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# 1 and 2 Stage 10.7 to 12.7 GHz Amplifiers Using the ATF-36163 Low Noise PHEMT

## Application Note 1091

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### Introduction

The Direct Broadcast Satellite (DBS) service is growing at an enormous rate. Although it has just recently been introduced to the general market in the U.S., it has been in place in Europe and the Far East where cable TV has a lesser hold on the TV viewing market. For the reception of present analog and future digital satellites in Europe, the Universal band from 10.7 to 12.75 GHz has been proposed. System noise figure is specified as less than 1.5 dB maximum between 10.7 and 11.7 GHz and less than 1.3 dB noise figure from 11.7 to 12.75 GHz. In the U.S., the Digital Satellite System, DSS, has been set from 12.2 to 12.7 GHz. System noise figure requirement is 1.1 dB maximum.

System noise figure is set by the Low Noise Block Downconverter (LNB) that is placed at the feed of the parabolic reflector (dish). The LNB consists of a Low Noise Amplifier (LNA) followed by a converter that converts the Ku Band signals down to L Band for further signal processing. The LNA sets the LNB noise figure and usually consists of three stages of amplification.

The first stage of the LNA is the primary device that drives the noise figure, and the second and third stages provide good gain at reasonable noise figure so that appreciable noise is not added to the first stage. Usually, the second and third stage contributions are desired to be less than 0.2 dB. The requirements for the combined second and third stage are about 18 to 20 dB gain with a noise figure of 1.5 to 1.8 dB. The second and third stages should also be very low cost and surface mount compatible.

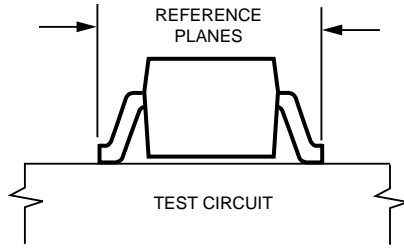
This paper describes the use of the Hewlett-Packard ATF-36163 in several low noise amplifiers suitable for the Direct Broadcast Satellite service at 12 GHz. The ATF-36163 device provides a nominal 1.2 dB noise figure and a minimum of 9 dB of associated gain at 12 GHz. The ATF-36163 is housed in a plastic surface mount SOT-363 (SC-70) package offering low noise performance in a low cost package. For most applications, the ATF-36163 is ideal for second and third stages of the LNA. However, for some applications, the noise figure may be adequate for the first stage.

The first two amplifiers are de-

signed for use in either the DSS or Universal service, since they both cover the entire 10.7 to 12.7 GHz frequency range. A single stage ATF-36163 amplifier provides a 1.4 to 1.6 dB noise figure and 9 to 10 dB of associated gain over the 10.7 to 12.7 GHz frequency range. A two stage amplifier is described which has a 1.35 to 1.7 dB noise figure and an associated gain of 18.75 to 20.5 dB gain from 10.7 to 12.7 GHz. The third amplifier has been optimized for the DSS service from 12.2 to 12.7 GHz. This amplifier provides 20.5 to 21.5 dB gain and a 1.4 to 1.9 dB noise figure. As with any wide bandwidth amplifier, a small amount of gain and noise figure must be sacrificed in order to obtain the broadband performance necessary for DBS applications. The addition of a low noise device such as the ATF-36077 as a first stage will decrease the overall noise figure to less than 0.8 dB over the band.

### LNA Design

The LNAs were designed using HP'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.



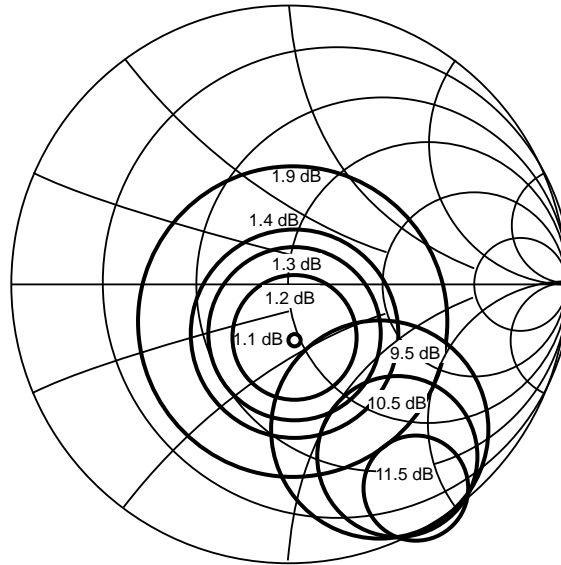
**Figure 1. Reference Plane for S and Noise Parameters.**

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 four source leads, all of which need to be 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, including plated through holes and any associated source lead length. All LNAs are designed for 0.015 inch thick dielectric material with a dielectric constant of 2.5. The use of 0.015 inch thick material as opposed to 0.031 inch thick material minimizes radiation losses which can raise noise figure and create stability problems.

### Single Stage 10.7 to 12.7 GHz Amplifier

Although the ATF-36163 is specified with the customary maximum noise figure and minimum gain specification at 12 GHz, the desired operation is from 10.7 to 12.7 GHz, slightly higher than where the device is tested. Close examination of the data sheet indicates a 0.8 dB drop in



**Figure 2. Smith Chart with Noise Figure and Available Gain Circles at 12 GHz,  $V_{ds} = 1.5$  V,  $I_d = 10$  mA**

gain from 12 to 13 GHz. Therefore, both the output and input matching networks presented to the device must be designed with greater emphasis on gain and bandwidth with noise figure secondary. Fortunately, the ATF-36163 has a fairly low noise resistance,  $R_n$ , which allows greater bandwidth to be achieved as compared to other devices.

A Smith Chart with Noise Figure and Available Gain Circles for the ATF-36163 at 12 GHz is shown in Figure 2.

An input match optimized only for noise figure would consist of a shunt capacitance at the gate of the device. However, the curves suggest a compromise input match that would only sacrifice noise figure by 0.2 dB while simultaneously increasing gain by 1 dB. Adding a high impedance microstripline in series with the shunt capacitance will provide the optimum match. The output was conjugately matched to provide good gain over the same band-

width. The resultant circuit board artwork is shown in Figure 3.

The original artwork will have to be modified in three places as shown in Figure 4. The artwork has been enlarged for clarity. Jumper in the first additional piece of etch at location number 1. Add a small 0.02 inch by 0.05 inch piece of etch at location number 2 with a slight overhang of about 0.02 to 0.03 inch off the main etch. At location number 3, add a 0.02 by 0.05 inch piece of etch at location shown. The exact tuning of the circuit will depend on the desired noise figure and gain performance desired and will vary depending on whether optimum performance is desired over the 12.2 to 12.7 GHz frequency range or the entire 10.7 to 12.7 GHz frequency range.

Component placement is shown in Figure 5 and a schematic diagram is shown in Figure 6.

The input matching network consists of a 2.7 pF blocking capacitor

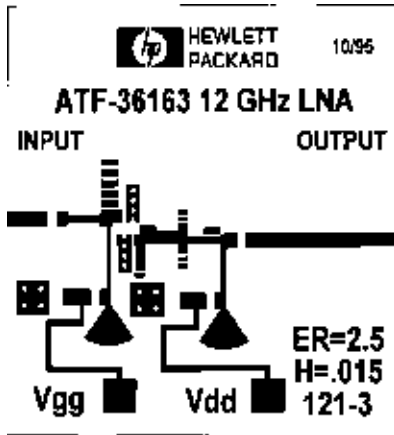


Figure 3. Artwork for One Stage ATF-36163 LNA

WARNING: DO NOT USE PHOTO-COPIES OR FAX COPIES OF THIS ARTWORK TO FABRICATE PRINTED CIRCUITS.

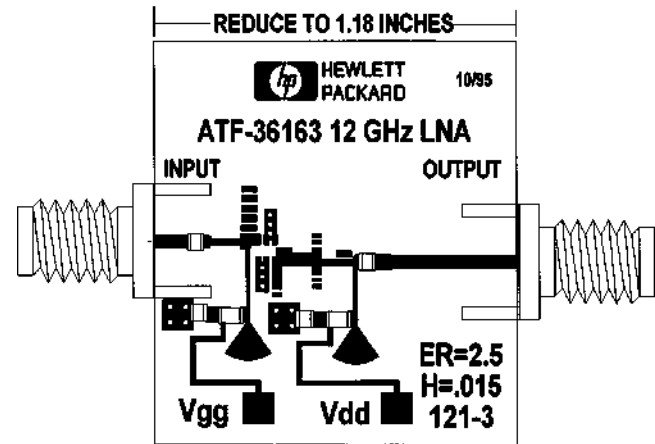


Figure 5. Component Layout for One Stage ATF-36163 LNA

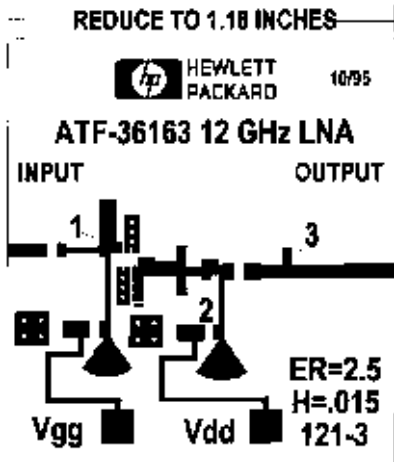
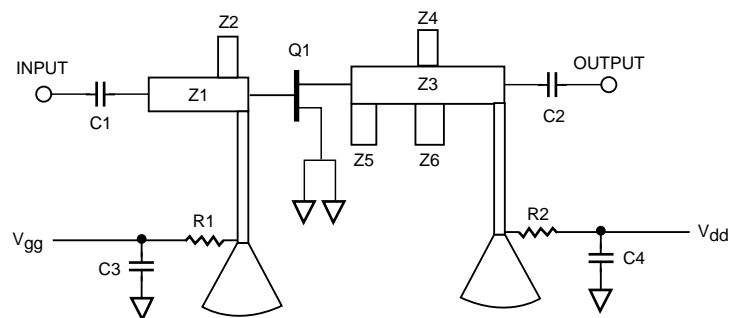


Figure 4. Modified Artwork for One Stage ATF-36163 LNA



- C1 = 2.7 pF CHIP CAPACITOR
- C2 = 1 pF CHIP CAPACITOR
- C3, C4 = 1000 pF CHIP CAPACITOR
- Q1 = HEWLETT-PACKARD ATF-36163 PHEMT
- R1, R2 = 50 OHM CHIP RESISTOR
- Z1, Z2 = INPUT MATCHING NETWORK
- Z3, Z4, Z5, Z6 = OUTPUT MATCHING NETWORK

Figure 6. Schematic Diagram of One Stage ATF-36163 amplifier.

along with a series transmission line Z1 and a shunt capacitor in the form of an open circuit stub at Z2. Increasing the impedance of Z1 or using a capacitor at C1 with greater parasitic inductance or slightly less capacitance, i.e., 1 pF, will tend to increase gain while sacrificing noise figure. The output circuitry consisting of transmission lines Z3 through Z6 has been optimized to enhance gain in the 10.7 to 12.7 GHz frequency range. The output blocking capacitor is 1 pF.

50  $\Omega$  chip resistors bypassed to ground with 1000 pF bypass capacitors are used to provide a VHF termination for the device. They are located at the junction of the radial stubs and the high impedance transmission lines attached to the input and output RF matching networks.

The graph in Figure 7 shows gain versus frequency and bias point of the completed amplifier. At the data sheet bias point of  $V_{ds}$  of 1.5 volts and  $I_d$  of 10 mA, the gain is typically 9 dB in midband. Increasing the bias to a  $V_{ds}$  of 2 volts and  $I_d$  of 15 mA increases the midband gain to almost 10 dB. Noise figure varies from 1.4 to 1.6 dB over the band and is relatively insensitive to bias point.

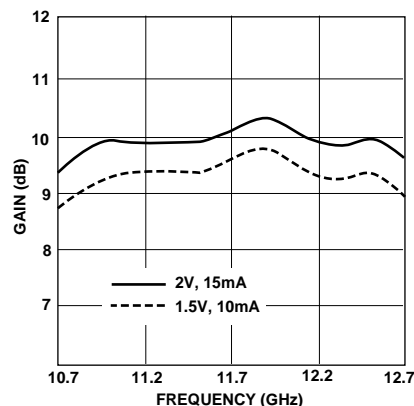


Figure 7. Gain vs. Frequency of One Stage LNA

The losses of the input and output matching networks were then measured so that the performance of the device by itself could be compared to the specifications on the data sheet. The loss of the output matching network was measured at a nominal 0.6 dB at 12 GHz increasing to 0.7 dB at 12.7 GHz. Based on this measurement, the input matching network will have approximately 0.2 dB of loss at 12 GHz. Subtracting the 0.2 dB loss due to the input matching network projects a device noise figure of about 1.2 dB maximum at 12 GHz. Adding both the 0.2 dB loss for the input network and 0.6 dB of loss for the output matching suggests a device gain of greater than 10 dB at 12 GHz at a  $V_{ds}$  of 1.5 V and  $I_d$  of 10 mA.

### Two Stage 10.7 to 12.7 GHz Amplifier

A two stage amplifier using a pair of the ATF-36163 devices is described in this section. The two stage amplifier provides a high performance yet low cost solution for the last two stages of a typical three stage sub 1 dB noise figure LNA. The artwork for a two stage ATF-36163 amplifier is shown in Figure 8.

For optimum performance over the 10.7 to 12.7 GHz frequency range, the artwork will have to be modified as shown in five places as shown in Figure 9.

Additional etch is jumpered in at locations numbered 1, 2, and 4. An additional piece of etch 0.020 by

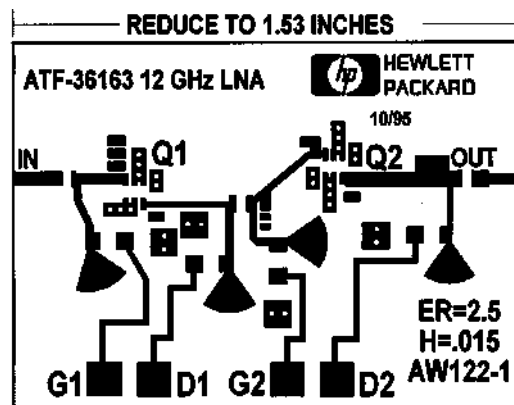


Figure 8. Artwork for Two Stage ATF-36163 LNA

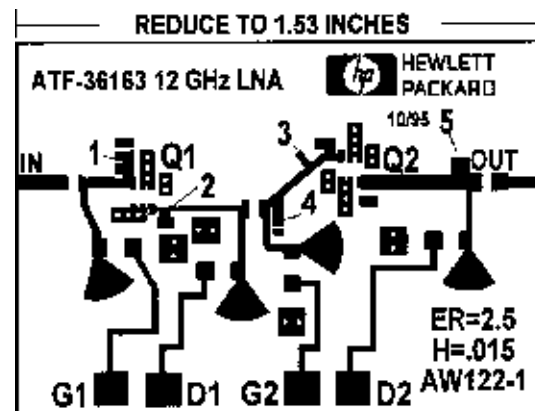


Figure 9. Modified Artwork for Two Stage ATF-36163 LNA

0.050 inch is connected to the interstage microstripline at location numbered 3. Reduce the width of the open circuited stub at location 5 by 50%.

A schematic diagram is shown in Figure 11. The input matching network consisting of Z1 and Z2 plus C1 provide a compromise noise figure / gain match to Q1. The interstage matching network

consisting of Z3 through Z6 and C2 provides gain equalization in the 10.7 to 12.7 GHz frequency range while Z7, Z8, and C3 provide an output match to 50  $\Omega$ .

The graph in Figure 12 shows swept gain of the completed two stage LNA. The plots suggest that an additional 1 to 1.5 dB of gain can be achieved by using the higher bias point described in the

preceding section on the single stage LNA. Noise figure was measured at 1.35 to 1.7 dB from 10.7 to 12.7 GHz.

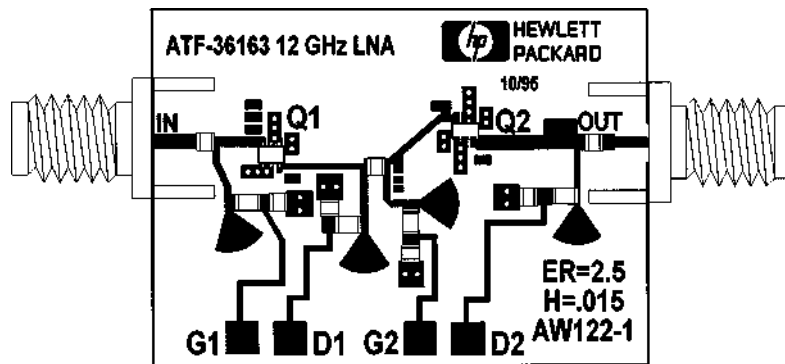


Figure 10. Component Layout for Two Stage ATF-36163 LNA

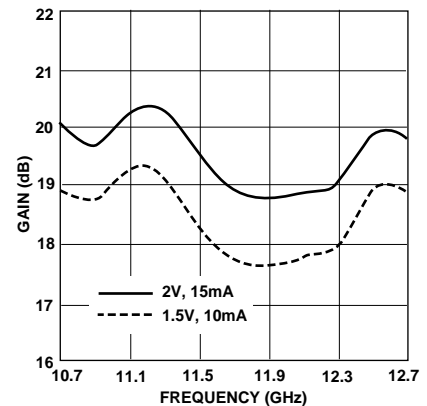
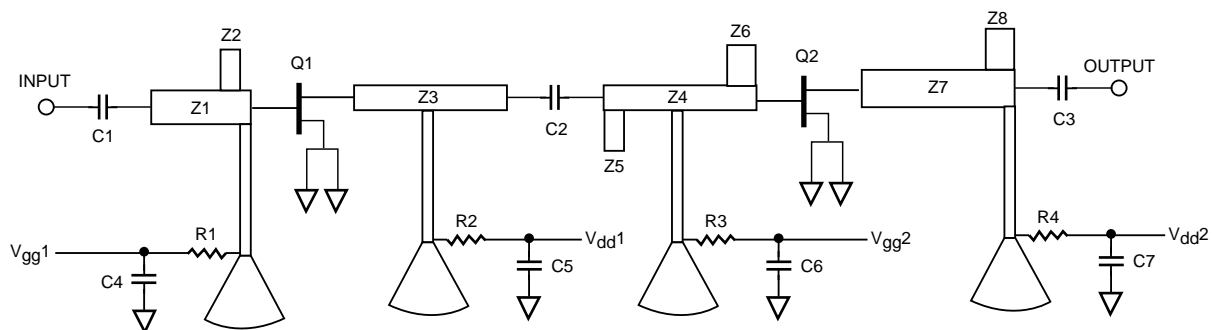


Figure 12. Gain vs. Frequency of Two Stage ATF-36163 LNA



- C1 = 2.7 pF CHIP CAPACITOR
- C2 = 0.5 pF CHIP CAPACITOR
- C3 = 1 pF CHIP CAPACITOR
- C4, C5, C6, C7 = 1000 pF CHIP CAPACITOR
- Q1, Q2 = HEWLETT-PACKARD ATF-36163 PHEMT
- R1, R2, R3, R4 = 50 OHM CHIP RESISTOR
- Z1 - Z8 = MICROCHIP MATCHING NETWORKS

Figure 11. Schematic Diagram for Two Stage ATF-36163 LNA

### Two Stage 12.2 to 12.7 GHz Amplifier

A two stage amplifier using a pair of the ATF-36163 devices optimized for gain in the 12.2 to 12.7 GHz frequency range is described in this section.

This amplifier provides a 1.4 to 1.9 dB noise figure and over 20 dB gain. This amplifier provides a solution for the last two stages of a typical three stage sub 1 dB noise figure LNA. The artwork for a two stage ATF-36163 amplifier is shown in Figure 13.

The original artwork will have to be modified in six places as shown in Figure 14. The modifications consist of the following changes. At location number 1, an additional piece of etch is jumpered in place. A 0.02 by 0.05 inch piece of etch is used to connect the additional pad into place at location number 2. At location number 3, the area is filled in as shown. At locations numbered 4, 5, and 6 jumper in the additional etch shown.

The component layout is shown in Figure 15.

The schematic diagram for the 12.2 to 12.7 GHz LNA is very similar to that shown in Figure 11.

The graph in Figure 16 shows swept gain of the completed two stage LNA. The plots suggest that an additional 1 dB of gain can be achieved by using the higher bias point described in the preceding section on the single stage LNA. Gain varies from 20.5 to 21.5 dB at a  $V_{ds}$  of 2 V and  $I_d$  of 15 mA. Noise figure was measured between 1.4 and 1.9 dB from 10.7 to 12.7 GHz.

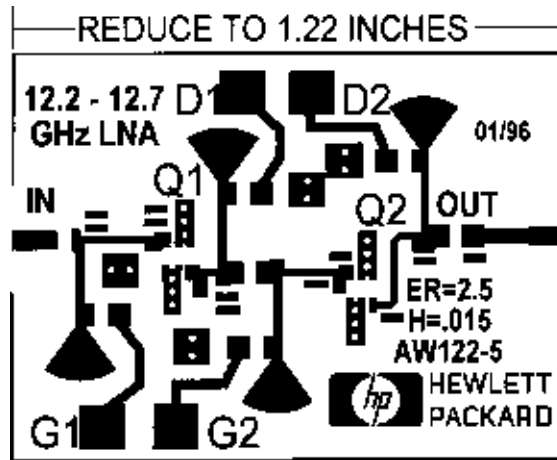


Figure 13. Artwork for Two Stage ATF-36163 LNA

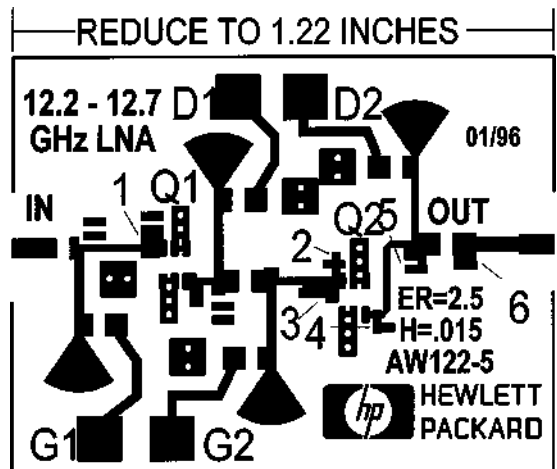


Figure 14. Artwork Modifications for Two Stage ATF-36163 LNA Optimized for 12.2 to 12.7 GHz

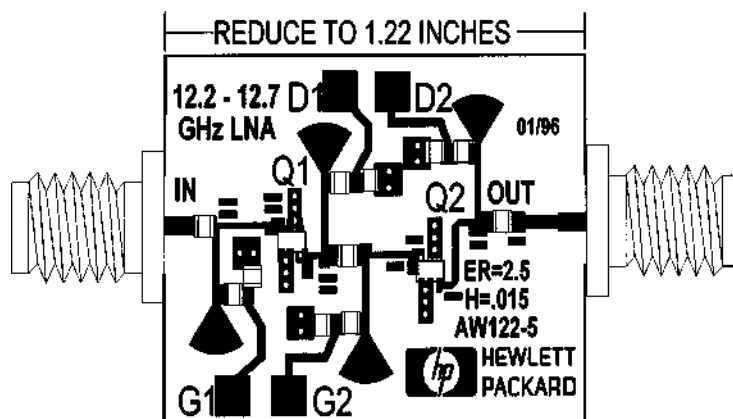
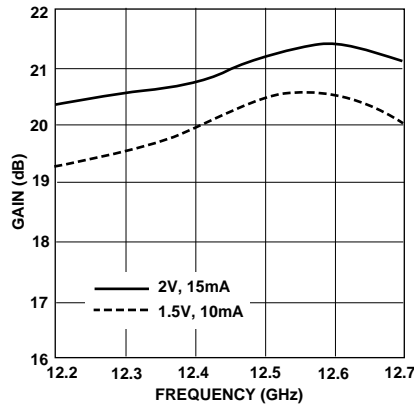


Figure 15. Component Layout for Two Stage ATF-36163 LNA



**Figure 16. Gain vs. Frequency of Two Stage ATF-36163 LNA**

## General Design Considerations

### SOT-363 PCB Layout

A PCB pad layout for the miniature SOT-363 (SC-70) package is shown in Figure 17. 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 get best correlation between 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. 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. Typi-

cal operation for best gain performance would be at a  $V_{ds}$  of 2.0 volts and an  $I_d$  of 15 mA. With a 50  $\Omega$  resistor in the drain bias decoupling network, a supply voltage of 2.75 volts will be required.

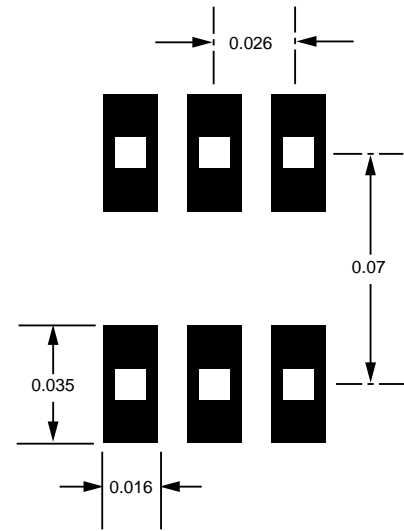
### Enclosures

The LNA is usually installed in some type 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 result of lowering noise figure by 0.1 dB and raising gain by a dB or so.

The data presented in this application note represents performance with the demo board installed in a metal enclosure which provides a cover for the LNA. None of the LNAs presented in this application note exhibited any instabilities or oscillations when a cover was placed over the LNA.

The size of the actual housing that a customer may use depends on how many other LNB functions are included with the LNA.

Depending on the height and width of the enclosure, as viewed from the end of the LNA, a waveguide effect may occur. Depending on the width of the cavity versus 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, and this may even occur at a frequency lower than the desired operating



**Figure 17. PCB Pad Layout (dimensions in inches).**

frequency. One idea to avoid this phenomena is to measure the swept gain of the LNA just to make sure that there is no excessive gain peaking out-of-band which could 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 can also be another means of providing a more highpass gain response.

Sectioning of the cavity may be required to break up the resultant waveguide modes. If all else fails, the use of microwave absorber material may be needed on the cavity walls or cover.

### Off Isolation

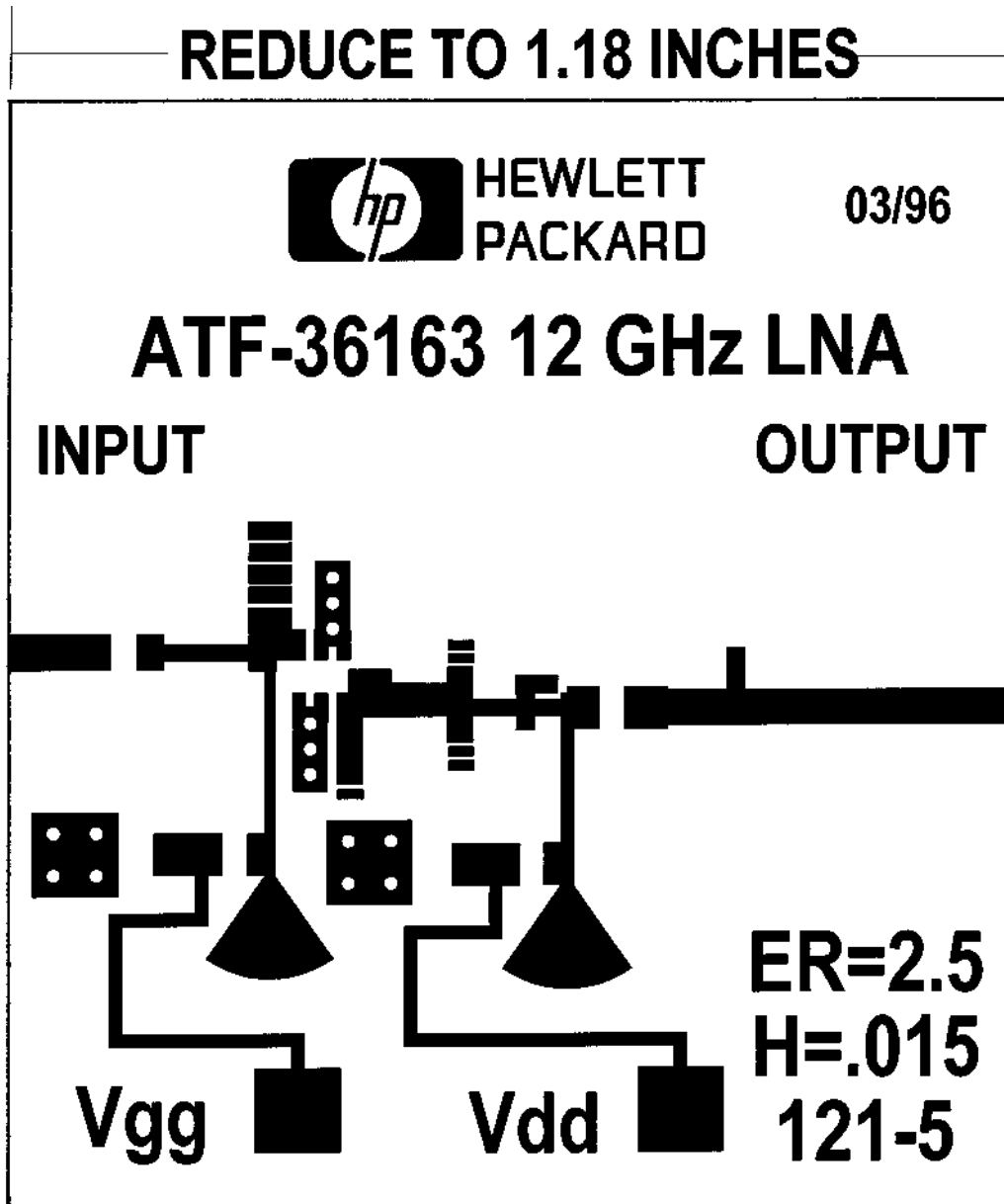
The dual polarity Universal LNB requires two LNAs, each driven separately from the feedhorn. This allows the viewer to receive two channels on the same frequency and to pick the program desired by turning on the appropriate LNA. This requires a certain

amount of isolation by the LNA that is non-energized. The ATF-36163 LNA was tested for "off" isolation by leaving the normal gate voltage intact and removing the drain voltage. This condition produced a loss of about 12 dB in band resulting in an "on to off" isolation of between 20 and 22 dB.

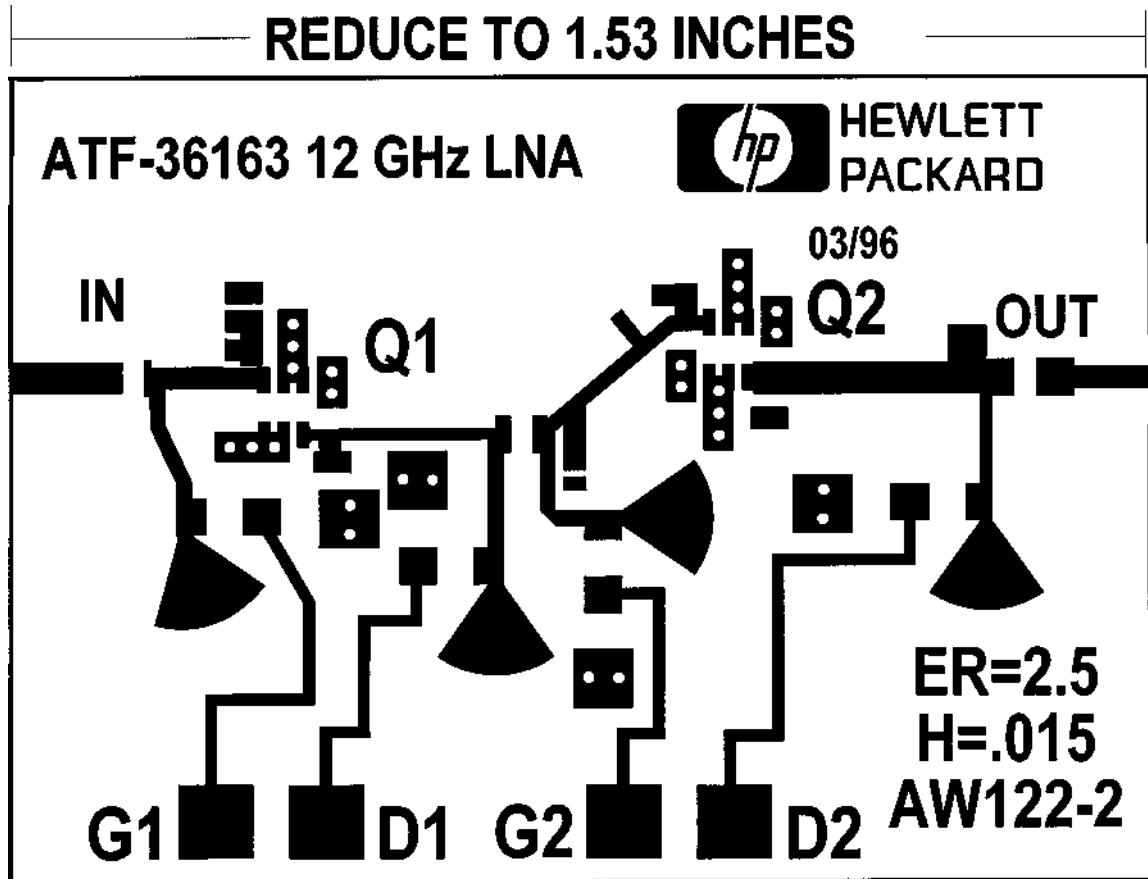
### Conclusion

PHEMT devices packaged in state-of-the-art low cost surface mount packaging can still provide near 1 dB noise figure and 9 to 10 dB gain at 12 GHz. The devices provide excellent performance for use in second and third stages of LNAs and, depending on the application, the device could be used as a first stage.

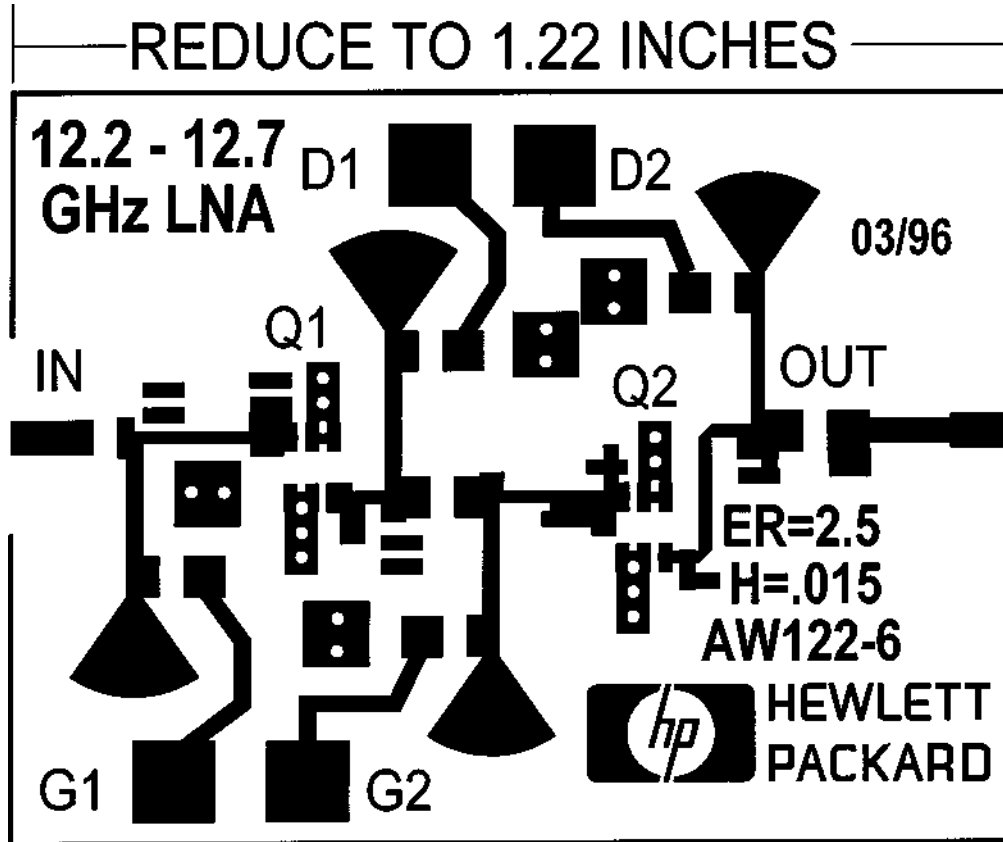
## Appendix I. Revised Artwork for Single Stage 10.7 to 12.7 GHz ATF-36163 LNA.





**Appendix II. Revised Artwork for Two Stage 10.7 to 12.7 GHz ATF-36163 LNA.**

### Appendix III. Revised Artwork for Two Stage 12.2 to 12.7 GHz ATF-36163 LNA.



For technical assistance or the location of your nearest Hewlett-Packard sales office, distributor or representative call:

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