Application Note

Comparator Input Types

Abstract

This Application Note will discuss the differences between the classic NPN, PNP, ESD clamp protected, "Fault Tolerant", "Failsafe" and "Above-the-Rail" input types.

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1 Introduction

There are several types of inputs for comparators, and this may cause some confusion. This appnote will attempt to explain and clarify the various differences between the types and precautions needed for these types.

2 Input Types

2.1 Classic Bipolar Inputs

Older bipolar devices, such as the LM311 and LM319 comparator families, are built on a bipolar junction isolated process. These older processes have larger junction sizes and are robust enough that dedicated ESD protection was not required. Therefore these older devices do not contain dedicated ESD structures and do not have input clamps and rely on device breakdowns when the input is above the supply and the intrinsic body diodes for inputs below the negative supply.

Because these older devices do not have ESD clamping structures, external clamping is required to ensure that the input voltages do not exceed the input specifications.

These devices were also designed for split supply voltages (e.g., ±15 V) applications, with the input signal reference expected to be around mid supply range (e.g., ±1 V). So the valid input range may fall short of the rail by 500 mV to 2 V (not "Rail to Rail" or "Ground Sensing"), limiting the input voltage range.

2.2 ESD Protected Inputs

CMOS and modern low voltage bipolar devices will have ESD clamps on the inputs to protect the inputs from ESD strikes and voltage excursions. These ESD structures are present on both Rail to Rail and non-Rail to Rail inputs.

The most common ESD protection is to have a diode from each pin to both supplies.

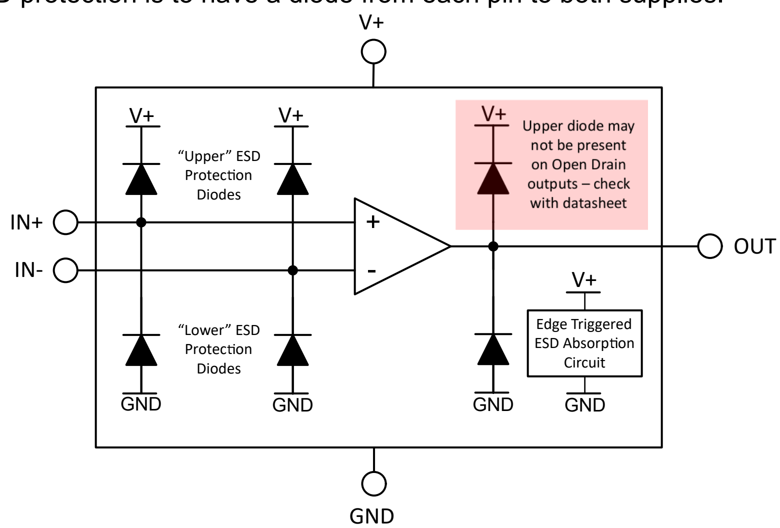

Figure 2-1. Typical ESD Protection Scheme

Having the "upper" ESD diode to the positive supply clamps the input to a diode drop above the positive supply. This limits the amount of voltage the input can go above the supply, usually just 0.2 V to 0.5 V above the supply. If a signal is applied to the input that is larger than the supply voltage and has sufficient current available (such as a battery or another power supply line), it is possible to back-feed the comparators V+ power supply line through the ESD diode. A series current limiting resistor is always recommended in series with the input.

2.3 "Fail-Safe" and "Fault Tolerant" Inputs

"Fault Tolerant" and "Fail-Safe" have been used interchangeably across several device families. These terms are essentially the same and can be used interchangeably within this paper.

"Fault Tolerant" and "Fail-Safe" inputs are defined as being able to be pulled-up to a maximum voltage, without damage, and will remain high impedance, even when Vcc is zero.

Care must be taken when both inputs are taken above the specified valid input range as the output can be indeterminate. Please consult the *Detailed Description* or *Application Information* section of the data sheet for information on the tendency of the output behavior.

These input types do not have the "upper" ESD clamping diode to the positive supply. If any ESD protection is provided, it is usually a snapback or zener-type clamp to the negative supply only.

2.3.1 LM339 Family - The Original "Fail-Safe" Input

The LM339, LM393, LM290x and TL331 family can be considered one of the first "Fail-safe" inputs. These devices are fabricated on a very robust junction isolated bipolar process with PNP's with high reverse breakdowns.

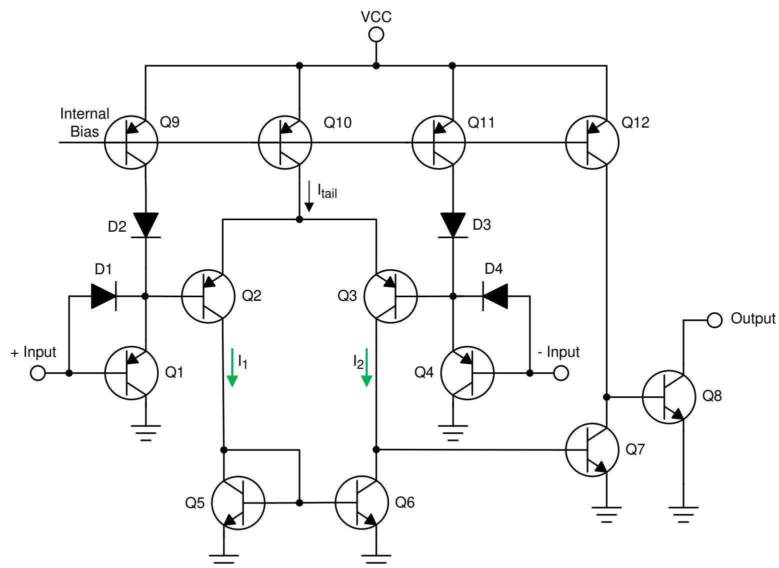

Figure 2-2. LM339 Family Simplified Schematic

In Figure 2-2, when either input is taken from (Vcc - 2 V) to all the way up to 36V, the PNP input stage devices, Q1 or Q4, as well as Q2 or Q3, Base-Emitter junctions are reverse biased and turn off. D2 and D3 block the reverse current to protect the current source transistors Q9 and Q11. This state cuts off the tail current (I1 and I2) and the output falls to a known state. The input bias current is in the sub nanoamp level as it is now just the reverse leakage currents of the transistor and diode junctions.

One of the "features" of the LM339 family is that the output remains correct as long as one input is still within the valid input voltage range. This is because the input device that is still within range still has tail current flowing to signal the following stages the proper output state. When both outputs are above the valid input range, all tail currents are cut off and the output defaults to a known state. For more information, please see section 2 of the application note "Application Design Guidelines for LM339, LM393, TL331 Family Comparators".

2.3.2 Modern "Fail-Safe" Inputs

Modern designs utilize advanced process features and proprietary design techniques to achieve similar functionality to the LM339 behavior in modern CMOS processes. In many cases, rail to rail input functionality is also added.

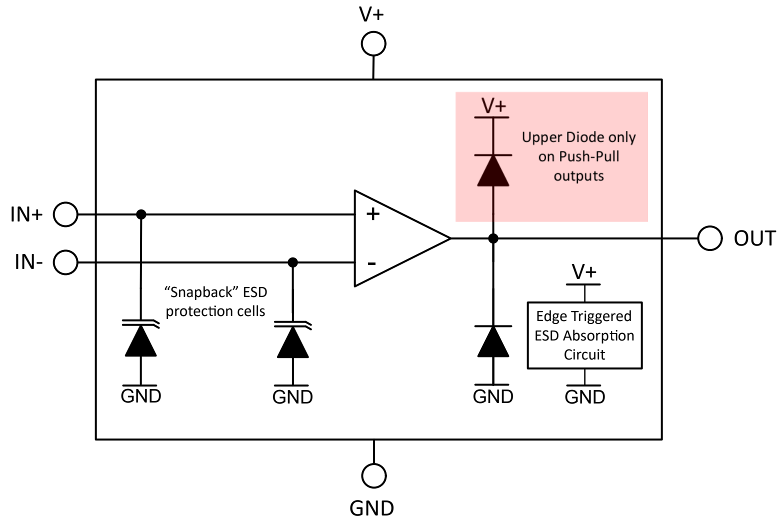

Figure 2-3. "Failsafe " ESD Protection

The "Fail-Safe" inputs do not have the "upper" ESD diodes. ESD protection is provided by Snapback or other ground-based clamps. Due to the lack of the upper ESD clamp, the inputs can be taken above the supply voltage, up to a specified maximum voltage, regardless of the supply voltage. The inputs remain high impedance with no damage during this state.

For "Fail-safe" inputs, depending on the device, the output can have a defined behavior when both of the inputs are above the supply voltage. Some devices can maintain a correct output as long as one of the inputs is still within the valid input voltage range, or default to a known high or low output state. Please consult the data sheet applications section for that device for any mention of the output behavior when the input voltage is above the comparator supply voltage. TI always recommends staying within the specified input range.

Because these inputs lack the upper input clamp, please see the Section 4 section.

2.4 "Over-the-Rail" Inputs

"Over-The-Rail" inputs are similar to the "Fail-Safe" inputs, but the difference is the valid input voltage range extends up to the specified maximum input voltage (e.g, 5.5 V) and is independent of supply voltage and proper output switching will still be maintained. The inputs will also remain high impedance even when the comparator supply voltage is removed.

This functionality does come at a cost. When the input voltage is greater than the supply voltage, the input bias currents may reverse direction and increase considerably (100x to 1000x). Offset voltages may also shift value and/or polarity. Propagation delay may also vary. The individual datasheet graphs and applications section of the particular device should be consulted.

The "Over-the-Rail" input is ideal for high-side measurement applications, such as monitoring a battery voltage without a divider while powered off the regulated processor supply voltage. An example would be measuring a 4.2V battery supply directly while the comparator is powered from the digital logic supply for proper output logic levels. Or other applications where the source input voltage is continuous and cannot be loaded down when the comparator power is removed.

Because these inputs lack the upper input clamp, please see the Precautions for "Failsafe" and "Over-The-Rail" inputs section.

3 Identifying The Difference Between The Input Types

The most obvious way to determine the input type for newer devices is to refer to the data sheet front page or Applications Section.

Lacking any front page mention, to determine the type of input, refer to the Maximum Input Voltage on the device *Absolute Maximum* (Abs Max) and/or *Recommended Operating Conditions* Tables in the device data sheet.

Please understand that the *Absolute Maximum Ratings* table just define limits to avoid damage. Proper output operation is not specified in the region between the Recommended (specified) limits and *Absolute Maximum* table ratings.

3.1 Older Bipolar Device Inputs

The older device inputs generally have the input voltage limits at, or slightly less than the supply voltages.

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

			MIN	MAX	UNIT
	Supply voltage	V_{CC+} (2)		18	V
		V_{CC-} (2)		–18	
		$V_{CC+} – V_{CC-}$		36	
V_{ID}	Differential input voltage (3)			±30	V
V_I	Input voltage (either input)(2)(4)			±15	V

(2) All voltage values, unless otherwise noted, are with respect to the midpoint between V_{CC+} and V_{CC-}.
(3) Differential voltages are at IN+ with respect to IN–.
(4) The magnitude of the input voltage must never exceed the magnitude of the supply voltage or ±15 V, whichever is less.

Figure 3-1. Example of LM311 Abs Max Table

Pay special attention to any footnotes. Note that footnote 4 above states that the input must **not** exceed the supply voltage ***or*** ±15 V, ***whichever is less.***

3.2 Identifying ESD Clamped Inputs

If the *Absolute Maximum Ratings* upper input voltage is referenced to the supply, such as "V+" or "Vcc + 0.2", then that is a good sign that there is an upper ESD clamp. Excursions outside the supplies need to be limited to prevent the ESD diodes from conducting (typically around 500 mV - 600 mV depending on process).

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

	MIN	MAX	UNIT
Supply voltage: V_S = (V+) – (V–)	–0.3	42	V
Input pins (IN+, IN–) from (V–), Rail-to-Rail Input(2)	–0.3	(V+) + 0.3	V
Current into Input pins (IN+, IN–)	–10	10	mA

Figure 3-2. Example of TLV1812 Abs Max Table for ESD Clamped Inputs

Figure 3-2 from the TLV1812 data sheet *Absolute Maximum Ratings* table shows an example of the ESD clamped inputs. Notice that the highlighted "Input Pins" row shows a Max of "(V+) + 0.3", which is referred to the V+ power supply rail.

3.3 Identifying "Failsafe" or "Over-The-Rail" Inputs

If the upper input voltage is an absolute number, such as "36 V" or "6 V", then that is a sign that there are not any upper ESD clamps.

7.2 Absolute Maximum Ratings for Non-B Versions

over operating free-air temperature range (unless otherwise noted)[(1)]

		MIN	MAX	UNIT
V_{CC}	Supply voltage[(2)]		36	V
V_{ID}	Differential input voltage[(3)]		±36	V
V_I	Input voltage range (either input)	–0.3	36	V
I_K	Input current[(5)]		–50	mA

Figure 3-3. Example of LM339 Abs Max Table for Failsafe Inputs

The above table from the LM339 data sheet *Absolute Maximum Ratings* table shows an example failsafe inputs with no upper ESD clamps. Notice that the "Input Voltage Range" line is not referenced to the supply and contains an absolute number of 36 V.

"Over-The -Rail" inputs are not as common as "Fail-Safe" inputs (more difficult to implement) and are prominently mentioned on the data sheet front page Features section, specification table table footnotes, or Applications Section.

4 Precautions for "Failsafe" and "Over-The-Rail" Inputs

The non-ESD clamped inputs do not have upper clamps to limit positive voltage excursions, so it is possible to drive the inputs higher than the positive maximum rated input voltage, possibly up to the device breakdown point (and possible damage).

Many customer designs simply place a current limiting resistor in series with the input, and rely on the internal ESD clamp diode to clamp the input voltage to the supply.

This can be an issue if a new fail-safe type input device is replacing a existing conventional ESD clamped comparator with a series resistor in an existing design.

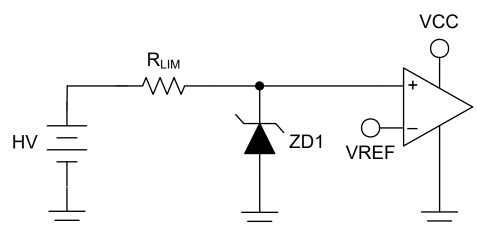

Figure 4-1. Recommended Input Voltage Zener Clamp

External clamping, such as a Zener or TVS to ground, or a Shottky diode to the positive supply, is required to prevent exceeding the maximum input voltage. Figure 4-1 shows adding a zener diode (or TVS) to limit the maximum applied input voltage. TI recommends a clamp current of 1 mA or less.

5 Negative Input Voltages

All the input types have a diode of some type from the input pin to the most negative power supply (Vee, or V-). These diodes can be actual ESD structures, or body diodes or junctions formed by the semiconductor process. The Absolute Maximum voltage for the negative limit is generally -0.2 V to -0.5 V below the negative supply pin.

Applying a negative voltage to any of the pins, not just the input pins, below the negative supply pin can forward-bias these internal parasitic junctions, and cause currents to flow where current is not designed to flow.

These currents can cause malfunction of the device, such as reversals, high supply currents or false outputs, and possibly even cause another channel within the device to malfunction.

In cases where a negative input voltage cannot be avoided, a current limiting resistor in series with the input can limit the current to a safe level, as shown in Figure 5-1. The diode must be a Schottky type for lowest forward voltage. TI always recommends using external clamping components and not to rely on the device internal clamps or ESD diodes.

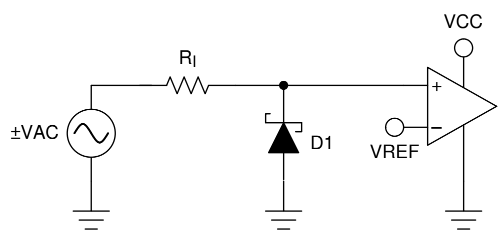

Figure 5-1. Recommended Clamp For Negative Voltages

The resistor must be calculated to limit the current to 1 mA or less at the highest expected voltage. A rule of thumb is 1 kΩ per volt of expected overvoltage. This resistance can be part of the divider or other resistive input network.

For more information on protecting the inputs, please see section 2.9 of the "*Application Design Guidelines for LM339, LM393, TL331 Family Comparators*" application note.

6 Input Types Comparison Table

Table 6-1 shows the difference between the various comparator family types.

Table 6-1. Comparison of Input Types by Family

Family	Upper ESD Diode?	Fault Tolerant or Fail-Safe?	Over-The-Rail?	Specified Input Voltage Range	Abs Max Input Voltage Range	Comments
LM111, LM211, LM311	N	N	N	Vee+0.5V to Vcc-2V	Vee to Vcc, or ±15V, whichever is less	Limited input range
LM119, LM219, LM319	N	N	N	Vee+2V to Vcc-2V	Vee to Vcc, or ±15V, whichever is less	Limited input range
LM339, LM393, TL331	N	Y	N	Vee to Vcc-2V	Vee to 36 V	Inputs Hi-Z when above Vcc, Output is correct when one input is within range. Defined output state when both outputs are above Vcc.
TLV1701, TLV1702, TLV1704	Y	N	N	Vee to Vcc	Vee-0.5V to Vcc+0.5V	Inputs above Vcc clamps to Vcc
TLV181x, TLV182x,	Y	N	N	Vee-0.2V to Vcc+0.2V	Vcc + 0.2	Inputs above Vcc clamps to Vcc
TLV185x, TLV186x,	N	N	Y	Vee to 40 V	Vee to 40 V	Output correct even when both inputs up to 40 V, independent of Vcc.
TLV701x, TLV702x, TLV703x, TLV704x,	N	Y	N	Vee-0.2V to Vcc+0.2V	Vee to 6 V	Inputs Hi-Z when above Vcc, Output undefined when both inputs are above Vcc.
TL331LV, LM339LV, LM393LV, TLV90xx	N	Y	N	Vee-0.2V to Vcc+0.2V	Vee to 6 V	Inputs Hi-Z when above Vcc, Output correct as long as one input is within range.
TLV3011, TLV3012	Y	N	N	Vee-0.2 V to Vcc+0.2 V	Vee-0.5 V to Vcc+0.5 V	Inputs above Vcc clamps to Vcc
TLV3011B, TLV3012B	N	Y	N	Vee-0.2V to Vcc+0.2V	Vee to 7 V	Inputs Hi-Z when above Vcc, Output is correct when one input is within range. Defined output state when both outputs are above Vcc.

7 Summary

- Older devices without dedicated ESD protection require external clamping to avoid exceeding input range.
- Conventional ESD (CMOS or low voltage) input devices will clamp the inputs to the supplies with a diode and should not exceed the supplies.
- "Fault Tolerant" or "Fail-Safe" inputs allow the input to exceed the supply up to a maximum voltage without damage, but the output may not be correct. Inputs remain high impedance.
- "Above-The-Rails" inputs can exceed the supply voltage and are functional up to a maximum voltage, regardless of the supply voltage. Input bias current may increase or reverse when input is greater than the supply voltage.
- Inputs that allow voltages above the supply voltage will need external clamps to avoid exceeding the maximum input voltage.
- Avoid negative voltages on any pin (lower than V-).

8 References

- Application Design Guidelines for LM339, LM393, TL331 Family Comparators