Data Sheet Intricacies—Absolute Maximum Ratings and Thermal Resistances

by Vicky Wong, Applications Engineer, Analog Devices, Inc.

IDEA IN BRIEF

Frequently asked questions about absolute maximum ratings and thermal resistances are answered.

Op amps that do not function as expected can be very frustrating to the users. There are many ways to build a successful circuit design, but there are even more ways to break one. Unfortunately, 90% of the problems/issues/failures that users face arise from careless or incorrect reading of the data sheet. Here are a couple of frequently asked questions on absolute maximum ratings and thermal resistances that may seem to have obvious answers but yet are often misinterpreted by the general audience.

IS IT ALRIGHT TO OPERATE MY AMPLIFIER SLIGHTLY ABOVE THE ABSOLUTE MAXIMUM RATINGS?

Absolutely not! It is critical to adhere to the absolute maximum ratings in a data sheet to avoid damaging the part permanently. The absolute maximum ratings indicate the limits that a device can tolerate, but not operate at. For example, having an input voltage greater than the absolute maximum causes the input differential pairs of the op amp to breakdown leading to excessive fault current. This not only results in a shift in parametric performance, but also metal migration that over time, destroys the part permanently. In short, keep away from the maximum ratings, or there is a very high chance the part will be destroyed!

TELL ME MORE ABOUT THE ABSOLUTE MAXIMUM RATINGS.

The absolute maximum ratings table contains maximum limits for voltage, temperature, and allowed current.

ABSOLUTE MAXIMUM RATINGS

Parameter	Rating
Supply Voltage	6 V
Input Voltage	$\pm V_{SY} \pm 0.3$ V
Input Current	±10 mA
Differential Input Voltage	$\pm V_{SY}$
Output Short-Circuit Duration to GND	Indefinite
Storage Temperature Range	−65°C to +150°C
Operating Temperature Range	−40°C to +125°C
Junction Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 60 sec)	300°C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Figure 1. Example Absolute Maximum Ratings Table

The maximum supply voltage that can be applied to an op amp is determined by the fabrication process. It refers to the instantaneous value, not the average or final value. Low voltage CMOS op amps from Analog Devices, Inc., are typically limited to 6 V, whereas high voltage bipolar parts are limited to 36 V.

Maximum input voltage depends on the input stage architecture and supply voltage of the op amp. Almost all op amps are protected by ESD diodes. The input ESD diodes determine how far the input voltage can go beyond the supply voltage. Typically, input voltage is limited to one diode drop (about 300 mV to 700 mV depending on the temperature) beyond the supply rails. When the op amp is operated out of the input voltage range, but within the absolute maximum, its parametric performance changes. It will not be damaged, but may not be functional, for example, it may phase reverse, the input bias current, or the input offset voltage may greatly increase. Once the input voltage exceeds the absolute maximum, the op amp is exposed to permanent damage. Users frequently face issues with having

©2011 Analog Devices, Inc. All rights reserved.

a voltage at the input terminals of an unpowered op amp (due to power sequencing). This violates the absolute maximum rating, causes input overvoltage and may destroy the part. An easy way to curb the problem is to use a monolithic input overvoltage protected amplifier. Vendors have integrated on chip input overvoltage protection circuitries as an easy-to-use alternative to discrete analog solutions. An example is Analog Device's overvoltage protected (OVP) precision amplifier, the ADA4091-2. It allows the input voltage to go as far as 25 V above and below the power supply without damaging the part.

Maximum differential input voltage refers to the maximum differential voltage that can be applied between the input terminals without inducing excessive current flow. Some op amps (see Figure 2) have internal back-to-back diodes to protect against base emitter breakdown in the input stage. The number of clamp diodes in between the input terminals gives a guideline of what the maximum input differential voltage is.

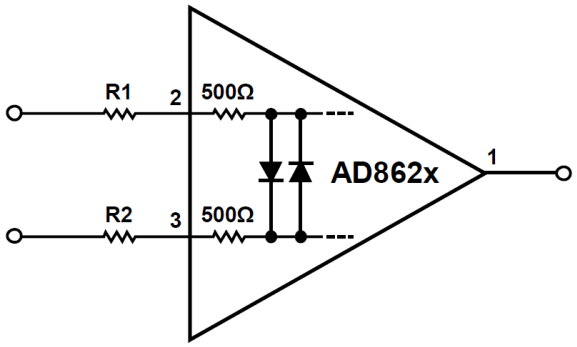

Figure 2. Input Differential Voltage Protection

The absolute maximum ratings table also includes the maximum input current allowed into the input terminals. For data sheets that do not have information on maximum input current, a good rule of thumb is to always limit the input current to less than 5 mA. If input current is expected to be greater than the absolute maximum, insert series resistors at the inputs (see Figure 2) to limit the current flowing into the part. This however, introduces noise and adds to the input referred offset voltage.

DOES THE DEVICE FAIL INSTANTLY WHEN I EXCEED THE ABSOLUTE MAXIMUM RATINGS?

There are a couple of failure modes when exceeding the absolute maximum ratings.

First, device failure occurs instantly when the maximum rating is exceeded. When an extraordinarily large voltage is applied to an amplifier, for example, 30 V supply voltage to a 6 V CMOS amplifier, the internal transistors or junctions break down almost immediately. The device is then permanently damaged.

Second, exceeding the absolute maximum ratings for an extended period can result in device failure. Sometimes, a device does not fail instantly when exposed to an exceeded voltage or current, but will eventually sustain damage in the long run. For instance, supplying 7 V to a 6 V amplifier might be tolerable for a short while. However, as the part is continuously overstressed, junctions are weakened. Ultimately, the part breaks down. In this case, long-term reliability of the device is hugely compromised.

Third, exceeding absolute maximum ratings causes performance degradation and junction overheating that eventually causes device failure. An excess input current can cause parametric performance changes and metal migration. As heat buildup becomes excessive, the junction thermal limits can also be exceeded. Even if the junction thermal limits are not exceeded, the device lifetime is significantly reduced with a higher operating junction temperature.

Therefore, to avoid any damage to the amplifier, it is necessary to avoid violating the absolute maximum ratings. It is also advisable to have ample safety margin from the absolute maximum to extend device lifetime.

WHAT IS THE DIFFERENCE BETWEEN STORAGE, OPERATING, JUNCTION, AND LEAD SOLDERING TEMPERATURE RANGES?

Storage temperature is the temperature at which the device can be safely stored when unpowered. This means the device can be kept in a storage for a temperature range of −65°C to +150°C (see Figure 1), and yet still function as it should when used in a circuit.

The operating temperature refers to the temperature of the surrounding environment or the system with the device powered on. Amplifiers are usually tested and specified to be functional in the operating temperature ranges specified in the electrical table. Some standard operating temperature ranges are:

Commercial range: 0°C to 70°C

Industrial range: −40°C to +85°C

Extended industrial range: −40°C to +125°C

Military range: −55°C to +125°C

The junction temperature is the temperature of the silicon die within the package when the device is powered on. Users

©2011 Analog Devices, Inc. All rights reserved.

often monitor the operating temperature to make sure that they do not violate the maximum rating but fail to consider the internal junction temperature that increases with power dissipation. A junction temperature calculation is discussed in the later part of this article.

Lead soldering temperature refers to the temperature that the package leads can be exposed to during hand soldering. Figure 1 shows 300°C as the absolute maximum lead soldering temperature for 60 seconds before the part is potentially damaged. However, note that hand soldering is not recommended due to reliability concerns.

Analog Devices uses two types of package leads, Sn-Pb leaded leads and Pb-free unleaded leads (as Analog Devices transitions to become RoHS compliant, all new parts released only contain Pb-free materials). Peak soldering temperature during reflow is different for both types, 220°C for Sn-Pb leaded leads and 260°C for Pb-free unleaded leads. More information is detailed in the IPC/JEDEC standard, IPC/JEDEC J-STD-020.

Again, always make sure that the device is maintained within its functional and maximum design temperature limits.

WHAT IS THERMAL RESISTANCE?

Thermal resistance defines the resistance that a heat flow encounters when transferring from one structure (for example: IC junction) to another (for example: ambient air). It is expressed in terms of temperature difference per unit heat flow (units of °C/W). The symbol θ is generally used to denote thermal resistance. Thermal resistance ratings in the data sheet serve as a metric of thermal performance comparison among different packaged devices. In Analog Devices, thermal resistance is specified per JEDEC industry test standard, and the test condition is stated in the data sheet. (JEDEC standards can be downloaded free from the JEDEC website). An op amp that has a junction-to-air thermal resistance of 120°C/W exhibits a temperature differential of 120°C for a power dissipation of 1 W, measured between the IC junction and ambient air.

WHY DO I CARE ABOUT Θ_{JA} AND Θ_{JC}?

Figure 3 shows an example of the thermal resistance table, with information on θ_{JA} and θ_{JC}.

THERMAL RESISTANCE

θ_{JA} is specified for a device soldered on a 4-layer JEDEC standard board with zero airflow. For LFCSP packages, the exposed pad is soldered to the board.

Package Type	θ_{JA}	θ_{JC}	Unit
8-Lead SOIC_N (R-8)	120	45	°C/W
8-Lead MSOP (RM-8)	142	45	°C/W
14-Lead TSSOP (RU-14)	112	35	°C/W
16-Lead LFCSP (CP-16-17)	55	14	°C/W

Figure 3. Example Thermal Resistance Table

θ_{JC}, the junction-to-case thermal resistance, indicates how much resistance a heat flow encounters when transferring between the silicon die junction and the case (package top or bottom). θ_{JC} is dependent on die thickness, surface area, and thermal conductivity of device material in the heat flow path. In the JEDEC test standard, θ_{JC} is defined such that all the heat is assumed to flow through the top of the package to a heat sink. By this definition, no heat flows through the sides or the bottom of the package. Therefore, θ_{JC} is only useful when the package is mounted directly to a heat sink. The lower θ_{JC} is, the more easily heat flows into the heat sink.

$$\theta_{JC} = \frac{T_J - T_C}{P_D}$$

where:
T_J = junction temperature.
T_C = case (package surface) temperature.
P_D = package power dissipation.

θ_{JA}, the junction-to-air thermal resistance indicates how much resistance a heat flow encounters when transferring from the silicon die to the ambient (still) air. It also reflects how well heat flows from the junction to ambient air via all paths. In most cases, the primary heat flow path is the leads to board. θ_{JA} is therefore relevant for packages used without external heat sinks. In practice, θ_{JA} is affected by surrounding environment and mounting techniques. Poor air circulation and use of sockets can significantly increase the thermal resistance. Using a fan to create an airflow and soldering the device onto a circuit board with wide traces allow greater heat dissipation. This helps reduce the junction to ambient thermal resistance, and therefore reduces the junction temperature.

$$\theta_{JA} = \frac{T_J - T_A}{P_D}$$

where T_A = ambient temperature.

www.analog.com
©2011 Analog Devices, Inc. All rights reserved.

Note that θ_{JA} is mostly used to rate packages and should not be used to predict thermal performance of a system. It serves as a metric for thermal performance comparison between different packages tested in the same environment. A lower θ_{JA} number indicates that the device has better thermal performance and is less likely to overheat. Larger packages (with larger surface area) can dissipate heat more effectively and thus, usually have lower thermal resistances.

With a known ambient temperature and power dissipation, θ_{JA} is also frequently used to calculate die junction temperature. However, note that θ_{JA} gives useful information only when the system environment is nearly identical to the JEDEC defined test environment. θ_{JA} is highly dependent on board design (such as, number of buried planes, other existing heating elements, amount of copper traces) and test environment conditions.

A word of advice: θ_{JA} should be used with great caution in temperature calculations. It usually gives inaccurate thermal computation results due to the differences between the real and test environments.

HOW CAN I APPROXIMATE JUNCTION TEMPERATURE TO MAKE SURE THE ABSOLUTE MAXIMUM IS NOT VIOLATED?

Assuming identical test conditions as the thermal test standard, die junction temperature can be calculated using the following equation:

$$T_J = T_A + (\theta_{JA} \times P_D)$$

T_A is known and θ_{JA} is given. Power dissipation of the package can be determined from the following equation:

$$P_D = (I_{SY} \times V_{SY}) + I_{LOAD} \times (V_{SY} - V_{OUT})$$

where:
$I_{SY} \times V_{SY}$ refers to the quiescent power dissipation.
$I_{LOAD} \times (V_{SY} - V_{OUT})$ is the power dissipation of the output stage transistor.

As an example, both channels of the dual AD8622 in SOIC package configured in Figure 4 have a total of 66 mW of power dissipation.

$$P_D = 2 \times \left((350\,\mu\text{A} \times 30\,V) + \frac{15\,\text{V}^2}{10\,\text{K}\Omega} \right)$$

$$P_D = 66\,\text{mW}$$

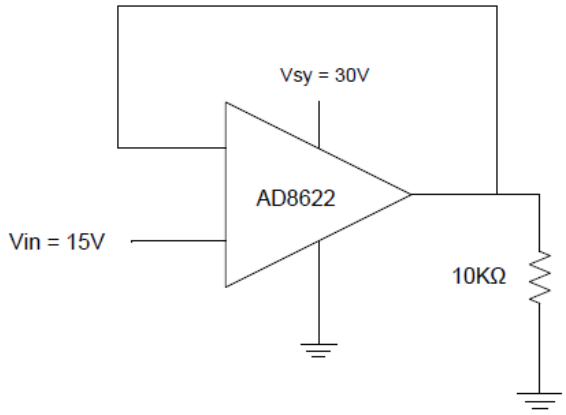

Figure 4. Unity Gain Voltage Follower

For an ambient temperature of 25°C, T_J can be calculated with the following. (Refer to Figure 3 for thermal resistance value.)

$$T_J = 25 + \left(\frac{120^\circ\text{C}}{W} \times 66\,\text{mW} \right)$$

$$= 32.92^\circ\text{C}$$

Had the quad AD8624 (TSSOP) been used, power dissipation would double to 132 mW and junction temperature would increase to 39.78°C.

$$P_D = 4 \times \left((350\,\mu\text{A} \times 30\,\text{V}) + \frac{15\,\text{V}^2}{10\,\text{K}\Omega} \right)$$

$$= 132\,\text{mW}$$

$$T_J = 25 + \left(\frac{112^\circ\text{C}}{W} \times 132\,\text{mW} \right)$$

$$= 39.78^\circ\text{C}$$

For a reliable design, develop a thermally efficient circuit board with large area of low thermal resistance copper traces and use multiple PCB layers with multiple vias to help conduct heat away from the package. Also, select a low thermal resistance package, or decrease power dissipation with a lighter load or lower supply voltage. Singles are often chosen over duals, and duals over quads to reduce local power dissipation on the PCB.

LASTLY, MY PACKAGE HAS AN EXPOSED PADDLE. WHAT SHOULD I DO WITH IT?

LFCSP packages (see Figure 5) are smaller and usually have an exposed paddle (at the bottom side) to dissipate heat. The exposed paddle works as a heat sink and needs to be soldered to a metal area on the printed circuit board that provides good thermal conductivity to the environment. The

©2011 Analog Devices, Inc. All rights reserved.

data sheet will specify where to solder the exposed paddle to, either to ground or to the negative or positive power supply pin. In many cases, θ_{JA} is tested assuming this connection, and thermal resistance will be higher than specified if the connection is not made.

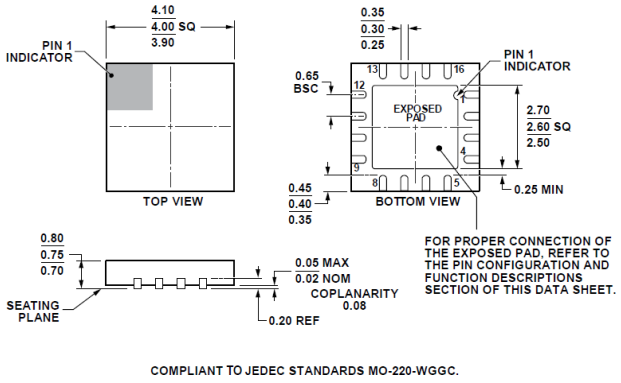

Figure 5. LFCSP Package with an Exposed Paddle

www.analog.com
©2011 Analog Devices, Inc. All rights reserved.

REFERENCES

ADA4091-2/ADA4091-4. *Precision Micropower, OVP, RRIO Operational Amplifier*. Analog Devices, Inc.

AD8665. *16 V, 4 MHz, Rail-to-Rail Output Amplifier*. Analog Devices, Inc.

AN-892 Application Note. *Temperature Measurement Theory and Practical Techniques.* Analog Devices, Inc.

MT-036 Tutorial. *Op Amp Output Phase-Reversal and Input Over-Voltage Protection*. Analog Devices, Inc.

MT-093 Tutorial. *Thermal Design Basics.* Analog Devices, Inc.

Rarely Asked Questions, *What's the big deal about ABSOLUTE MAXIMUM RATINGS?* Analog Devices, Inc.

Zumbahlen, Hank. *Basic Linear Design*, Analog Devices, Inc. Chapter 1. 2007. Also available as *Linear Circuit Design Handbook*, Elsevier.

RESOURCES

Products Mentioned in This Article

Product	Description
ADA4091-2	Dual, Precision, Micropower, OVP, Rail-to-Rail Input/Output Operational Amplifier
AD8622	Dual, Lowe Power, Low Noise, Low Bias Current, Precision Rail-to-Rail Output Op Amp
AD8624	Quad, Low Power, Precision Rail-to-Rail Output Op Amp
AD8665	16 V, 4 MHz Rail-to-Rail Output Amplifier

One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 • Fax: 781.461.3113 • www.analog.com
Trademarks and registered trademarks are the property of their respective owners.
TA10332-0-12/11
www.analog.com
©2011 Analog Devices, Inc. All rights reserved.