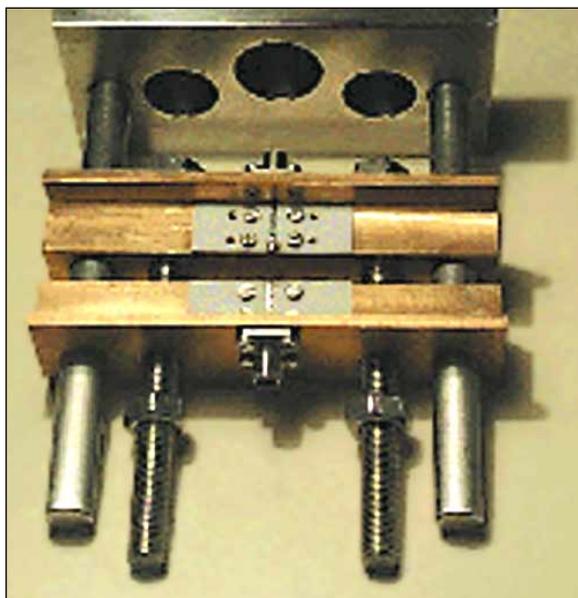
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This article discusses the design and development of a low noise amplifier at the frequency range of 9.9 to 10.1 GHz. The gain of the amplifier is fixed at 31 dB, and the input and output return losses are very low. In addition, we focus on the thermal compensation of the main characteristics of the LNA such as gain, noise figure and power consumption. The dynamic range is quite high and the gain ripple very low. For the design of the LNA, we used data files for the transistors which were created through measurements that were realized using a microstrip test fixture. The test fixture was manufactured in our laboratory.

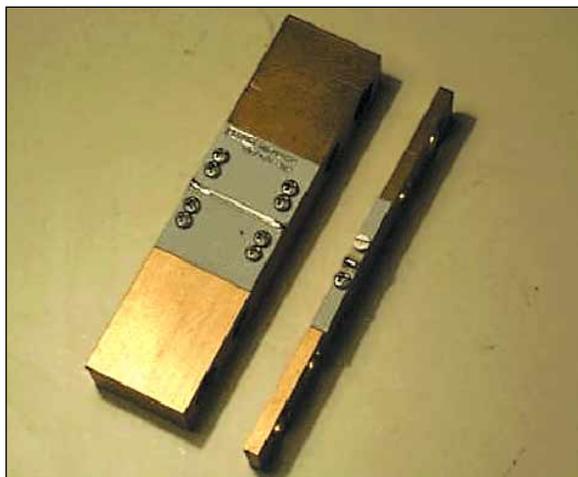
The amplifier is designed through the use of commercially available CAD. Often, although the results of the simulation are very satisfactory and meet the specifications that we have defined, the behavior of the manufactured circuit is not very good. The gain, input and output return losses are quite different from what is expected. After many designs and re-designs of different circuits (mainly amplifiers) we are convinced that these problems are caused by the imperfections of the transistors' models. In order to avoid the described problems we have created our own models (*S*-parameter files) for the transistor that we use.

TRL calibration and measurements

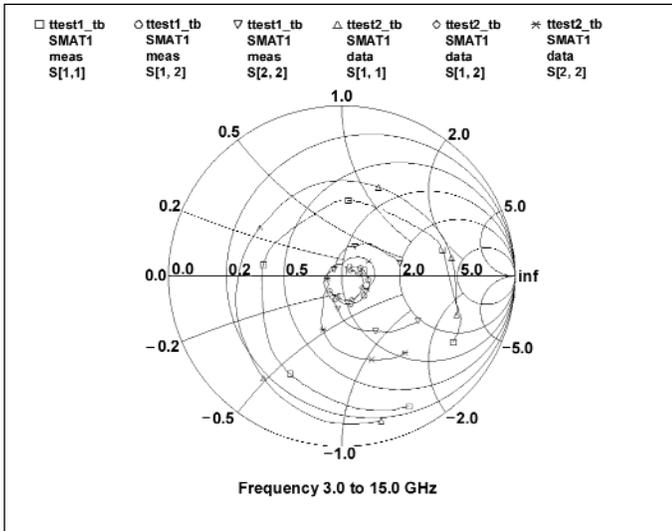
A major problem encountered when making network measurements in microstrip or other non-coaxial media is the need to separate the effects of the transmission medium in which the device is embedded for testing from the device characteristics. Although it is desired to predict how a device will behave in the environment of its final application, it is difficult to measure



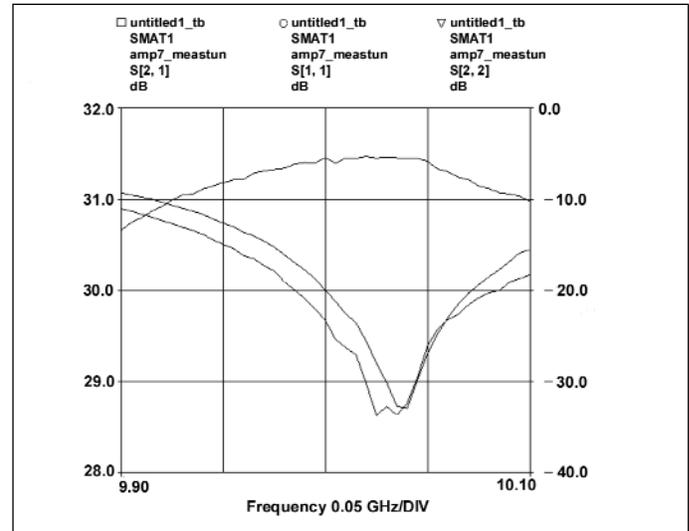
▲ Figure 1. Microstrip test fixture.



▲ Figure 2. Microstrip line test standards.



▲ Figure 3. Measured and given S-parameters of an FET.



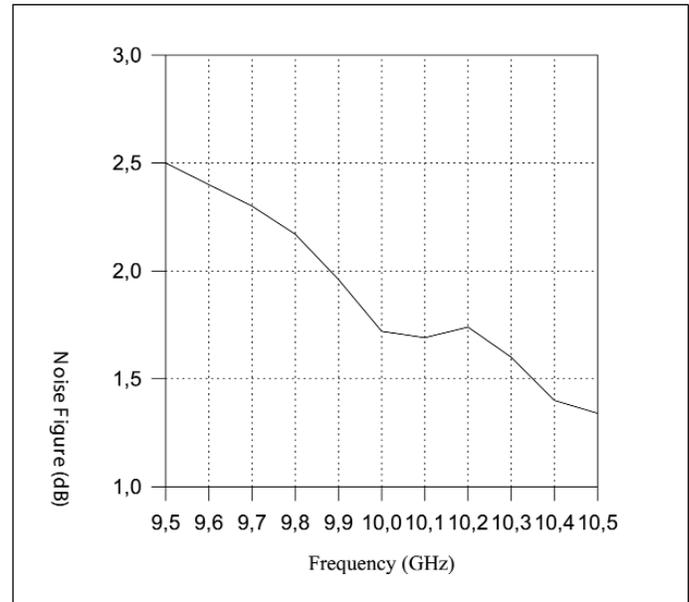
▲ Figure 4. S-parameter response of the LNA.

this way, because the accuracy of this measurement depends on the availability of quality calibration standards. Unlike coaxial measurements, a set of three distinct, well-characterized impedance standards is often impossible to produce for non-coaxial transmission media. For this reason, an alternative calibration approach may be useful for such applications.

The Thru-Reflect-Line (TRL) calibration technique relies only on the characteristic impedance of a short transmission line. From two sets of 2-port measurements that differ by this short length of transmission line and two reflection measurements, the full 12-term error model can be determined. The microstrip test fixture used to realize the calibration and the measurements is shown in Figure 1. The test fixture offers a repeatable connection to the device, which insures consistent results and a predictable transition between calibration and measurement. The two halves of the fixture are separated to easily accommodate the calibration reference standards.

The TRL calibration process contains three basic measurement steps using through, reflect and line standards to derive the complete error model. The through measurement is used to set the zero phase reference plane. To perform this measurement, the end block launch circuit must be bonded together. Next, a reflect measurement is made. High reflection, along with through information, are used to define the frequency response terms and source and load match terms of the error model. The most simple reflect is an open circuit and is achieved by separating the fixture halves. Finally, the line measurement is used to set the reference characteristic impedance of the system.

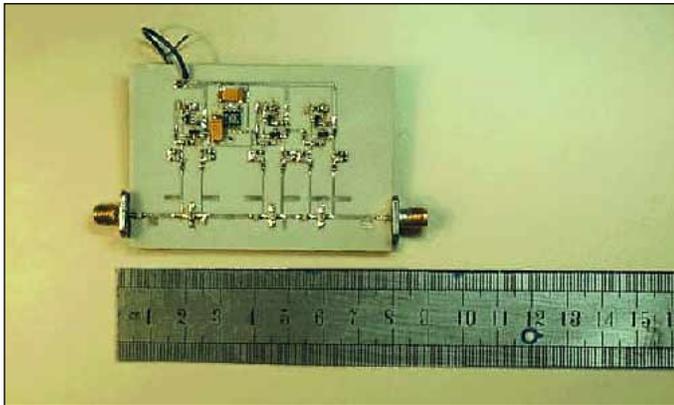
The line standard is a short microstrip line inserted between the fixture halves. To ensure independence between the equations derived during the through and



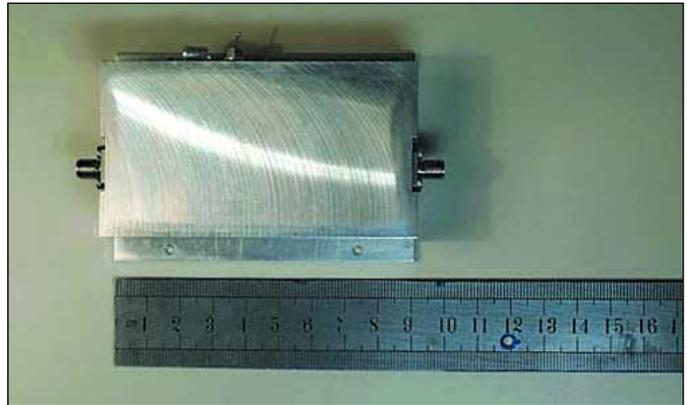
▲ Figure 5. Noise figure response of the LNA.

Gain	31 dB \pm 0.4 dB
Frequency range	9.9 to 10.1 GHz
Input return losses	<11 dB
Output return losses	<10 dB
Noise figure	<1.9 dB
Output 1 dB compression	+14.5 dBm
Bias current	70 mA
Bias voltage	+5 volts
Maximum input RF power	+13 dBm
RF connectors	SMA 3.5 mm
EMI/EMC protection	>80 dB

▲ Table 1. Specifications of the LNA.



▲ Figure 6. The printed circuit of the LNA.



▲ Figure 7. Photograph of the LNA.

line steps, S_{21} and S_{12} from through and line steps must always be distinct. If at some frequency the phase of the line reaches 180 degrees, or any other integer multiple of pi with respect to the through standard, insufficient independent equations may exist to compute the error model. To prevent this condition, a phase margin of 20 degrees is kept. The use of lines of different lengths is often indispensable.

The measurements of the transistors are performed with the same test fixture. The measured and the given from data files S -parameters of an FET, for the same DC bias point are shown in Figure 3. We can easily recognize the differences between the two sets.

Low noise amplifier

The amplifier is housed in an EMI/EMC shielded aluminum box with SMA female connectors and feedthrough. Low cost substrate material R4003 from Rogers Corporation has been used for its fabrication. It is essential that active bias circuitry is used in order to compensate for the gain, power consumption and noise figure variations versus temperature. The power supply is a single positive configuration with an input voltage of +5 volts.

Because of the precise modeling of the transistors, the careful simulation, and the accuracy of the fabrication of the printed circuit, the measured results met the simulated results moving one stub that is part of the matching circuitry by only 1 mm. The specifications of the amplifier are shown in Table 1.

The S -parameter response of this amplifier is shown in Figure 4. The vector network analyzer HP-8719D was used. The nominal temperature is 25 degrees Celsius.

The noise figure of the amplifier was measured using the HP-8970B noise figure meter. Figure 5 shows the

response for the nominal temperature. The noise figure is less than 2 dB within the frequency range of interest.

Since the LNA must have a high dynamic range behavior, the power gain compression at 1 dB is critical. As a result, swept power measurements were performed using the HP EPM-441A power meter. The output power 1 dB compression point is +14.5 dBm over the whole frequency range from 9.5 to 10.5 GHz.

The amplifier out of its box is shown in Figure 6. Figure 7 shows the same amplifier housed inside the aluminum box.

Summary

In this article, the design of a low noise amplifier was presented. The amplifier has the following unique features: low noise figure, low gain ripple, thermally compensated design, low return losses, low cost and single positive configuration using active bias technique.

For the simulation, we used transistor models that we created using a “homemade” microstrip test fixture. As a result, no re-design was necessary, saving us time and money. The amplifier can be delivered quickly (less than two months) for small quantity orders. Custom specifications can be realized on request. ■

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