The Microwave Low Noise Amplifier—*Part 1*

Quite often we employ RF amplification prior to the first mixer in our receivers. In situations where the sensitivity of the receiver system is low, and especially where there is loss before the mixer, it is helpful to preamplify signals. There are also situations where preamplification does not help, or is not worth the cost. In two parts we will explore these situations and the workings of the preamplifier itself. Today we will explore the circuits and construction of low noise amplifiers. The next issue will continue with an understanding of noise and what improvements to expect when applying an LNA.

Over the course of the past few decades, technology advances have improved our ability to amplify low-level signals at high frequencies without introducing lots of noise. Packaged LNAs for all amateur bands through 24 GHz are now readily available. These advances have both increased the frequency of operation and reduced the noise contribution to the point where we have very effective low noise amplifiers (or LNAs) for frequencies up to and above 100 GHz. The Amateur Radio 10 GHz unit pictured in Figure 1 is from DB6NT, and sold in the US through SSB Electronic.

SSB ELECTRONIC USA

Figure 1—Here is a modern packaged high performance LNA for the 10 GHz band.

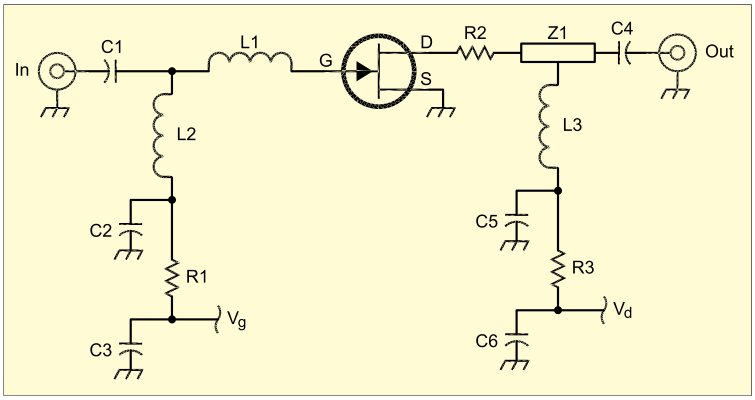

Figure 2—Schematic of a microwave PHEMT LNA.

How are they Made?

The modern LNA employs field effect transistors. These semiconductor devices have several very impressive performance characteristics that make them nearly ideal for use in VHF and above LNAs. When properly biased, the FET can have gain of over 10 dB, noise figures below 1 dB (noise figure will be explained in the next installment of this column) and dissipate very little power. There are two types in common use, the GaAs FET (gallium arsenide FET) and the PHEMT (pseudomorphic high electron mobility transistor). The former is best for application in circuits running below about 1.5 GHz, and the latter is much more suitable for circuits running above about 1 GHz.

The circuit components that surround the FET in a modern microwave LNA provide bias, filter the power, control (reduce) low frequency gain, and match impedances. Several circuit design approaches have been taken to provide these functions. Some of them have advantages such as bandwidth control, improved stability, and ease of construction or tuning. Because of the common application of the PHEMT for frequencies above 1 GHz, we will examine circuits that are appropriate for this type of LNA.

In Figure 2, the schematic shows the elements of a modern microwave PHEMT LNA, suitable for a part such as the Agilent ATF36077. This basic design is useful from about 1296 MHz through 24 GHz, although the actual implementation of the circuit will change above 10 GHz. Figure 3 shows a particular LNA design that can be used with minimal modification from 2 GHz through 5 GHz.

Amateur Radio LNAs are almost always fabricated on two-sided printed circuit board, where the bottom of the board is a ground plane, and the circuits on top form controlled impedance using microstrip. Care must be taken with lead lengths at any VHF and higher frequency. This is especially true when making the source connections to the FETs used in LNAs. Just the smallest amount of inductance can change impedances and cause instability resulting in oscillations.

The Circuit

Let's examine the different sections of the circuit and the implementation. At frequencies below 1 GHz, self-biasing techniques that electrically lift the source from ground work well, but at higher frequencies they are not stable. Therefore, our circuit will have a very well grounded source, in terms of both dc and RF. Bias will have to be supplied with a negative dc voltage applied to the gate.

A reasonable amount of on-frequency gain for a single stage is between 10 and 20 dB. Because these devices have typically much more gain at lower frequencies, and this gain could easily lead to oscillation, low frequency gain must be limited in the circuit, and all bias paths must be bypassed very well.

The RF input circuit to the FET starts with a decoupling capacitor to keep stray dc charges or return paths at the input from affecting bias. Next is a pair of high quality air wound or printed inductors that match the FET to the 50 Ω input. L1 is in series with the FET and L2 goes to RF ground and supplied dc bias. L1 must be adjusted for best match at the design frequency. L2 is an RF choke for gate bias. C2 provides the majority of RF ground reference for the input circuit. The resistor R1 provides some low frequency loading (because L2 and C2 are not a large enough value to remove VHF components). R1 also provides some isolation to keep the RF out of the gate supply leads. C3 provides gate supply bypassing.

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Quite often, quarter wave stubs are applied to bias lines at appropriate spots to provide superior RF reference grounds and bypassing. In the design shown in Figure 3, a stub is used in place of C2. Also, it is common to use printed circuit decoupling chokes that are implemented as either straight or serpentine very thin lines, and this kind of choke is used for L2 as shown in Figure 3. At the frequency that the preamp shown operates, the value of L1 is so low that the microstrip provides sufficient inductance.

The RF output circuit, or drain circuit, has a resistor immediately following the drain (R2). This component, not found in lower frequency or GaAs FET LNAs provides isolation between input and output and provides a stable load at all frequencies. Even though this results in less gain, it also reduces the likelihood of oscillation and provides some dc voltage drop. This resistor has an additional benefit in that the amplifier is less susceptible to external influences on the output port. Improper output loading or connection to a mixer will cause reflections, notably at frequencies outside the normal operating frequency. The resistor dissipates some of this (attenuates it) so that the FET is less likely to create intermodulation products. Next are the matching network and the output capacitor, which respectively match the FET output to the 50-Ω load and remove the drain bias from the output connector.

Drain power is supplied through a resistive network in a fashion similar to the input circuit. A resistor is connected through an RF choke (L3) to a chip capacitor C5 that provides better wideband decoupling than a stub would. Again, the choke is simply a thin line on the PCB. Another resistor (R3) that can be a leaded part for easy substitution to adjust bias. This is followed by C6, another power decoupling capacitor.

Bias Supply

Recall that the current drawn by an FET increases as the gate voltage moves from a more negative to a less negative value. If the gate voltage were to drop (raise) to zero, the device might draw excessive current and burn out. Because of this, the bias circuit for an LNA (where the FET uses a grounded source configuration) requires that the negative bias voltage be present prior to the application of the drain voltage. Usually, these preamplifiers are supplied externally from a +12 Vdc nominal source.

Internally to the preamp, there must be a circuit that regulates the +12 to a reasonable drain power voltage such as 5 or 6 V prior to series resistances that

DOWN EAST MICROWAVE

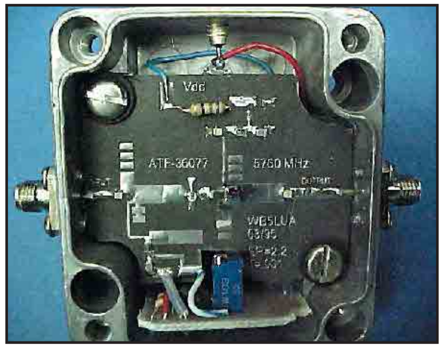

Figure 3—As described in the text, this is an implementation of a modern microwave PHEMT LNA, designed by WB5LUA and sold through Down East Microwave. The gate supply is at the bottom of the image.

will drop it to about +3 V at about 40 to 60 mA (a good operating point for a PHEMT). In order to develop the negative gate voltage a voltage inverter integrated circuit such as the 7660 is employed. This is essentially a fast operating solid state switch that charges an electrolytic capacitor and then reverses its polarity to supply voltage to the circuit. An internal oscillator drives the switch. Although this can supply only low current, it is plenty for the gate bias.

To prevent the drain from coming on until the gate voltage is present, some designs employ a transistor in the drain regulator circuit, which is switched on by the negative supply. However, if appropriately high values of drain bypass capacitance and series resistance are chosen, it will naturally come up to voltage after the gate bias has settled. Once all the biases are correctly set, this bias circuit will operate flawlessly for many years.

Tuneup and Bias Adjustment

The bias for a PHEMT is fairly complicated to adjust, and during tuneup it is possible to destroy the device if the right sequence is not followed. The problem is that the gate-to-drain maximum voltage is only 6 V. One always follows the practice, when energizing an FET, of applying the gate bias first. The other common practice is to apply a starting gate bias that will be sufficiently negative to pinch off the device so that no current will draw on the drain when that voltage is applied. This is done to limit the current drawn. However, and this is important, because the PHEMT can only withstand 6 V drain to source, it is mandatory to set the gate voltage to a turned-on value, such as –0.7 V, prior to applying the drain supply.

Why is this so important? The reason is that usually the drain circuit is supplied with a +5 V regulator. If the gate is at pinch off and the drain supply is turned on, there is almost no current draw, so there is no voltage drop across the drain series resistors and the full +5 V appears on the drain terminal. With pinchoff voltage, such as –1 V or greater (more negative) on the gate, this puts more than 6 V between the gate and drain, and the device will fry in a few milliseconds. To ensure this won't happen, it is advisable to temporarily place a diode in the gate bias circuit to limit the gate voltage to –0.7 V. Then bias adjustments can be made according to the manufacturer's or designer's instructions. PHEMTs will often provide the best performance with a drain voltage around 2 to 3 V.

Because at higher frequencies circuits are much less tolerant of component and circuit material variations, it is common to design into the circuit board a means of tuning out these variables. To do this, designers place a series of small pads at key spots to form tuning stubs. By bridging the pads with solder (or braking those bridges) small amounts of reactance can be adjusted to bring the circuit back into spec. These effects are usually very small, and unless every last bit of performance is needed, can be left untuned. To perform proper tuning, a noise-figure meter is required. Fortunately, these rather expensive meters are often available at microwave and VHF conferences to help us out.

The Future

Some LNAs are now being implemented as MMICs (Monolithic Microwave Integrated Circuits). As such, they may contain several stages of amplification, complete bias networks and some decoupling. These devices can be used with some external bias bypassing resulting in simpler PCB designs with surprising performance. Such MMICs are now available at up to 100 GHz for various specialized applications. No doubt, there will be Amateur Radio 24 and 47 GHz LNAs that utilize these devices in the near future.

I wish to thank Al Ward, W5LUA; Steve Kostro, N2CEI; Paul Wade, W1GHZ, and Jerry Rodski, K3MKZ, for their help with this column and their contributions to making modern amateur microwave LNAs available.

In the next issue we will delve into the nature of noise and the way we characterize LNAs. We will also explore the advantages and in some cases diminishing returns associated with using very low noise figure LNAs.

Resources

Down East Microwave Inc, **www.downeastmicrowave.com/**

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