L and S Band Amplifiers using the ATF-36163 Low Noise PHEMT

Application Note 1097

Introduction

The ATF-36163 PHEMT device has numerous applications as a low noise amplifier in the 900 MHz through 12 GHz frequency range. The ATF-36163 has a tested 12 GHz noise figure of 1.4 dB maximum, with 1.2 dB being typical. At lower frequencies, such as 4 GHz, the ATF-36163 has a typical noise figure of 0.6 dB decreasing to about 0.5 dB at 2 GHz and below. With proper circuit design, the ATF-36163 can be successfully used as a low noise amplifier in the L and S band frequency ranges.

This paper describes the use of the Avago Technologies' ATF-36163 in a low noise amplifier providing a 0.8 dB noise figure from 2.0 to 2.4 GHz with 16 dB of gain. The circuit can be easily modified to provide low noise performance for GPS, IMMARSAT, WEFAX, PCS, and other applications in the 1 to 2 GHz frequency range. The ATF-36163 is housed in a plastic surface mount SOT-363 (SC-70) package offering low noise performance in a low cost package.

LNA Design

The LNA was designed using EESOF's Touchstone™ for Windows and published S and Noise parameters.

The reference plane for both the S and Noise parameters is shown in Figure 1.

Unlike the customary ceramic microwave type package, the plastic SC-70 package has its reference plane for both S and Noise parameters at the end of the device leads and not at the package to lead interface.

The ATF-36163 has 4 source leads, all of which need to be well grounded for proper RF performance. The S Parameters were measured in a test fixture designed specifically for the SOT-363 package. The effects of source grounding in the fixture have been de-embedded so that the designer can add circuit grounds, such as plated through-holes and any associated source lead length.

Since the ATF-36163 is a rather small 200 micron gate width device, the typical application is generally in the 4 GHz and higher frequency range. At lower frequencies, the device is still capable of very low noise figures and higher gain. Whenever a device is capable of greater than about 18 dB of gain at the desired operating frequency, the circuit should be designed to limit the gain in order to guarantee stable operation. When the ATF-36163 is used as a low noise amplifier at 12 GHz, the input can be matched for minimum noise figure, the output can be matched for maximum gain, and the circuit will be unconditionally stable at 12 GHz. At lower frequencies, the gain of the device can approach 18 to 20 dB and higher with similar matching criteria. Although more gain may be desirable, it is not without compromise. This phenomenon is characteristic of all state of the art low noise 12 GHz devices and must be dealt with properly to achieve desired performance at the lower frequencies.

The use of resistive loading in the drain circuit and inductance between the source and ground are two good methods for enhancing low frequency stability. Both of these techniques have been covered in detail.[1]
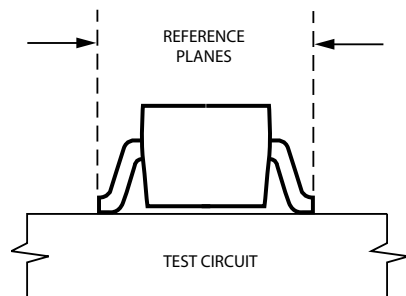

Figure 1. Reference Plane for S and Noise Parameters.

The use of source inductance between each of the source leads and ground provides series feedback whose effect varies with frequency. At higher frequencies, such as 12 GHz, adding source inductance makes the device regenerative which increases gain and causes instabilities. At lower frequencies, source inductance makes the device degenerative, thereby reducing gain and improving stability. The trick is to add a limited amount of source inductance that ensures that the device is unconditionally stable at frequencies significantly higher than the frequency of operation. Although this may not make the device unconditionally stable at the frequency of operation, it does improve inband stability. Resistive loading on the drain side can further improve the inband stability.

Resistive loading in series with the drain or shunt with the drain is the easiest and most practical way of achieving broadband stability. The only disadvantage is decreased power output since some of the power is lost in the resistive termination.

The circuit design presented here includes a shunt resistor in series with a short microstripline to terminate the device. With the aid of the computer, it was found that the device cannot tolerate much source inductance before instabilities are created in the X band frequency range. However small the inductance of the plated through-holes appears to be, the inductance does limit the amount of additional inductance that can be added to help low frequency stability.

Source inductance can be derived from several components, all of which need to be modeled properly to achieve the desired performance. Start with modeling the plated through-holes, one for each source lead. A thinner circuit board, i.e., 0.031-inch thickness, is preferred. Next, model the source lead length between the edge of the plated through-hole and the reference plane at the device. The third item is to model the bypass capacitor(s). This may be associated with RF bypassing the source resistor if self-biasing is used. In the case of the ATF-36163, the device is unable to tolerate the inductance associated with even the best quality microwave chip capacitors. It is therefore recommended that the source leads of the device be dc grounded to minimize the additional inductance that is added if bypass capacitors are used. This dictates that a negative voltage be used to bias up the gate. The nominal gate voltage is only -0.2 volts at less than 100 microamps.

The input noise match consisting of a single series inductor provides a low Q broadband noise match in the 1.8 to 2.8 GHz frequency range. With a low Q matching circuit, the effects on the circuit due to device-to-device variations are minimized. The inductor is a single piece of wire bent into a U shape. The bias decoupling network consists of a series microstripline bypassed with a 10 pF chip capacitor. Low frequency stability is achieved by using an additional 50 Ω resistor bypassed with a 1000 pF chip capacitor. The output network was designed solely for broadband

stability and gain. The resultant circuit board artwork includes a space for a resistor in series with the drain of the device as shown in Figure 2. This can be used to further enhance stability and reduce gain. The suggested value is no greater than 33 Ω. Greater values of resistance tend to increase noise figure.

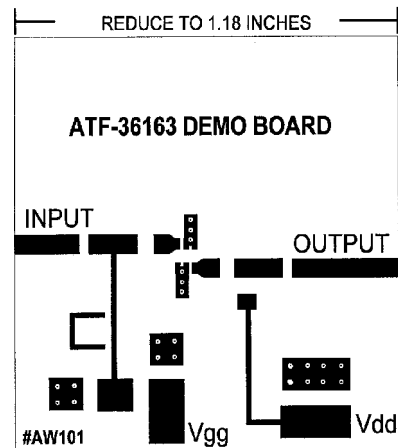Component placement is shown in Figure 3 and a schematic diagram is shown in Figure 4.

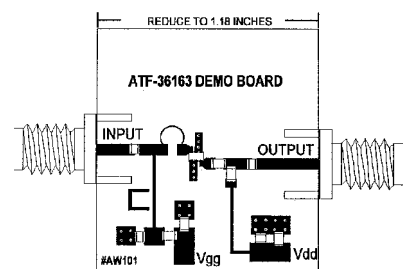Figure 2. Artwork for 1 stage ATF-36163 LNA

Figure 3. Component Layout for ATF-36163 LNA

Notes:
[1]. *Using the ATF-10236 in Low Noise Amplifier Applications in the UHF through 1.7 GHz Frequency Range,* Avago Technologies Application Note 1076, Pub No. 5963-3780E(2/95)
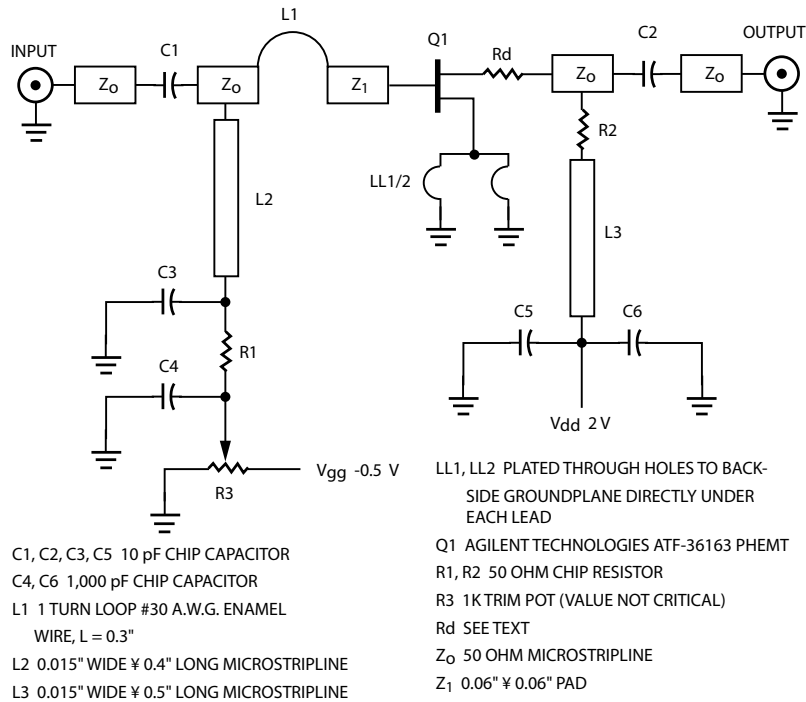
The graph in Figure 6 shows gain versus frequency of the completed amplifier. Gain is a nominal 16 dB from 2 GHz to 2.4 GHz. Noise figure, shown in Figure 7, is nominally 0.8 dB over the same frequency range. The frequency at which maximum gain occurs generally coincides with the frequency where minimum noise figure occurs. Therefore, increasing or decreasing the value of inductor L1 either lowers or raises the operating frequency of the amplifier. For lower frequency operation down to 1 GHz, L2 can be increased in length by tapping in the additional line length shown on the printed circuit board.
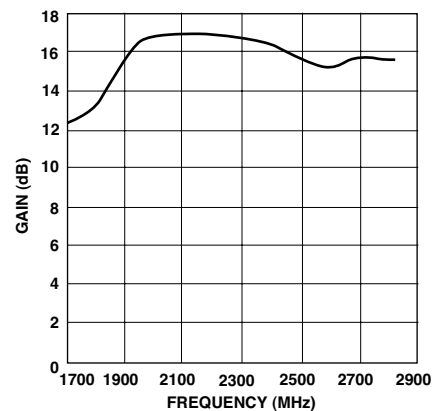
Figure 4. Schematic Diagram of ATF-36163 amplifier.

C1, C2, C3, C5 10 pF CHIP CAPACITOR
C4, C6 1,000 pF CHIP CAPACITOR
L1 1 TURN LOOP #30 A.W.G. ENAMEL
    WIRE, L = 0.3"
L2 0.015" WIDE ¥ 0.4" LONG MICROSTRIPLINE
L3 0.015" WIDE ¥ 0.5" LONG MICROSTRIPLINE

LL1, LL2 PLATED THROUGH HOLES TO BACK-
    SIDE GROUNDPLANE DIRECTLY UNDER
    EACH LEAD
Q1 AGILENT TECHNOLOGIES ATF-36163 PHEMT
R1, R2 50 OHM CHIP RESISTOR
R3 1K TRIM POT (VALUE NOT CRITICAL)
Rd SEE TEXT
Z_O 50 OHM MICROSTRIPLINE
Z_1 0.06" ¥ 0.06" PAD

Figure 6. Gain vs. Frequency

Figure 5. Schematic Diagram of ATF-36163 amplifier using dc-dc converter and active bias.

C1, C2, C3, C5 10 pF CHIP CAPACITOR
C4, C6 1,000 pF CHIP CAPACITOR
C7, C8 10 µF CHIP CAPACITOR
C9 0.1 µF CHIP CAPACITOR
L1 1 TURN LOOP #30 A.W.G. ENAMEL
    WIRE, L = 0.3"
L2 0.015" WIDE ¥ 0.4" LONG MICROSTRIPLINE
L3 0.015" WIDE ¥ 0.5" LONG MICROSTRIPLINE
LL1, LL2 PLATED THROUGH HOLES TO BACK-
    SIDE GROUNDPLANE DIRECTLY UNDER
    EACH LEAD

Q1 AGILENT TECHNOLOGIES ATF-36163 PHEMT
R1, R2 50 OHM CHIP RESISTOR
R3 100 OHM CHIP RESISTOR
R4 1.3K OHM CHIP RESISTOR
R5, R7 10K OHM CHIP RESISTOR
R6 1K OHM CHIP RESISTOR
Rd SEE TEXT
U1 LINEAR TECHNOLOGY LTC1044CS8
    VOLTAGE CONVERTER
Z_O 50 OHM MICROSTRIPLINE
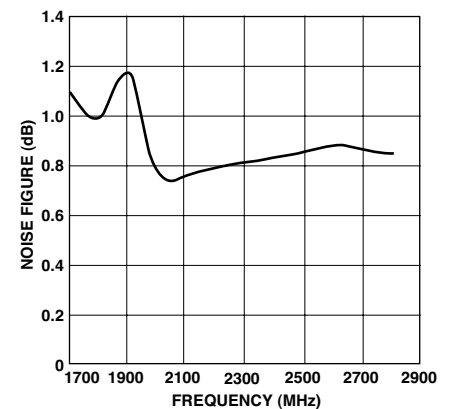Z_1 0.06" ¥ 0.06" PAD

Figure 7. Noise Figure vs. Frequency

General Design Considerations
SOT-363 PCB Layout
A PCB pad layout for the miniature SOT-363 (SC-70) package is shown in Figure 8. Dimensions are in inches. The layout is shown with a nominal SOT-363 package footprint superimposed on the PCB pads.

It is important to properly model the PCB pad layout when doing the design to achieve the best correlation between the simulation and actual performance. The pads add shunt capacitance at the drain and gate leads of the device. It is also best to add plated through-holes as close as possible to the four source lead pads.
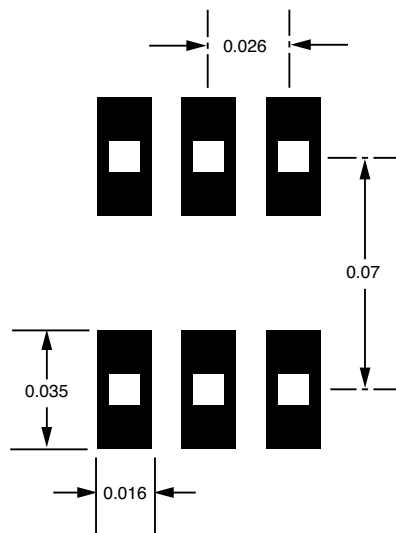

Figure 8. PCB Pad Layout (dimensions in inches).

Excessive source lead length, i.e., 0.050", can cause gain peaking in the 13 GHz range, which can ultimately produce instabilities.

Biasing
For best performance, the ATF-36163 should be operated with the source leads dc grounded. This requires a negative voltage on the gate to "bias-up" the device. Nominal gate voltage is a (negative) -0.20 volts for 10 mA drain current and somewhat less negative for a drain current of 15 mA. Typical operation for best gain performance is at a Vds of 2.0 volts and an Id of 15 mA. With a 50 Ω resistor in the drain bias decoupling network, a supply voltage of 2.75 volts is required.

Enclosures
The LNA is usually installed in some sort of conductive or RF "reflective" enclosure or housing. The housing has various effects on the overall performance. The addition of walls and a cover can actually reduce radiation losses with the "good" result of lowering noise figure by 0.1 dB and raising gain by a dB or so.

Now for the "bad" effect. Depending on the height and width of the enclosure as viewed from the end of the LNA, a waveguide effect can occur. Depending on the width of the cavity versus the operating frequency and the ability of any component on the circuit board to launch a wave into the "waveguide," various other undesired phenomena can occur. The most obvious is instability resulting in oscillations. The ability of the LNA plus enclosure to oscillate is generally determined by the frequency where maximum gain occurs. This may even occur at a frequency lower than the desired operating frequency. It is a good idea to measure the swept gain of the LNA just to make sure that there is no excessive gain peaking out-of-band which can potentially cause trouble. The use of the lowest possible value blocking capacitors helps provide a highpass response to roll-off low frequency gain. Adjusting the impedance of the inductors used for bias decoupling is also another means of providing a more highpass gain response.

Conclusion
The ATF-36163 in a low cost surface mount package provides a nominal 0.8 dB noise figure and 16 dB of associated gain in the 2 to 2.4 GHz frequency range.