Application Note 447 Protection Schemes for BI-FET Amplifiers and Switches

Literature Number: SNOA736
Protection Schemes for BI-FET™ Amplifiers and Switches

To use integrated circuits in real applications, designers must know the limitations of the devices. The major limitations are published in the datasheets, and these fall into two categories: Absolute Maxima — which, if violated, can cause damage or destruction of the device; and Electrical Characteristics — which indicate the performance limitations. Unfortunately, these specifications don’t explain the consequences of a violation, nor what may happen between the violation of an Electrical Characteristic limit and an Abs. Max. limit. This information is needed so the designer can design an appropriate protection scheme.

This article will focus on National Semiconductor Corp. BI-FET op amps: how to improve their reliability and performance. In most cases, the results are similar for bipolar op amps also.

THE BI-FET FAMILIES

Our BI-FET op amps are divided into families: LF411, LF441 and LF356. The LF411 family consists of LF411, LF351, and TL081 (all singles); LF412, LF353, and TL082 (duals); and LF347 (quad). This is a good general purpose set of op amps that all have the same internal design, differing only by grade.

The LF411 family consists of the LF441 (single), LF442 (dual), and LF444 (quad). This family gives nearly the same DC performance as the LF411’s for 1/12th the supply current. However, because they are low-power devices, they are also proportionally slower than the 411’s.

The LF356 family includes the LF355, LF356, and LF357 (in the commercial temperature range). The 355 is the low-Ic part, and the 357 is the wide-bandwidth part. All of the family have good DC specs and can drive a lot of capacitance (to 0.1 µF, typically). They are also among our fastest op amps, having slew rates which vary from 5V/µs (for the 355) to 50V/µs (for the 357).

The operating restrictions for these families are nearly all the same, as are the methods of protection. In some cases (as will be pointed out) certain families are better at surviving the abuses than others.

EXCEEDING COMMON-MODE INPUT VOLTAGE RANGE

The input common-mode range of any operational amplifier is the range of voltages on the input terminals for which the amplifier operates correctly. To understand what happens when the common-mode range is exceeded, four cases must be considered: open- and closed-loop operation at both the positive and negative common-mode limits.

Exceeding Negative Common-Mode Limit

In open-loop operation (i.e., no feedback from output to inverting input, or, during any time that the op amp is slew-rate limited), taking the non-inverting input below the inverting input causes the output to slew toward the negative supply rail. If the voltage at the non-inverting input is more negative than the negative common-mode limit, the input stage ceases to function properly and the output swings to its positive limit. This apparent “phase-reversal” is temporary; bringing the non-inverting input back within the legal input common-mode range restores the part’s normal operation.

If the inverting input is taken below the non-inverting input while the op amp is operated open-loop, the output slewed toward the positive rail. Exceeding the negative common-mode limit in this condition does not cause a “phase reversal”, as the output will still head toward, or remain at, the positive rail.

In closed-loop operation, exceeding the negative common-mode at either input limit, also causes the output to swing to the positive supply rail.

Exceeding Positive Common-Mode Limit

In general, the positive common-mode limit is at or beyond the positive supply. Taking either input above the positive common-mode limit while in open-loop operation does not cause a “phase reversal” at the output; the output will slew toward whichever rail one might expect. However, if both inputs are driven above the positive common-mode limit, the output will slew to the positive rail. In addition, while operating in a closed-loop mode, taking either input above the positive common-mode limit will also drive the output to the positive rail.

INPUTS EXCEEDING SUPPLY RAILS

If either input is pulled above V+ nothing happens until the difference between the input and V+ gets near the breakdown voltage, typically 50V. At this point, the FET’s gate-source junction avalanches and will draw all the current it can. Limiting this input current to something less than 3 mA helps prevent damage. The best protection (in addition to limiting the input current) is a diode clamp from each input to V+.

If transients are expected, use a fast-recovery diode, such as an IN4148. For low-leakage (but less speed), the C-B junction of a good transistor (i.e. 2N3904) is recommended. Failure to clamp the voltage or limit the current adequately may not destroy the part, but the offset voltage and bias current will be permanently degraded.

If either input is pulled more than a few tenths of a Volt below V- (even if this pin is floating), a lightly-doped parasitic substrate transistor turns on. This transistor’s collector current cannot be controlled externally, so allowing it to turn on can cause metal migration and destruction of the input stage (or at least a major unbalancing). In the newer LF411 and LF441 families, this transistor has been controlled by the addition of a diode from base to emitter which kills the gain of the transistor and keeps its current low. Any input current should still be limited to 1 mA or less. However, the older parts and members of the LF356 family are still susceptible, so it is best to protect all the BI-FETs from this potential abuse by using the clamp diodes (see Figure 1 below).

Bi-FET™ is a trademark of National Semiconductor Corp.

© 1998 National Semiconductor Corporation

AN447

Protection Schemes for BI-FET Amplifiers and Switches

AN-447

Wanda Garrett

July 1987
Since this parasitic transistor turns on easily, the best way to keep it turned off is to use a Schottky diode, its on-voltage being less than that required to turn on the transistor. For lower leakage, a short-base switching diode (such as the Fairchild FD200 series) may be used. Its forward drop will be larger at low currents, but will stay constant for a wide current range, as opposed to the relatively leaky Schottky diodes.

POWER SUPPLY SEQUENCING

Adding the clamp diodes shown in Figure 1 not only protects the inputs from transients when the circuit is operating, but protects them as power is being applied to the circuit. Because the parasitic transistor appears when the input voltage is less than the negative supply, applying the positive supply or input voltage before the negative supply is applied can cause this problem. For this reason, it is always recommended that the negative supply be turned on first, if the supplies can be turned on independently. This is especially important for protection of the BI-FET switches.

Also, even if the input stage is well protected with clamp diodes and current limiting, the inputs should not be allowed to be heavily unbalanced (for example, one input at ground and the other at the rail) for extended periods of time (for example, many hours). The long-term effects of an unbalanced differential pair are increased offset voltage and offset current.

SUPPLY VOLTAGES OUT OF RECOMMENDED RANGE

Attempting to run a BI-FET on supply voltages less than the recommended total of 10V will narrow the common-mode input and output ranges, and slow the part down. In the LF411 family, at supply voltages less than 7V, an internal biasing zener turns off and the entire part quits working. With the LF441 family, a supply voltage of less than 6V is not enough to support the internal current source biasing, so eventually these also turn off. And the LF356 family needs all of the 10V to stay in operation.

Running the BI-FETs on supply voltages greater than the Abs. Max limit generally does no harm until the parasitic diode from V+ to the substrate breaks down (in LVDD), or the input gate-source junction breaks down (BVgs). Limiting the supply current to something less than 10 mA improves the chances of the op amp's survival. These breakdowns typically occur at about 50V, but the devices are only tested up to 36V or 40V, depending on the device. In addition, power dissipation must be considered when the supply voltage is large.

OPERATING TEMPERATURE OUT OF ABSMAX RANGE

BI-FETs generally operate well when the ambient temperature is cold. The bias current becomes minimal, the input noise often decreases, and the bandwidth increases. However, if the device is in a marginally stable design, it may oscillate as its phase margin will also decrease.

Conversely, running the BI-FETs at temperatures greater than 100°C brings the bias current into the nanoamp range, and drops the gain-bandwidth product by 20% or more (compared to 25°C performance). Most op amps quit working between 180°C and 250°C due to excessive leakage currents or internal thermal shutdown mechanisms, and the BI-FETs are no exception. The maximum guaranteed junction (die) temperature of our ICs is 150°C, and some lower-grade parts and those in plastic DIP packages are guaranteed to as low as 100°C.

The type of package used affects the maximum ambient temperature allowed, since the junction temperature must remain in the "legal" range and the different packages have different heat-sinking properties. The metal can packages have the lowest thermal resistance, and have the additional advantage that heat-sink fins are easy to find and attach to the package (when needed).

DRIVING CAPACITANCE

Both the LF411 and LF441 families have a lot of trouble driving more than about 200 pF without oscillating. Standard techniques to get around this problem are to add a small resistor (about 50 Ω) in series with the output (see Figure 2) or to use one of the LF356 family (the 356 itself being the most popular for this purpose). An explanation of why the 356 output stage is so unusually strong is provided in the second reference listed.

POWER SUPPLY BYPASSING

Another potential cause of oscillation is inadequate power supply bypassing.

When extra output filtering is desired, a series RC damper will often be more effective than just a large filter capacitor.

www.national.com
ductance of the power supply leads degrades the effectiveness of the op amp’s internal compensation, which invites oscillation.

The BI-FETs need the supply bypassing most on their V− terminals, as do many of the bipolar-input amplifiers. Good bypassing techniques include (1) putting the bypass capacitors right next to the IC, and (2) using an appropriate type and size of capacitor. Ceramic types are often used because of their small size and low cost, but their effectiveness is limited to about 1 MHz. Typical values used are between 0.01 µF and 0.47 µF.

Tantalum capacitors are often used for high-frequency bypassing. However, their lead inductance can sometimes aggravate the situation instead of correcting it. Adding a small (0.01 µF) ceramic disc capacitor in parallel with the tantalum improves the overall performance. Typical values used for tantalum bypass capacitors range from 2.2 µF to 10 µF.

Mylar capacitors are also used for bypassing, but the monolithic ceramics have better high frequency performance and cost less.

Where the supply voltages have poor load regulation, electrolytic capacitors (typically 10 µF to 47 µF) can provide additional filtering.

DEALING WITH THE OFFSET VOLTAGE

If the offset voltage of a BI-FET op amp is first measured in a test circuit, and then again after the device is installed in the final circuit, a change in Vos will often be detected. This is due to a difference in stress put on the die when the device (packaged or not) is installed in the two circuits. Because the input JFETs are largely surface devices, any stress on them changes their characteristics noticeably. This, then, changes the Vos of the input stage. This problem is more apparent with the larger devices and packages, i.e. when there is more surface to be stressed. Thus, the most sensitive would be a large quad in a 14-pin DIP; the least, a small single op amp in a metal can (TO-5) package.

To improve the accuracy of the BI-FET op amps, the offset voltage should be nulled after the devices are in their final circuits. The BI-FET offset voltage has an associated drift of between 2 µV/°C and 10 µV/°C (depending on the device) for every millivolt of offset at room temperature. The Vos null schemes will affect the offset drift; it is equally likely that the drift will increase rather than decrease, because the sources of BI-FET Vos are complex.

The easiest Vos cancelling technique is the trim scheme provided in the op amp’s datasheet. The LF411 and LF441 require a 10k potentiometer between the trim pins (1 and 5), with the wiper to V−. The LF356 family requires a 25k pot with the wiper to V−. A larger pot would extend the trim range, but this is not necessary since the specified resistance is sufficient to correct even the worst case Vos.

Dual and quad op amps have no trim pins, so they are used most often when small offsets can be tolerated. An external bias voltage can be added at the input to cancel the Vos at a given ambient temperature (Ta). Typical trim schemes are given in Applications Note AN-3.

In general, the reasons for the Abs. Max. ratings and recommendations are a combination of convention and necessity. Exceeding the ratings and recommendations does not always mean death of the op amp, but the reliability and performance of the amplifier are kept at their highest when the part is used properly and protected from excesses.

References:


LIFE SUPPORT POLICY

NATIONAL’S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.

2. A critical component in any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

National does not assume any responsibility for use of any circuitry described, no circuit patent licenses are implied and National reserves the right at any time without notice to change said circuitry and specifications.
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for compliance with all legal and regulatory requirements concerning such use. Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any damages arising out of the use of TI products in such applications.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

<table>
<thead>
<tr>
<th>Products</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio</td>
<td>Communications and Telecom</td>
</tr>
<tr>
<td>Amplifiers</td>
<td>Computers and Peripherals</td>
</tr>
<tr>
<td>Data Converters</td>
<td>Consumer Electronics</td>
</tr>
<tr>
<td>DLP® Products</td>
<td>Energy and Lighting</td>
</tr>
<tr>
<td>DSP</td>
<td>Industrial</td>
</tr>
<tr>
<td>Clocks and Timers</td>
<td>Medical</td>
</tr>
<tr>
<td>Interface</td>
<td>Security</td>
</tr>
<tr>
<td>Logic</td>
<td>Space, Avionics and Defense</td>
</tr>
<tr>
<td>Power Mgmt</td>
<td>Transportation and Automotive</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Video and Imaging</td>
</tr>
<tr>
<td>RFID</td>
<td></td>
</tr>
<tr>
<td>OMAP Mobile Processors</td>
<td></td>
</tr>
<tr>
<td>Wireless Connectivity</td>
<td></td>
</tr>
</tbody>
</table>

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2011, Texas Instruments Incorporated