GaAs MMIC Low Noise Amplifier SOIC-8 Platform

Rev. V3

Introduction

Early in 1994, M/A-COM began offering a family of plastic packaged GaAs MMIC low noise amplifiers (LNAs) featuring single positive supply voltage, low noise figure, high dynamic range, and low power consumption for the high volume commercial wireless communications market. These MMIC LNAs use M/A-COM's 0.5-micron, low noise GaAs MESFET process and are housed in low cost, 8-lead SOIC packages. These LNAs are tested in M/A-COM's volume automated facility to achieve low production cost. The LNAs share a common 'platform,' a product concept explained in the first major section below, enabling fast development and delivery cycles.

This application note will show the user how to achieve the performance in the product data sheets, i.e., how to "get what we get," and will answer some commonly asked questions such as how performance varies over bias. This note also expands on the data sheet information to show some interesting properties of the MMIC LNAs for use in other applications and at slightly different frequencies than those in the product data sheet.

To allow the reader to use only those sections that are of interest, the following is a brief synopsis of the major sections of this application note:

GaAs MMIC LNA SOIC-8 Product Family: This section discusses the 'platform' concept and gives an overview of the salient features for each MMIC LNA.

MMIC LNA Product Design and Performance Features: This section is a detailed look inside the design, manufacturing, and reliability issues for these GaAs MMIC LNAs.

MMIC LNA Product Customer Use Considerations: This section discusses the issues of importance to the customer in order to "get what we get " in the data sheet.

MMIC LNA Product Applications: This section shows additional performance features of the MMIC LNAs for their designed applications, as well as performance characteristics for other applications such as power amplifier driver amplifiers and using off-chip tuning networks to shift the frequency range of performance.

Performance Data & Recommended Board Layouts: This section discusses the measurement data that is available, evaluation samples, and printed circuit boards.

Conclusion: This section summarizes the application note and gives names, addresses, and phone numbers for worldwide support.

Glossary: This section defines the abbreviated terms and acronyms used in this application note.

GaAs MMIC LNA SOIC-8 Product Family

The MMIC LNA SOIC-8 product family establishes a 'platform' for M/A-COM's Integrated Circuits Business Unit. A 'platform' is a proven product concept and manufacturing methodology that translates core competencies into product families which fulfill the needs of strategic markets. The MMIC LNA SOIC-8 platform products share some common attributes, namely:

Standard Circuit Design: All internal design blocks such as low noise stage, gain stage, and biasing schemes are based on proven design topologies.

Standard IC Fabrication: Only one fixed production IC process is used; it has proven yields and well defined SPC parameters.

Standard Manufacturing: All chips are assembled on the same ISO-9001 certified manufacturing line in the same SOIC-8 package. The methods for product assembly, test, qualification, in-line quality monitoring, and documentation are identical for each device in the platform.

The advantages of a platform approach to GaAs MMIC product development are several. Using a common design topology and methodology for similar products means that many such products can be designed in parallel-essentially a batch process-enabling fast development times. The entire development cycle from inception to preliminary release for the original five LNAs (MAAM12021, MAAM12022, MAAM12031, MAAM12032, and MAAM22010) in this platform took six months. Additionally, these five LNAs are housed in one style package, the SOIC-8, with identical pin assignments. This commonality greatly simplifies the assembly, fixturing, test, and documentation requirements.

Another advantage to the platform approach is that derivative products, such as those with a different frequency range or gain level, can be developed quickly in one single design and manufacturing cycle; it is not unusual to make the transition from concept to full production in three months. Both the AM50-0001 and AM50-0002 LNAs are derivative products which have benefited from the platform approach. The AM50-0001 is a higher dynamic range LNA in a lower frequency band which utilizes the SOIC-8 platform design methodology and has identical pin assignments to the original LNAs. The AM50-0002 combines design topologies from the original LNAs to produce a higher gain LNA in the SOIC-8 platform.

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GaAs MMIC Low Noise Amplifier SOIC-8 Platform

The present MMIC LNA product family consists of the following products:

Part #	Intended Market	Features	
AM50-0002	GPS, PDC	Frequency:	1.575 GHz
		Gain:	27 dB
		Noise Figure:	1.15 dB
		Bias:	3-5V @ 20 mA
MAAM12021	GPS, PDC	Frequency:	1.5-1.6 GHz
		Gain:	21 dB
		Noise Figure:	1.55 dB
		Bias:	3-5V @ 8 mA
MAAM12022	GPS, PDC	Frequency:	1.5-1.6 GHz
		Gain:	14 dB
		Noise Figure:	1.85 dB
		Bias:	3-5 V @ 5 mA
MAAM12031	PCN, PCS, PHS, DECT DCS-1800	Frequency:	1.7-2.0 GHz
		Gain:	20 dB
		Noise Figure:	1.65 dB
		Bias:	3-5 V @ 8 mA
MAAM12032	PCN, PCS PHS, DECT DCS-1800	Frequency:	1.7-2.0 GHz
		Gain:	13 dB
		Noise Figure:	1.8 dB
		Bias:	3-5 V @ 5 mA
MAAM22010	ISM, WLAN	Frequency:	2.4-2.5 GHz
		Gain:	14 dB
		Noise Figure:	1.9 dB
		Bias:	3-5 V @ 5 mA
AM50-0001	GSM, AMPS, TACS	Frequency:	0.8-1.0 GHz
		Gain:	14 dB
		Noise Figure:	1.5 dB
		Output IP3:	+30 dBm
		Bias:	5 V @ 50 mA

All these products are offered in industry standard (JEDEC) SOIC-8 narrow body plastic packages.

MMIC LNA Product Design and Performance Features

The GaAs MMIC LNAs discussed in this application note were carefully designed, considering not only the electrical specifications but also ease and cost of manufacturing as well as quality and reliability. The following three subsections discuss in detail the inner workings of these MMIC LNAs in terms of circuit design, manufacturing, and quality.

MMIC Electrical Design Considerations

The key to any IC design is a well modeled stable process to predict circuit performance. The MMIC LNAs are based on M/A-COM's mature 0.5-micron (µm) low noise GaAs MESFET process. The active layer of the GaAs substrate is formed using ion-implantation for high throughput and low cost. A "buried-p" doping layer combined with 0.5-µm T-gates results in high performance MESFET's; the f_T of the process is 30 GHz and the F_{min} and G_{max} at 12 GHz are 1.3 and 13 dB, respectively. Every wafer is characterized for DC and RF performance. Process control parameters, as well as MIM capacitance, thin film resistance, and FET RF equivalent circuit, are stored in a database. From this database, a statistical circuit model is derived for designers to use in optimizing their design for maximum yield.

Another critical aspect in the success of this MMIC LNA product family is the ability to model all aspects of the product performance in the plastic packaging environment. Quantifying the impact of the plastic encapsulant on the electrical performance of the die for both the FETs and spiral inductors was a significant challenge. No less a challenge was the electrical circuit modeling of the SOIC-8 package itself in terms of the self and mutual inductances of the leads, bond wires, and split paddle lead frame.

This extensive modeling of the MMIC elements (FETs, MIM capacitors, thin film resistors, and spiral inductors), bond wires, and plastic package effects has allowed M/A-COM to predict with high confidence the performance of these and other designs. Utilizing these models with our statistical design methodology has allowed us to achieve high performance, unconditionally stable LNAs with high yield and, therefore, low cost. Figures 1 and 2 show the statistical distribution of the gain and noise figure, respectively, for the MAAM12021.

In this product platform there are essentially two circuit design types, a low gain (LG) and a high gain (HG). The LG design (MAAM12022, MAAM12032, MAAM22010, and AM50-0001), shown in Figure 3, employs a single stage cascade configuration with series feedback to simultaneously achieve impedance match and minimum noise figure. The HG design (MAAM12021 and MAAM12031), shown in Figure 4, uses two cascaded common source stages biased in series to achieve the high gain at low current consumption, and also employs series feedback to simultaneously achieve impedance match and minimum noise figure.

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The AM50-0002 employs a combination of the LG and HG designs to create a three stage, higher gain, LNA. The AM50-0002, however, uses a simple external input matching network to obtain minimum noise figure. A detailed discussion of this external matching network is contained in the section on customer use considerations.

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The MMIC layout of Figure 5 is the MAAM12021, the largest chip of the family; it measures 1 mm on a side. Figure 6 illustrates the assembly of this MMIC into the SOIC-8 package. Immediately one notices that the lead frame is split and there is more than one chip in the plastic package. The amplifier employs a custom fused split paddle lead frame to ensure unconditional stability when used on a typical FR4 board application. The other chip in the package is a metal-nitride-silicon (MNS) single-layer capacitor used for internal RF by-passing to allow biasing from a single positive 3-5 V supply. These MNS capacitors, supplied by M/A-COM's Semiconductor Business Unit, have almost ideal performance for very little cost. After assembly, the MAAM12021 has the functional diagram as shown in Figure 7. Six of the seven LNAs in this product platform share these assembly and functional diagrams. The AM50-0002 utilizes a slightly different lead frame and pin assignment to accommodate the special requirements of its three stage, high gain design.

MMIC Manufacturing Considerations

The MMIC LNAs are automatically assembled onto custom designed, fused, split paddle lead frames as shown previously in Figure 6. Careful consideration is given to die placement, both for the GaAs MMIC LNA and the MNS capacitor, to ensure repeatable bond wire inductance and good mechanical strength for reliability. The ground leads are fused to ensure low inductance grounds as well as low thermal impedance. These fused ground leads also lower cost in volume production by eliminating eight ground bonds (2 per lead). Once assembled onto the lead frames, the assembly is transfer molded with a plastic which has both good moisture resistance properties for reliability and well controlled dielectric constant for repeatable RF performance. Fully assembled MMIC LNAs are stored in antistatic tubes, ready for automatic test.

Fully assembled MMIC LNAs are 100% RF tested for compliance against the guaranteed data sheet performance of gain, nose figure, and DC current. Standard automatic digital IC testers have been modified to make rapid RF measurements. Accuracy is maintained by establishing correlation coefficients between the high speed automated production testers and the highly accurate engineering measurement system.

Quality and Reliability

The MMIC LNA products are subjected to a one-time product qualification, either before product releases or when there is a major process change. In the case of the MMIC LNAs, the one-time qualification, according to Table 1, has established the MMIC LNA product family to be capable of serving the high volume global commercial electronics market with a 400-FIT reliability rate (300 devices at an activation energy of 0.7 eV, normal operating temperature of 85˚C, and 90% confidence level). The MMIC LNAs are also ESD classified as low level class 1—as low as 350 volts can induce damage. Table 2 shows the on-going quality monitoring of plastic packaged devices in production to maintain the established level of product quality.

This 400-FIT reliability level is established at a junction temperature of 150˚C or less. This is the reason for the maximum rating on the data sheet of 150˚C or less. The junction temperature can be calculated from the product of the thermal resistance and power dissipated. The thermal resistance for the MMIC LNAs is 165˚C/W on all LNA's, except for the AM50-0001 where it is 125˚C/W.

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Sub Lot	Operation	Condition	Qty.
	Visual Inspection	General	500
	Electrical Test	ATP at +25°C	500
	Sub Lot Split		
A	Electrical Test	ATP at -40,25,80°C	40
A	Infrared Reflow Simulation	35 seconds above 235°C max 245°C total of 180 seconds	392
A	Electrical Test	ATP at +25°C	392
	Sub Lot Split		
B	High Temperature Operation Bias	150°C for 600 hrs	300
B	Electrical Test	ATP at 25°C -40,25,80°C	280 20
C	Autoclave	96 hrs 100% RH 15 psi	76
C	Electrical Test	ATP at +25°C	76
D	Temperature Cycle	200 cycles -55 to +150°C 30 min dwell at extremes	96
D	Electrical	ATP at 25°C -40,25,80°C	76 20
E	ESD Classification	MIL-STD-3015	6
F	DPA	REL-002	4
G	Physical Dimensions	100% of dimensions coplanarity < 4 mils	22
G	Resistance to Solvents	MIL-STD-2015	22

Table 1. One-time Product Qualification Procedure

MMIC LNA Product Customer Use Considerations

The SOIC-8 MMIC LNAs are fairly straightforward to use. By following some basic design considerations, the performance in the data sheet is easily achieved. The following sections discuss the electrical (DC and RF), manufacturing, and reliability considerations the customer must keep in mind for proper use of these MMIC LNAs.

Customer Electrical Considerations

These MMIC LNAs were designed to be used on low cost FR4 printed circuit boards. Before discussing the proper board layout, an understanding of each of the pins of the LNA family is necessary. All the products of the MMIC LNA family have the same pin assignments, shown previously in Figure 7, except for the AM50-0002, which will be discussed separately below. Pins 1, 4, 5, an 8 are DC and RF ground. Pins 3 and 6 are RF_{IN} and RF_{OUT}, respectively. Pin 7 is V_{DD}, a positive voltage, and pin 2 is an optional bias control pin. For nominal current operation, no external connection is made to pin 2.

An important consideration is the off-chip components used for DC biasing, Pin 7, the V_{DD} pin, must be by-passed with a 500-pF surface mount MLC capacitor mounted as close as possible to the pin. RF decoupling of the power supply with a chip inductor of at least 15 nH is recommended. Pin 2 is a parallel connection to the first stage FET source resistor and is normally left open. Connecting a chip resistor from pin 2 to ground will increase the current draw and extend the dynamic range of the LNAs as shown on the data sheets and discussed below in the product applications section. For the low gain MAAM12022, MAAM12032, and MAAM22010, connecting a 30-35 ohm resistor from pin 2 to ground will increase the current 20 mA from nominal 5 mA. For the high gain MAAM12021 and MAAM12031, connecting a 35-40 ohm resistor from pin 2 to ground will increase the current to 20 mA from the nominal 8 mA. For the higher current AM50-0001, a resistor ranging from 10-40 ohms can be used. For each of these six LNAs, care must be taken so the maximum current rating on the data sheet is not exceeded.

The AM50-0002 has DC and RF ground pins everywhere except for pin 2, RF_{IN}, and pin 6, which is both the RF_{OUT} and V_{DD}. To realize minimum noise performance, the AM50-0002 requires a simple low loss external input matching network. Figure 8 shows the functional diagram of the AM50-0002 and details the requirements of the matching network at 1.575 GHz.

If the system does not provide the bias (V_{DD}) on the RF output line, the bias can be coupled to the RF output line using a simple bias tee network. Please note that the AM50-0002 has no optional bias pin.

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The recommended PCB layout for this MMIC LNA product family, except the AM50-0002, is shown in Figure 9; the AM50-0002 layout is in Figure 10. The main point of both PCB layouts is, first and foremost, proper low inductance grounding. The use of plated through holes close to and under package is strongly recommended. Board thickness is a trade-off between RF transmission line losses on thin boards and ground inductance and transmission line width on thick boards; M/A-COM has used RF board thicknesses from 0.008 to 0.032 inches without significant change in RF performance.

Customer Manufacturing Considerations

Most commercial microwave high volume applications use automated soldering techniques. M/A-COM provides guidelines for surface mount board layout, solder selection and screening, and reflow soldering temperature versus time profile in the application note "Surface Mounting Instructions."

Another manufacturing consideration is getting the heat out of the package. With all of the MMIC LNAs, except for the AM50-0001, the typical temperature rise is less than 20˚C even with the higher current optional bias installed. However, care must be taken when using the AM50-0001 not to exceed the 150˚C junction temperature maximum rating; with a thermal resistance of 125˚C/W and an operating temperature of 85˚C, the maximum power dissipation is 0.5 W.

Customer Quality and Reliability

There are two main areas of concern for the long term reliability of these MMIC LNAs: heat from exceeding the junction temperature maximum ratings and ESD. Thermal effects are relatively straightforward to correct-namely, provide adequate heat sinking. For all the LNAs, except for the AM50-0001, a good RF ground will provide sufficient heat sinking. For the AM50-0001, care must be taken to provide an adequate thermal path, also.

ESD is a major issue for customers to take seriously to ensure long term reliability. As stated before, M/A-COM's GaAs MMIC LNAs low level class 1 EST devices. What this means is that ESD voltage as low as 350 volts can damage the ICs. Remember , static kills; please do as much as possible to eliminate ESD from the manufacturing floor.

MMIC LNA Product Applications

M/A-COM's GaAs MMIC LNAs are intended to be used in the receive chain as the first gain stage of a low noise, high dynamic range receiver. They provide the requisite gain, very low noise figure, high dynamic range, and very low bias current at low cost. While the receive chain applications for the MMIC LNA family are relatively obvious, these MMIC LNAs can provide unique solutions for LO buffering, transmitter driver amplifiers, and a wide variety of applications in addition to those depicted in the data sheet. The following subsections describe a few alternative applications for these MMIC LNAs.

MAAM12022 As An LO Buffer Amplifier

The MAAM12022 was originally designed as a GPC or JDC receive MMIC LNA. However, if you bias the device at 8 volts on pin 7 (V_{DD}) and 20 mA through the use of an external resistor of approximately 30 ohms from pin 2 to ground, it becomes an excellent LO buffer amplifier. It exhibits 16 dB gain, better tan 40 dB of reverse isolation, and produces +14 dBm of output power at –1 dB gain compression. The noise figure performance remains essentially unchanged. The performance graphs of this amplifier over bias are shown in Figures 11 and 12 for gain and P1dB, respectively.

Five other LNAs in this platform share the capability to increase gain and dynamic range through the use of an external resistor from pin 2 to ground and higher bias voltage. The increase in performance for the AM50-0001 is discussed below in a separate subsection. The other two low gain LNAs, the MAAM12032 and MAAM2010, will exhibit performance gains similar to those shown above for the MAAM12022. The two high gain LNAs, MAAM12021 and MAAM12031, will exhibit a gain increase of 2 dB and produce better than +14 dBm at -1 dB gain compression when biased at 8 V and 20 mA.

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MAAM12022 over the 1.2 - 1.6 GHz Frequency Range

Both the MAAM12021 and MAAM12022 can be tuned to cover the 1.2 - 1.6 GHz frequency range with the addition of some external matching networks. The matching networks to accomplish this for both LNAs are shown schematically in Figure 13. Distributed matching is shown, although an equivalent lumped element approach would also suffice. The gain performance of the MAAM12022 when matched using the distributed topology of Figure 13 is shown in Figure 14; the nose figure performance is shown in Figure 15. For this LNA, the external matching has even improved the noise figure in the original frequency range, but at the expense of input match in that range.
External matching networks can be used to extend the frequency range of all the LNAs in this product platform. In fact, the AM50-0002 has been designed to require an external matching network to achieve a good match and minimum noise figure performance at the intended frequency. In some instances, as shown above for the MAAM12022, it may be possible to improve the noise figure of the LNA at the expense of input match. It is also possible to combine external tuning with the bias options described in the previous subsection to create additional performance possibilities with these LNAs.

AM50-0001 as A Transmit Driver Amplifier

The AM50-0001 was originally designed for the cellular industry as a high dynamic range, base station receive amplifier with a noise figure of 1.5 dB and output IP3 of +30 dBm. However, if V_{DD} (pin 7) is set to 8 volts with the same current drain of 50 mA, the AM50-0001 can put out more than +20 dBm of power as shown in the output power versus input power curve of Figure 16.

Performance Data & Recommended Board Layouts

To facilitate ease of evaluation by the customer for either alternative matching networks or to simulate system performance directly, de-embedded S-parameter and noise parameter data is available for all members of the GaAs MMIC LNA family discussed in this application note.

These data files are in DOS ASCII Touchstone® format. Please note that not all biases of each device are available; please consult the factory. Additional performance data, which is discussed in the product applications sections, is also available.

Another avenue for evaluating these MMIC LNAs is by mounting the SOIC-8 to an FR4 board. A typical sample board layout is shown in Figure 17. This sample board accommodates the AM50-0002 and includes the recommended external input matching network for 1.575 GHz operation. A similar sample board layout accommodates the other six LNAs in this product platform. The .dxf files for these layouts are available from the factory. Additionally, these sample boards, as well as LNA samples, can be ordered from the factory.

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Conclusion

This application note was written to show the user how to achieve the performance in the product data sheets, i.e., how to "get what we get." Hopefully, this note has answered some commonly asked questions and expanded on the data sheet information to show some interesting properties of the MMIC LNAs for not only the intended applications of the products but also other applications not immediately obvious from the data sheet.

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Glossary

.dxf	Drawing Interchange File: a standard format for graphics software
AMPS	Advanced Mobile Phone Service: an 800-MHz analog cellular system
ASCII	American Standard Code for Information Interchange
DCS-1800	Digital Communication System: an 1800-MHz mobile cordless system
DECT	Digital European Cordless Telecommunications: a 1900 MHz system
DOS	Disk Operating System
ESD, class 1	Electrostatic Discharge: class 1 ranges from 250 to 2000 volts
FET	Field Effect Transistor
FIT	Failures In Time: a figure of merit for reliability
F_{min}	Minimum Noise Figure
FR4	An epoxy fiberglass dielectric material used for printed circuit boards
f_T	Frequency at which current gain equals unity: a figure of merit for field effect transistors
GaAs	Gallium Arsenide
G_{max}	Maximum Available Gai
GPS	Global Positioning System
GSM	Global System for Mobile Communications: a 900 MHz digital cellular system
IC	Integrated Circuit
IP_3	Third Order Intercept Point: a figure of merit for intermodulation distortion performance
IR	Infrared
ISM	Industrial, Scientific, and Medical: 900 MHz, 2.4 & 5.8 GHz spread spectrum applications
ISO-9001	International Standards Organization Quality Specification 9001
JDC	Japanese Digital Cellular - now known as PDC (Personal Digital Cellular)
JEDEC	Joint Electron Device Engineering Council
L1	Global Positioning System band centered at 1.575 GHz
L2	Global Positioning System band centered at 1.227 GHz
LNA	Low Noise Amplifier
LO	Local Oscillator
MESFET	Metal Semiconductor Field Effect Transistor
MIM	Metal-Insulator-Metal
MLC	Multilayer Capacitor
MMIC	Microwave Monolithic Integrated Circuit
MNS	Metal-Nitride-Semiconductor
PCB	Printed Circuit Board
PCN	Personal Communications Network
PCS	Personal Communications Service
PDC	Personal Digital Cellular: 900 and 1500 MHz systems
PHS	Personal Handy-phone Service: a 1900 MHz digital cordless system
RF	Radio Frequency
SOIC-8	Small Outline Integrated Circuit 8-Lead Plastic Package
SPC	Statistical Process Control
TACS	Total Access Communications a 900 MHz analog cellular system
WLAN	Wireless Local Area Network

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