Stability and Low Noise Amplifiers

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Introduction

The amateur radio community has certainly benefited over the years from the TVRO and DBS industry's need for low noise devices in the 4 and 12 GHz frequency range. One such device is the ATF-36077, a 200 micron gate width depletion mode Pseudo-morphic High Electron Mobility Transistor (PHEMT) that provides a 0.5 dB noise figure and 12 dB gain at 12 GHz. The ATF-36077 has been described in numerous low noise amplifier designs over the years. [1,2,3] A side benefit of these high frequency devices is extremely low noise figures down to L band and VHF providing very low noise figures in amateur terrestrial and EME systems. The challenge in using these small gate width devices is the very high gain at low frequencies necessitating the use of various feedback and resistive loading techniques which are used in most successful low noise amplifier (LNA) designs today. The discussion to follow covers some of these techniques which can be applied to all LNA designs. The ATF-36077 is used in a design example.

Stability in the System

One of the biggest issues we face when trying to achieve the lowest noise possible from any high frequency FET is stability. This is a common problem that we all have faced including myself. Our first desire is to achieve the lowest possible noise figure that our device is capable of. This requires matching 50Ω to a reflection coefficient called Gamma Opt, Γo. This is a known value for a particular frequency and is presented on the manufacturer's data sheet. Next we attempt to match the output of the device for Maximum Associated Gain Ga. This requires matching to Γ_L which is shown by the following equation

$$\Gamma_L = \left[S_{22} + \frac{S_{12}\, S_{21}\, \Gamma o}{1 - S_{11}\, \Gamma o} \right]^*$$

This involves using the device S parameters which are also presented on the data sheet.[4] Now that we have matched our device for minimum noise figure and maximum gain for one frequency, we need to analyze our circuit over the entire frequency range over which the device has gain. Our number 1 concern at this point is stability at ALL frequencies, not just the frequency we are interested in. We can analyze stability at each frequency of the device by itself or the entire amplifier by measuring the S Parameters. These are vector parameters that have both amplitude and phase information.[4]

Substituting the S Parameters into the Rollett Stability Factor equation provides insight into amplifier stability. The equation is as follows.

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |D|^2}{2|S_{12}||S_{21}|}$$

$$D = S_{11}S_{22} - S_{12}S_{21}$$

The amplifier is unconditionally stable for K greater than or equal to 1. This must be calculated at every frequency at which the device has gain.

The real test is installing the LNA into your system. Quite often the antenna impedance is only near 50Ω at the design frequency. In some cases, one has to install a cavity filter in front of the LNA to minimize terrestrial interference. The output of the LNA generally feeds another RF stage in the downconverter. These different loads can impact the performance of your LNA.

Looking more closely at the use of a filter on either the input or output of the LNA, we find that the filter will only present a reasonable match in the pass-band of the filter. Most filters that we utilize make use of inductors or resonators and capacitors to obtain the desired pass-band response. The filter therefore obtains its' out of band rejection by simply shunting the out of band signals to ground or providing a high impedance in series with the signal path. That means the impedance seen by the LNA will be close to 50Ω in-band and nearly 0Ω out-of-band. This is certainly a different situation than when the LNA was tested on the bench as both input and output terminations for the LNA were near 50Ω.

Let's study what causes stability issues in an LNA design and what can be done to cure them.

Input Network – This network provides the noise match to the device and for our interests a low noise match is our major concern. This generally takes priority over best S11 or input return loss. Generally this network is as loss free as possible. The matching network can take on

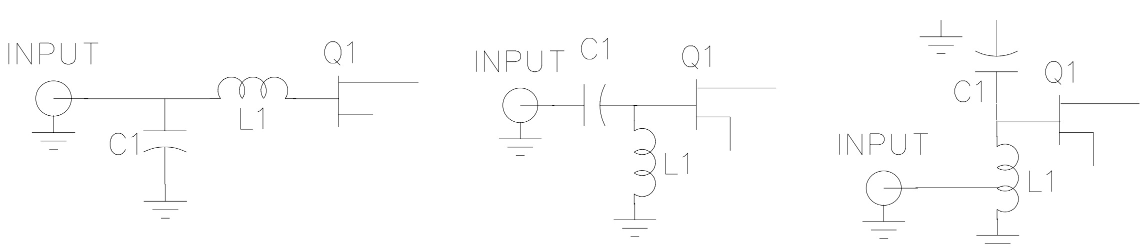

Figure 1. Typical matching networks used for noise matching a FET consisting of a low-pass, high-pass or band-pass structure.

multiple forms as shown in Figure 1. The network can be either low-pass, high-pass or band-pass in nature. Usually lumped Ls and Cs are used at VHF through 2304 MHz or even 3456 MHz. At 5760 MHz and higher most inductive elements are replaced by an equivalent microstrip line for lowest loss. VHF LNAs are typically band-pass in nature while higher frequency designs are generally more low-pass or high-pass. Even a low-pass network begins to appear more like a high-pass or band-pass when one adds in the bias decoupling network. The biasing network can be used as an aid in reducing gain at frequencies below the frequency of operation. More on this later.

Output Network – The output network can also take on the form of a low-pass, high-pass or band-pass structure. The primary job of the output network is to provide a gain match (best S22 or output return loss) while the input is matched for lowest noise figure. Keep in mind that providing a conjugate match at the output port does not necessarily provide the best match for highest linearity. Linearity can be improved by matching to an optimum load coefficient that provides higher P1dB or OIP3. Generally this is not done with amateur LNAs. If we wanted to boost linearity, we would normally raise the device's bias point as suggested in the manufacturer's data sheet and take what we get with a conjugate or gain match.

Again this network can have multiple uses. One is to help with stability. Back in the old days we used to parallel a resistor across the parallel tuned LC network. In addition we also used a ferrite bead on the drain of a dual gate MOSFET LNA to squelch parasitic oscillations. We do the same thing today with our high frequency FETs by adding a small amount of resistance in series with the drain. Anything from a few ohms to 50Ω can be used to enhance stability over a very broad frequency range. A shunt resistor attached from the drain to an RF ground can supply voltage to the device while providing a nice stable load for the FET. This is common practice in VHF through L band LNAs where device gain is very high.

Source Grounding – Generally microwave FETs have 2 source leads which helps to minimize the inductance from the source leads to ground. This is shown graphically in Figure 2. Typically microstrip is used which relies on the bottom copper acting as a ground plane. Each source lead has its own plated through hole to connect the top side of the circuit board to the bottom side ground plane. There is usually some small amount of top side etch shown as LL between the device and the edge of the plated through hole. Both this etch and the length or height of the plate through hole combine to give some equivalent amount of inductance. Having 2 similar paths halves the inductance to ground. Although the equivalent inductance for this method of source grounding is only tenths of a nH, it can have a profound effect on LNA stability. This inductance can make a FET regenerative at high frequencies and degenerative at low frequencies. End result is it can and will affect overall LNA stability.

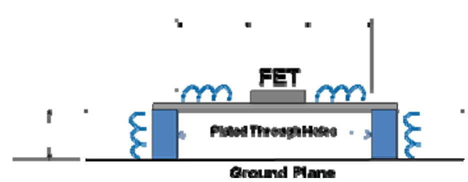

Figure 2. FET with source grounding to bottom of printed circuit board

1296 MHz LNA Design using the ATF-36077

We will now look at a complete amplifier design for 1296 MHz using the Avago ATF-36077. This circuit is described in Avago Application Note AN 1128.[2,4] The complete amplifier schematic is shown in Figure 3. Design is based on .031" thick FR-4.

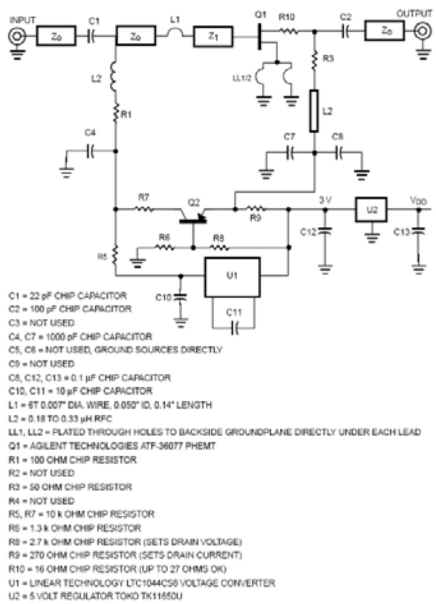

Figure 3. ATF-36077 1296 MHz Low Noise Amplifier

The input matching network is low-pass consisting of a series inductor L1 which provides the optimum noise match for the FET. The bias network on the input consisting of L2 and R1 bypassed with C4 provides a high-pass structure which when tailored properly provides some low frequency gain reduction which does help stability.

The ATF-36077 has significant gain at 1.3 GHz and therefore must be resistively loaded heavily to be stable. This is true of many 12 GHz rated devices. Conjugately matching these devices would certainly produce an LNA that would be very hard to tame on stability. The output network consists of a shunt resistor in the form of R3 and small amount of printed circuit board inductance. A series resistor R10 is also used to provide broadband stability. A controlled amount of source inductance as shown as LL1 and LL2 is used to optimize stability.

With the help of Agilent' Advanced Design System (ADS) an analysis is done to analyze the effect of various LNA components on stability. The circuit as simulated by ADS is shown in Figure 4. The dc bias circuitry has been omitted since the LNA circuit has proper bypassing on the RF circuitry.

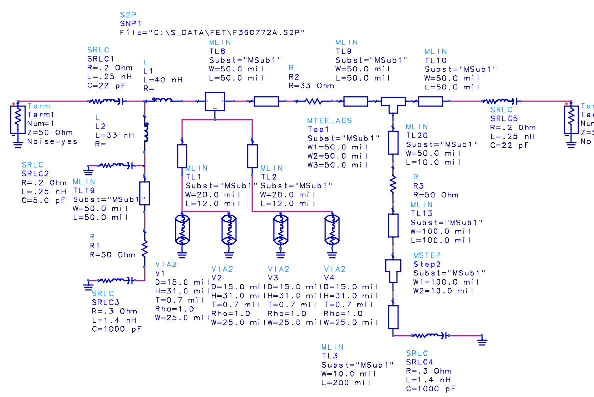

Figure 4. ADS Circuit for 1296 MHz ATF-36077 LNA optimized for noise figure and stability

The most important parameter for low noise is matching the devices' Γo to 50Ω. This is accomplished by the series inductor L1 and to a lesser degree shunt inductor L2. The predicted performance is shown in Figure 5. Although having a resistor in series with L2 can help low frequency stability, it can also raise the noise figure slightly. Therefore having L2 bypassed with a small 10 to 20 pF capacitor often helps noise figure.

Noise figure is not measurably affected by small changes in source inductance but can be influenced by any resistive loading in the drain circuit as S12 or reverse isolation of any FET is not zero.

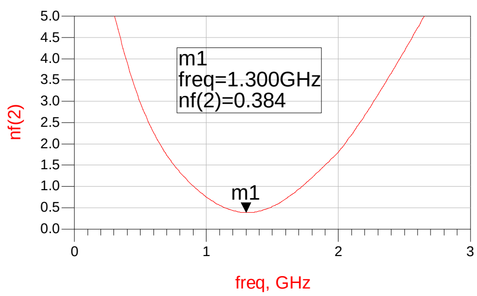

Figure 5. ADS prediction on LNA noise figure

Although resistive loading in the drain is very important for stability, the first order of business in any LNA design is analysis of the grounding of the source leads. As shown in Figure 2, the thickness of the printed circuit board is also a critical parameter when it comes to stability. Generally .031" thick material will work fine through 3456 MHz. At 5760 MHz and 10368 MHz, .015" or .010" is preferred as it provides a less inductive lower impedance path for the source leads to ground. Figure 6 shows a plot of Rollett Stability Factor K versus frequency. The zero source inductance curve represents the entire LNA with zero inductance between the FET source leads and ground. The amplifier is very stable at high frequencies and very marginal at low frequencies. The solid curve represents K with the optimum amount of source inductance per the latest design. It shows K greater than 1 at high frequencies and improved at low frequencies. The source inductance makes the device regenerative at high frequencies which increases high frequency gain and lowers stability. At the low end of the frequency range, this same optimum source inductance lowers LNA gain making it more stable than it would have been with zero source inductance. The plot shown as excessive source inductance is with each source lead being .030" longer than the optimum dimension. The excessive source inductance does not really help stability at low frequencies and has most likely generated an amplifier that will really be load sensitive around 18 GHz.

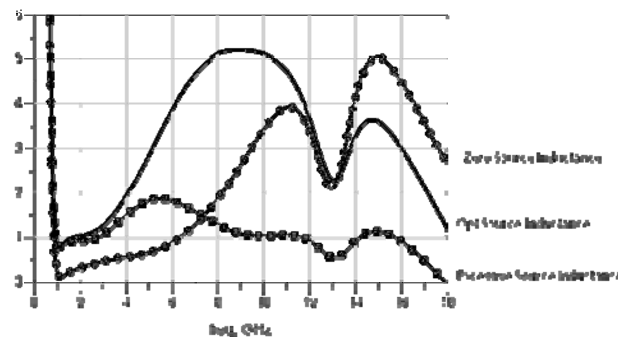

Figure 6 Rollett Stability Factor K vs Frequency

The optimum amount of source inductance is really determined by the maximum amount the device can handle without becoming unstable generally in the Ku band or 12 to 18 GHz frequency range. Once this maximum tolerable amount of source inductance has been determined then stability circles can be reviewed or other means can be used to make the device K > 1. I generally try to make the LNA K > 1 but sometimes it becomes very difficult to show the lowest noise figure that the device is capable of and still be able to realize a practical reproducible LNA design. Compromise is the name of the game.

Figure 7 shows a plot of Rollett Stability Factor K vs frequency and drain resistance R10. Figure 8 shows the corresponding change in gain for the same resistance values. There is a direct relationship between high gain and poor stability.

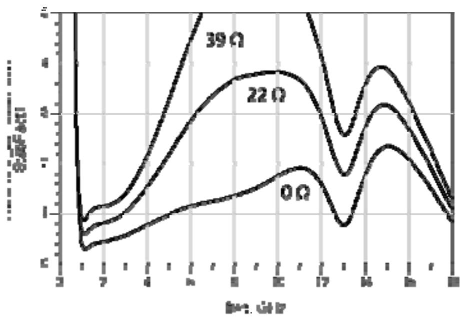

Figure 7. LNA Rollett Stability Factor K vs frequency and drain resistance

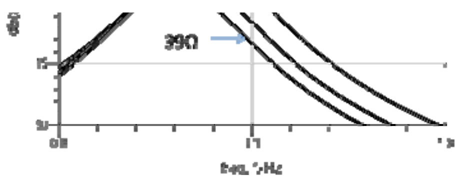

Figure 8. LNA Gain vs frequency and drain resistance.

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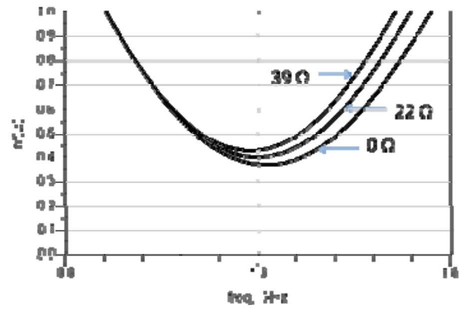

Figure 9. LNA noise figure vs frequency and drain resistance

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on amateur frequencies and still obtaining low noise figures. Other solutions to obtaining high stability with low noise include the design of multi-stage LNAs which can be optimized for stability.[4,5] The search for the perfect LNA continues.

Al Ward August 26, 2011

References

1. A. Ward, W5LUA, “Low Noise Amplifiers for 2304, 3456, 5760, and 10368 MHz Using the ATF-36077 PHEMT”, Proceedings of Microwave Update 1997, ARRL, pp. 283-287.
2. “ L Band Amplifier using the ATF-36077 Low Noise PHEMT, Avago Technologies AN 1128, publication number 5966-0783EN – August 11, 2010
3. A. Ward, W5LUA, “Inexpensive Components for 24 GHz”, Proceedings of Microwave Update 1998, ARRL, pp. 246-256
4. A. Ward, W5LUA, T. Henderson, WD5AGO, “Designing Stability into Low Noise Amplifiers for 1296 MHz and 2304 MHz”, Proceedings of Microwave Update 2007, ARRL, pp. 111-138
5. T. Henderson, WD5AGO, A. Ward, W5LUA, “L and S Band Low Noise Amplifier Designs – Cooling, is it necessary?”, Proceedings of Microwave Update 2008, ARRL, pp. 227-235