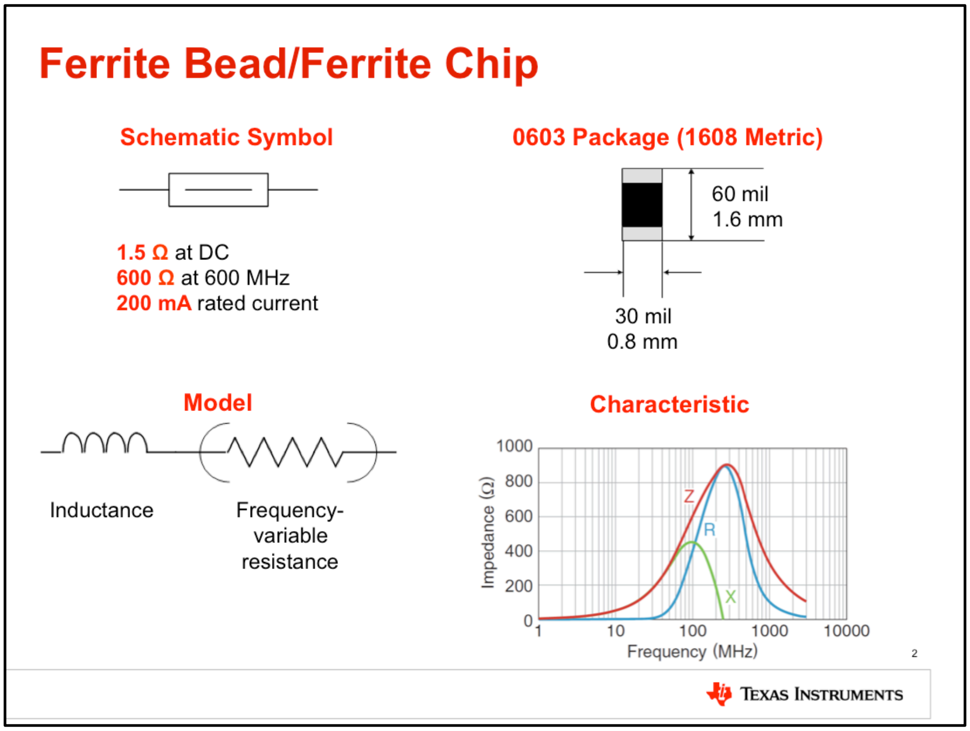
Hello, and welcome to the video for the TI Precision Labs discussing electrical overstress, or EOS, part 2. In this video we'll discuss more devices which are used for EOS protection, such as bidirectional TVS diodes, ferrite beads, and RC filters. We'll also discuss how the internal input protection and ESD structures of op amps behave during EOS events.

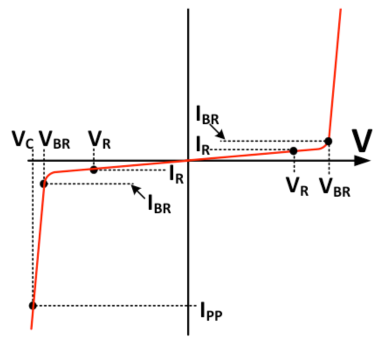


The ferrite bead, or ferrite chip, is a device which is useful for protecting against the effects of radio-frequency, or RF, energy coupled to a circuit's input or output.

At DC and low frequencies, the resistance of a ferrite bead is practically zero. At high frequencies, the resistance increases significantly as shown in the figure on the bottom-right. The characteristics of several ferrites are shown, but you can see that the resistance can increase to over 800Ω at 200MHz. The ferrite bead is especially useful in cases where a large fixed resistor is not practical, and RF pick-up is a problem.

Bidirectional TVS Diode

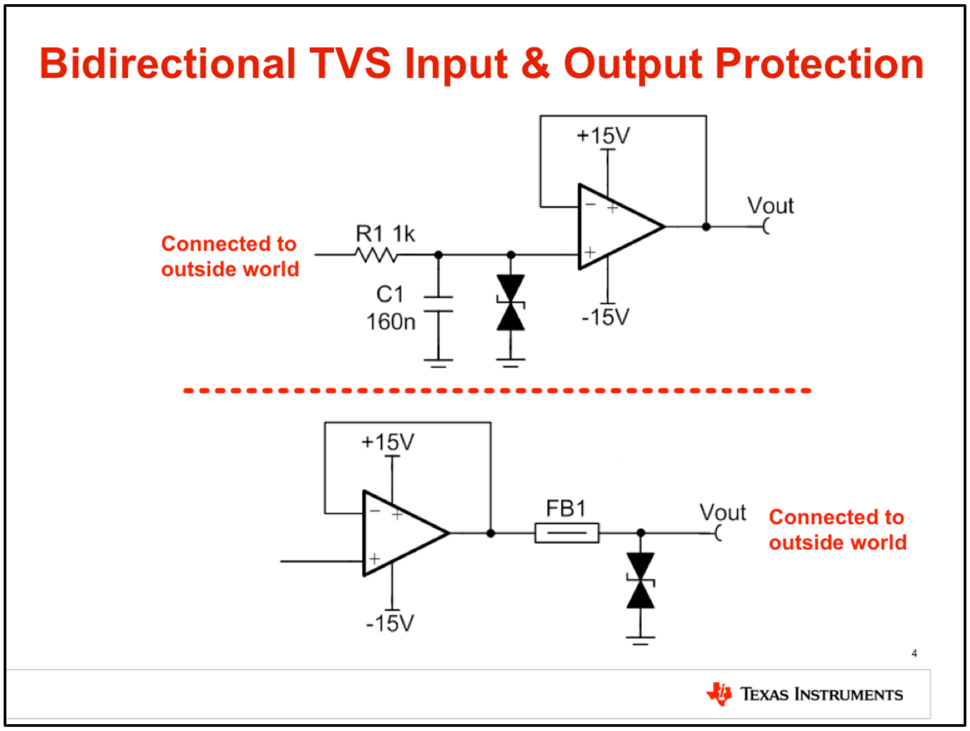
Symbol	Parameter
V_{BR}	Breakdown voltage
V_R	Stand-off voltage
V_C	Clamping voltage
V_F	Forward voltage drop
I_{BR}	Breakdown Current @ V_{BR}
I_R	Reverse Leakage @ V_R
I_F	Forward Current @ V_F
I_{PP}	Peak Pulse current @ V_C



3

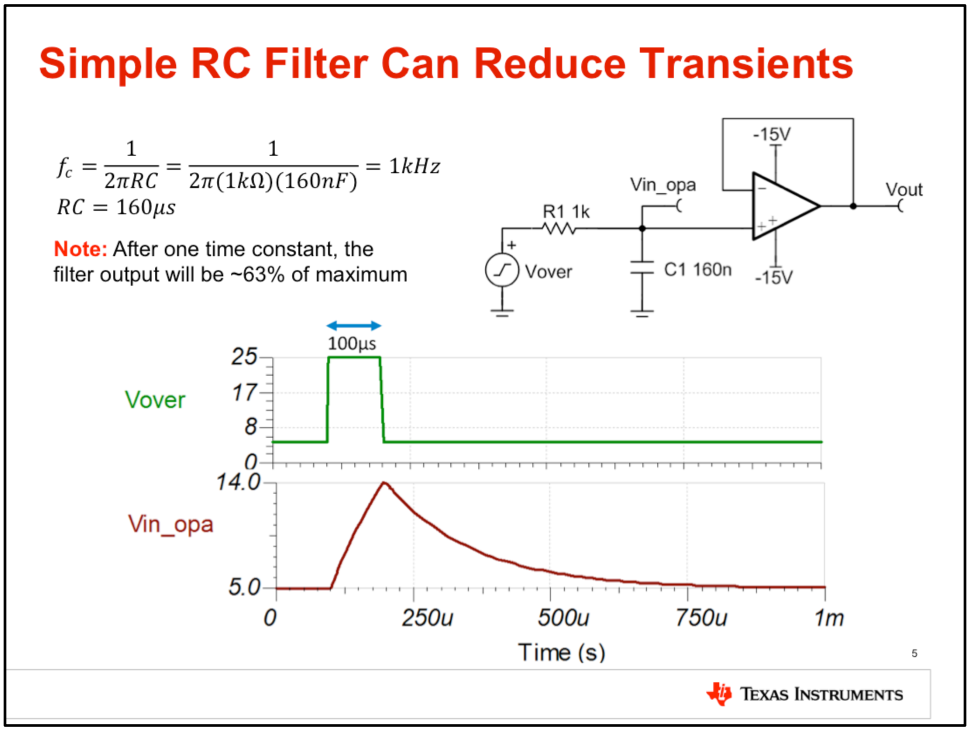
TEXAS INSTRUMENTS

In EOS 1 we introduced the transient voltage suppressor, or TVS, diode. Let's now discuss the bidirectional TVS diode. This device simply acts like two TVS diodes connected at their cathode. It will remain off from the negative breakdown voltage to the positive breakdown voltage. Once the breakdown voltage is exceeded, it will turn on and dissipate large amounts of power.



A bidirectional TVS diode can be used to protect the input or output of an amplifier circuit. At the input, the TVS diode limits the input voltage to levels which are safe for the op amp. An RC circuit is used to attenuate fast input transients, which we'll discuss more on the next slide.

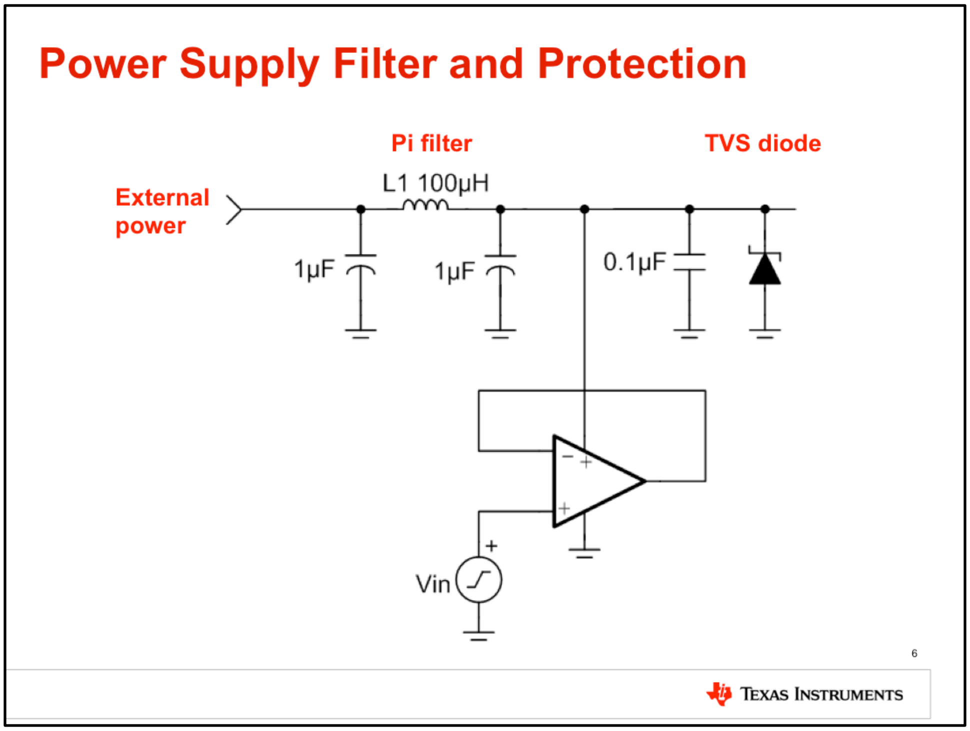
The output protection uses a ferrite bead and a bidirectional TVS diode to again limit the output voltage to safe levels. The ferrite bead is used in the output because a fixed resistor would introduce voltage drop errors and possibly limit the output swing. Note, however, that the ferrite bead does not offer protection against low frequency EOS events.



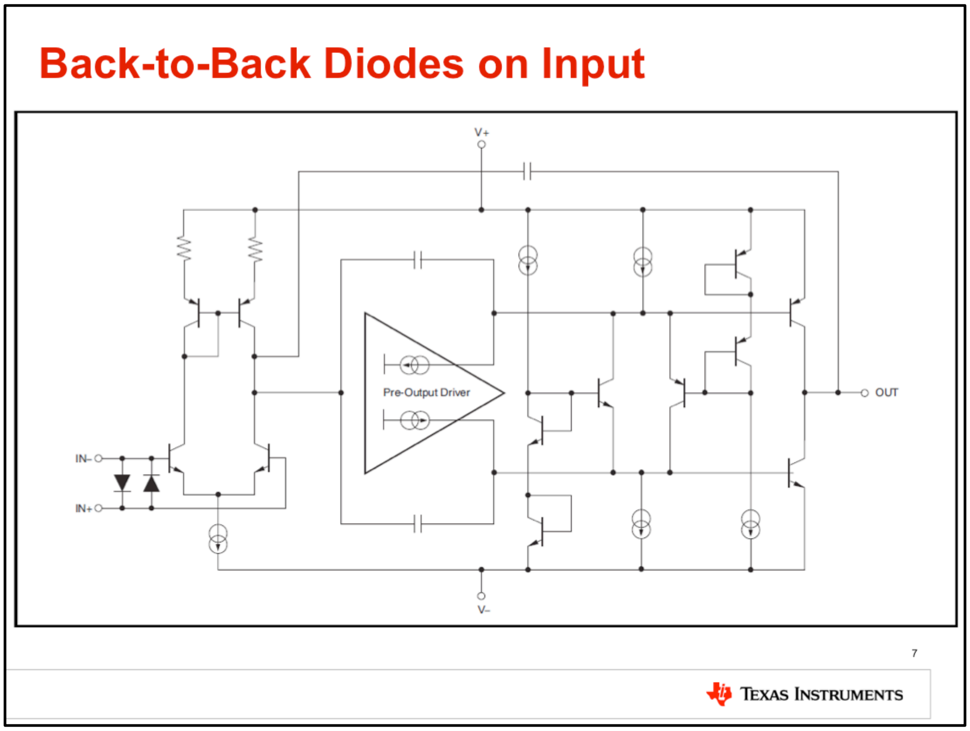
We discussed in EOS part 1 that EOS events can be long events of milliseconds or more. However, EOS events can also be short transient pulses of high voltage. In these cases, a simple RC low pass filter can help minimize the input transient.

This example considers an EOS event at the input of an op amp circuit. An RC low-pass filter is placed on the input with a cutoff frequency of 1kHz and therefore a time constant of 160µs. A general rule of thumb for RC circuits is that the filtered voltage will reach 63% of full value after one time constant and will be nearly fully charged at five time constants.

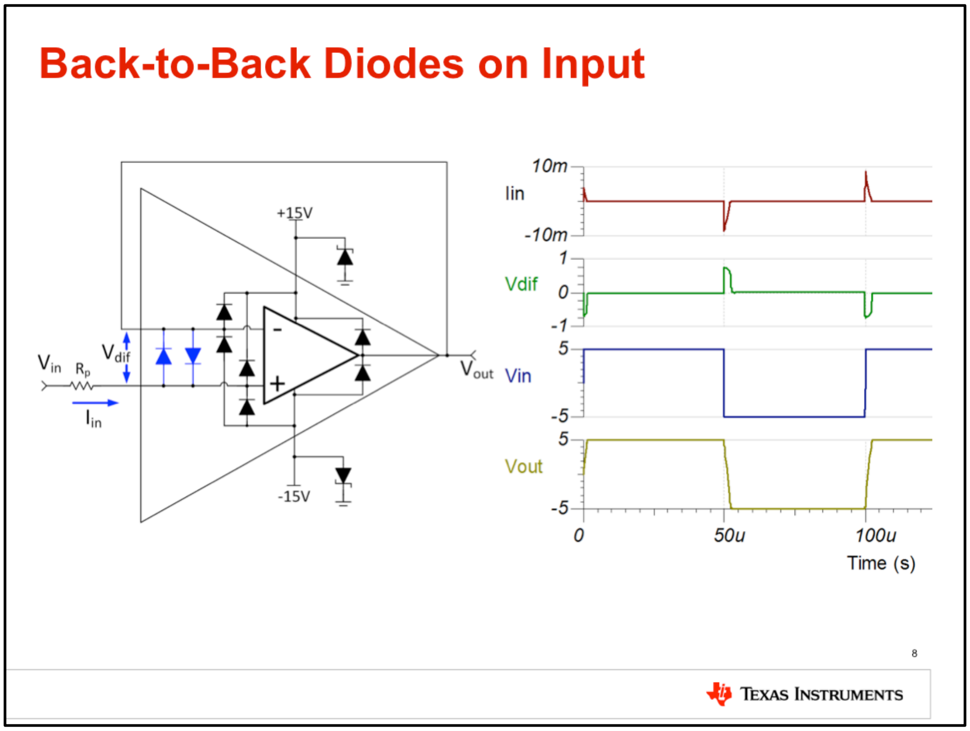
The effect of the RC circuit on an overvoltage pulse can be seen in this simulation example. The pulse is 25 V high and 100 µs wide. 100 µs is less than one time constant, so the pulse will not even reach 63% of its maximum value. Looking at the transient simulation, the op-amp's input voltage is limited to a safe level of 14V. Of course, the effectiveness of this method depends on the bandwidth of the circuit and the magnitude and timing of the overvoltage pulse.



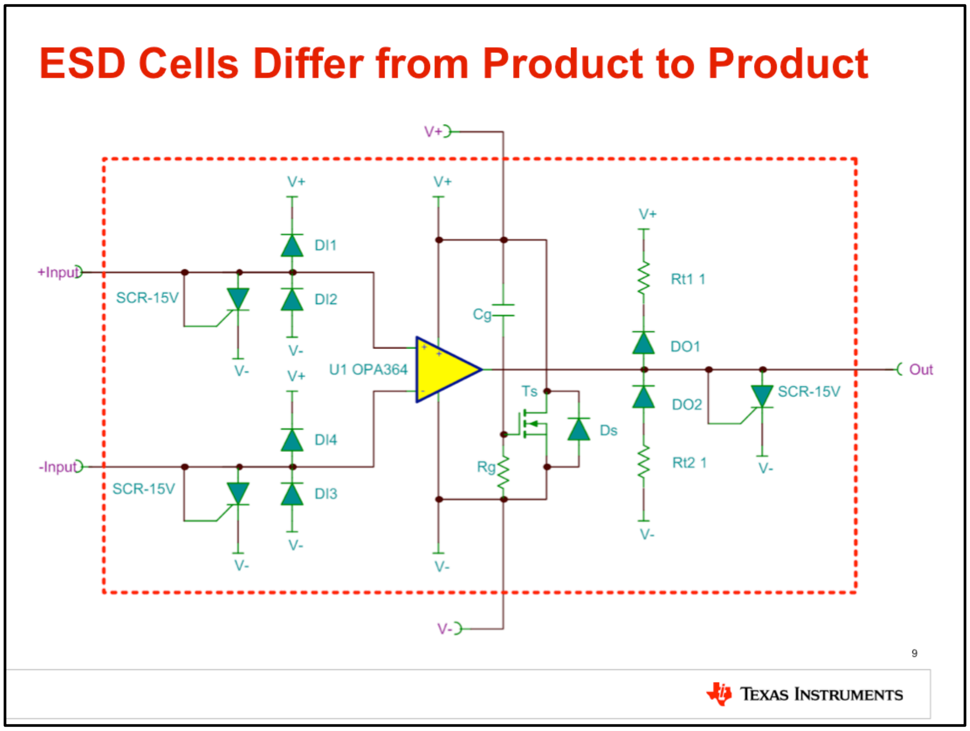
Besides the input and output pins, another common entry point for harmful EOS energy is the power supply. The TVS diode is also effective in suppressing EOS energy on the power supply. Filtering, such as the pi filter shown here, can also minimize the amplitude of any power supply glitch.



Exceeding the maximum differential input voltage on amplifiers will also cause EOS damage. Some amplifiers allow the differential input voltage to be equal to the supply voltage. On the other hand, some amplifiers only allow for a relatively small differential input voltage, such as 0.7 V. This small differential input is common in bipolar amplifiers, where the differential input pair is sensitive to a base-to-emitter breakdown which can cause substantial damage to the device. Because of this sensitivity, a pair of diodes are connected to the input to limit the voltage to a safe level. If a differential input greater than the diode drop is applied, the diodes will limit the voltage. Although the diodes protect the input from breakdown damage, the diodes can be damaged if excessive current flows through them. Remember, the absolute maximum input current for most amplifiers is 10mA, so the current flow into these diodes must be limited to less than 10mA.



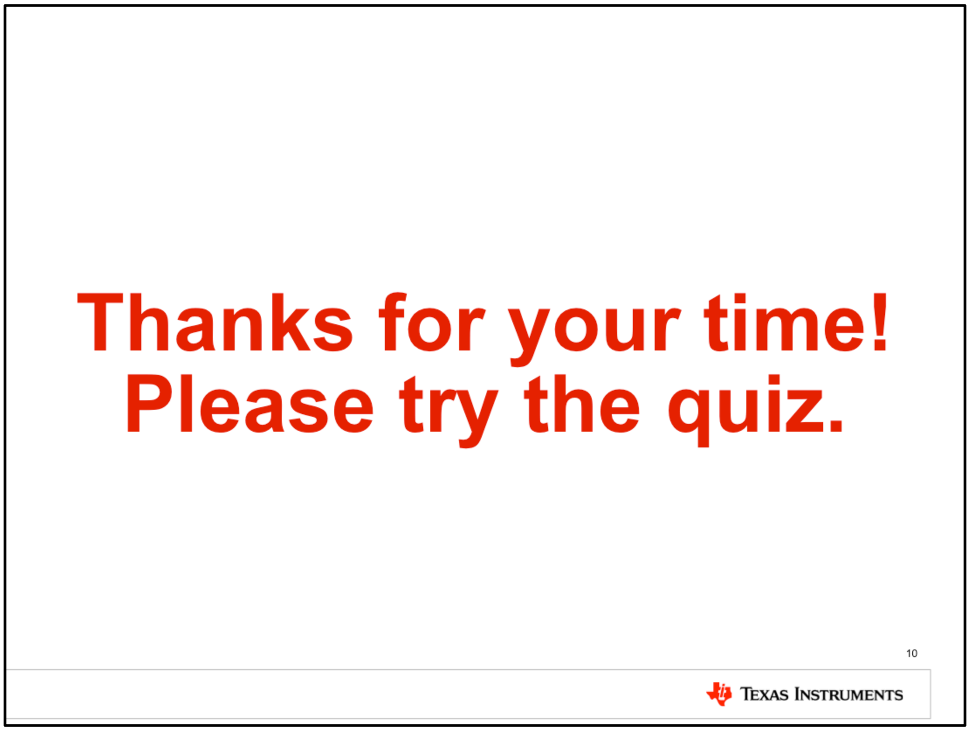
Let's look at an example of when a large differential voltage can develop on an op amp. Applying a square wave to the voltage follower circuit shown here causes the device to become slew rate limited, as discussed in TIPL 1221 through 1223. When an amplifier is slew rate limited, it is possible for very large differential input voltages to develop. For example, when the input transitions from +5V to -5V the output can not instantaneously follow that transition. Thus, the instant the transition occurs, the differential input could be the full 10V. However, the back-to-back diodes limit the input to 0.7V. Without some type of current limitation, large currents can flow during this time. To prevent this, input resistor Rp is used to limit the current during slew limit to less than 10mA. The transient plots on the right show how the resistor limits the input current to less than 10mA and the back-to-back diodes limit the differential input voltage to less than 1V.



In the previous slides we described the most common ESD structures. However, in some cases process technology limitations or device performance requirements necessitate the use of different protection structures.

Here we show the ESD protection devices inside the OPA364 op amp. The inputs of the OPA364 have the familiar ESD diodes, but they also have SCR devices. An SCR, or silicon controlled rectifier, is a diode that will latch on once a maximum voltage is applied across it. It acts very much like the absorption device that was discussed in the video on ESD. In this case, the SCRs on the input will turn on when the input voltage is greater than 15V. Note that this amplifier has an absolute maximum voltage of 5.5V, so 15V should never be applied to the input. Nevertheless, if the input voltage exceeds 15V the SCR structure will turn on, large current will flow, and the SCR will not turn off until power is cycled. The reason that the SCR is included is that it is capable of turning on much faster than the ESD diodes for mitigating ESD transients. So, the SCR devices are very helpful for ESD protection when the device is off but may cause issues during an EOS event that occurs when the device is powered on.

The output also contains an SCR device and ESD diodes with current limiting resistors. The resistors are used to prevent damage to the ESD diodes from inductive kickback which may occur in some applications. Finally, the absorption device, Ts, is designed



That concludes this video – thank you for watching! Please try the quiz to check your understanding of the video's content.

Electrical Overstress – 2

Multiple Choice Quiz

TI Precision Labs – Op Amps

Texas Instruments

Quiz: Electrical Overstress – 2

1. A bi-directional TVS diode is _________.

a. Recommended for dual supply devices.
b. Used to limit the input swing to a voltage range such as ±10V
c. Two TVS diodes connected at their anode

2. What are the characteristics of a ferrite bead?

a. It has low resistance at low frequency and high resistance at RF frequencies.
b. It has high impedance at all frequencies except a narrow band near 60Hz
c. It is normally placed in parallel with a TVS diode to improve EOS protection.
d. It increases impedance at high current; it acts like a resettable fuse.

3. (T/F) An RC low-pass filter can be effective for minimizing EOS from fast transients.

a. True
b. False

Quiz: Electrical Overstress – 2

4. When a pulse is applied to a low-pass RC filter, in one RC time constant the output will charge to approximately ______________.

a. 40%
b. 63%
c. 95%
d. 99.5%

5. (T/F) Without proper input current limiting, some amplifiers can be damaged when the amplifier is in slew rate limit.

a. True
b. False

Quiz: Electrical Overstress – 2

6. Which of the following is not useful for op amp external EOS protection?

a. Zener Diodes
b. Schottky Diodes
c. Semiconductor Transient Voltage Suppressors
d. Resistors
e. Bipolar Transistor
f. Capacitors
g. Ferrites
h. Inductors

Electrical Overstress – 2

Multiple Choice Quiz: Solutions

TI Precision Labs – Op Amps

Quiz: Electrical Overstress – 2

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Quiz: Electrical Overstress – 2

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Quiz: Electrical Overstress – 2

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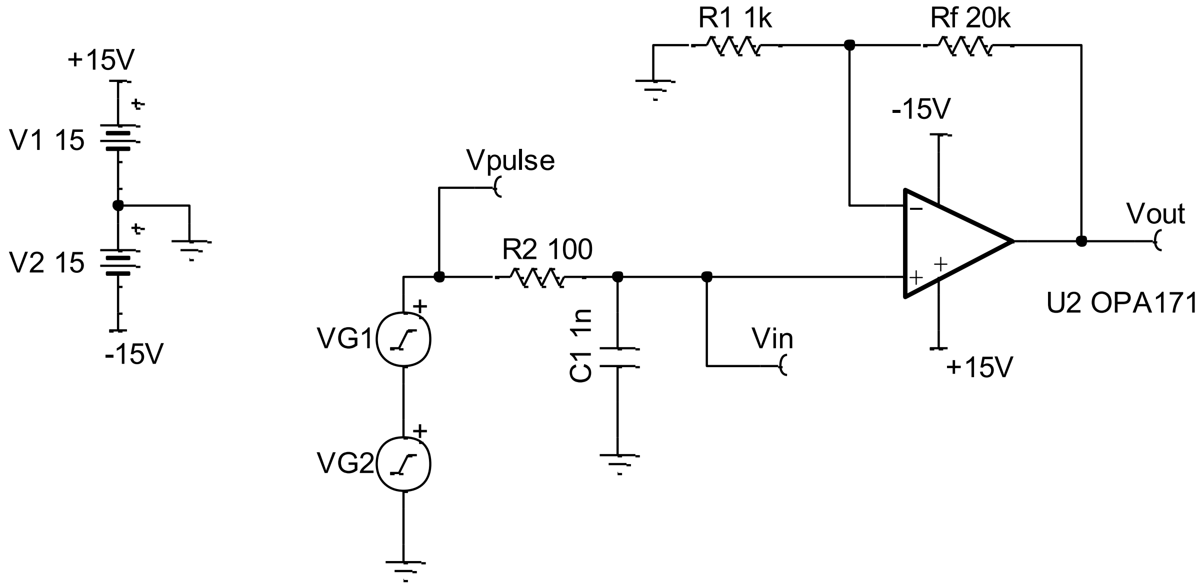
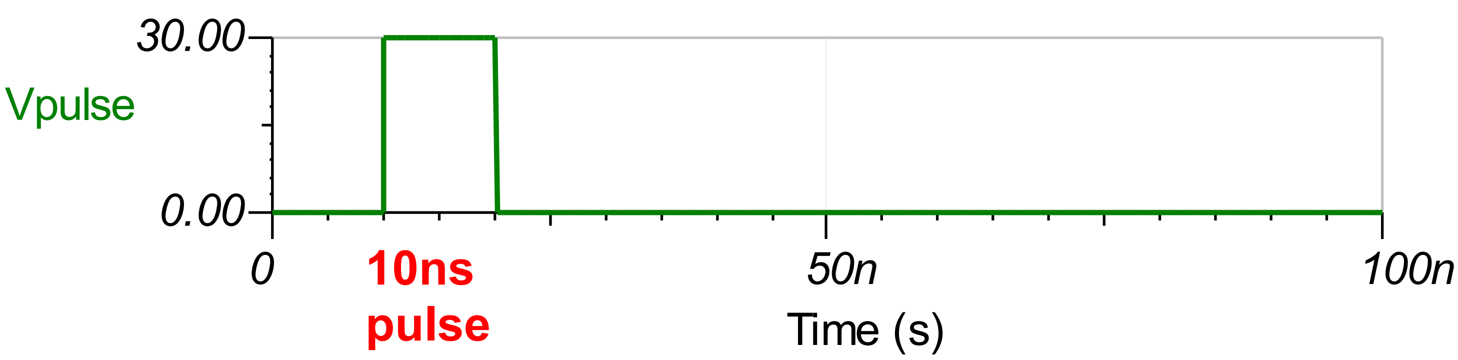
Electrical Overstress – 2

Exercises

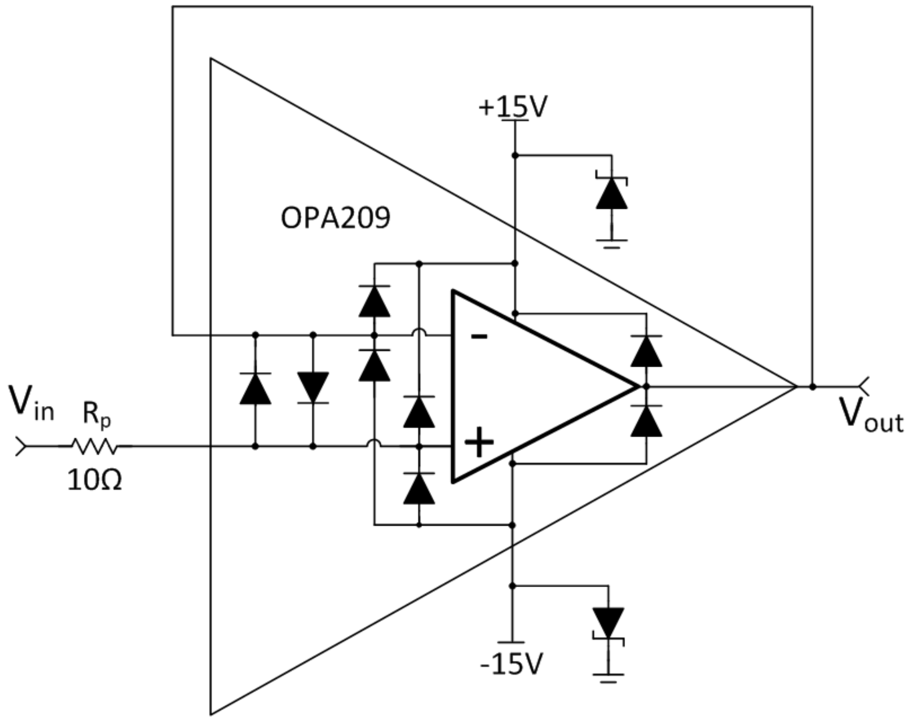
TI Precision Labs – Op Amps

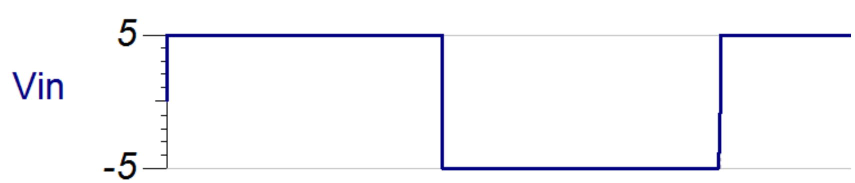
1. For the circuit below: simulate the response to this pulse. Will the 30V pulse cause EOS damage?





2. For the circuit below: simulate the response to this pulse. Will the ±5V square wave cause EOS damage? Draw the differential input waveform, the output waveform, and input current waveform.

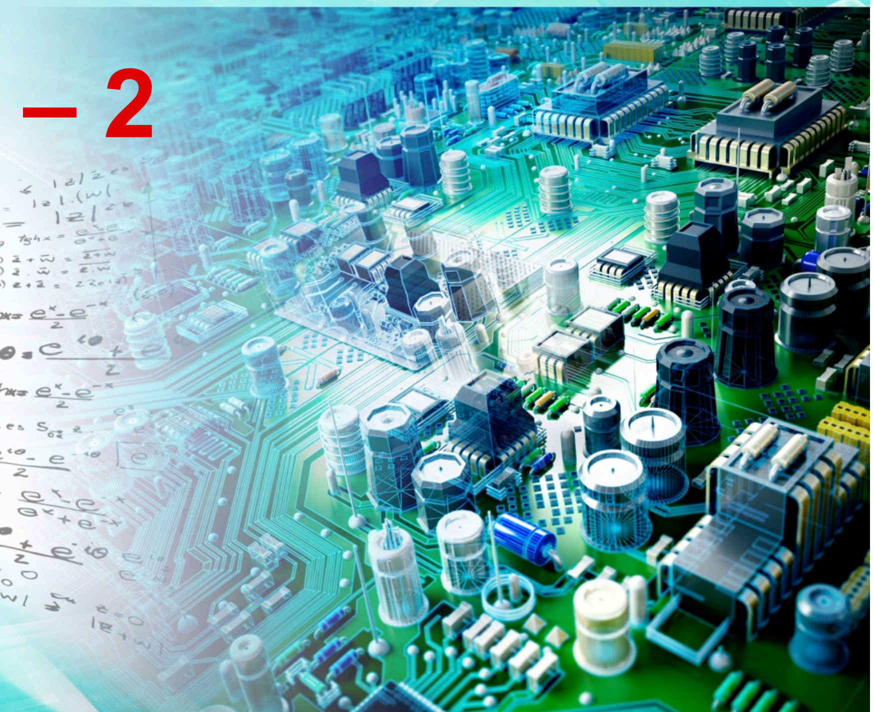




Electrical Overstress – 2

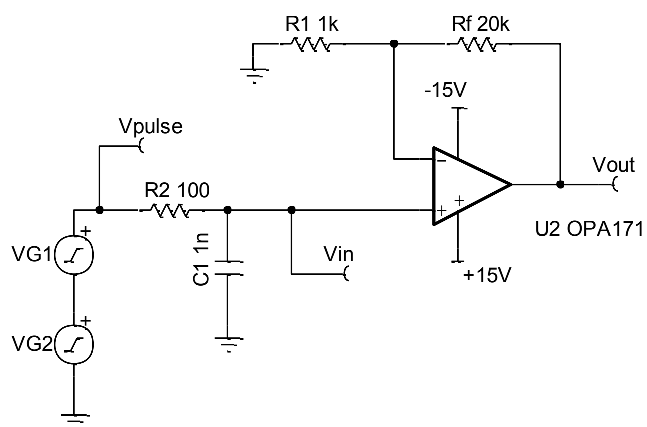
Solutions

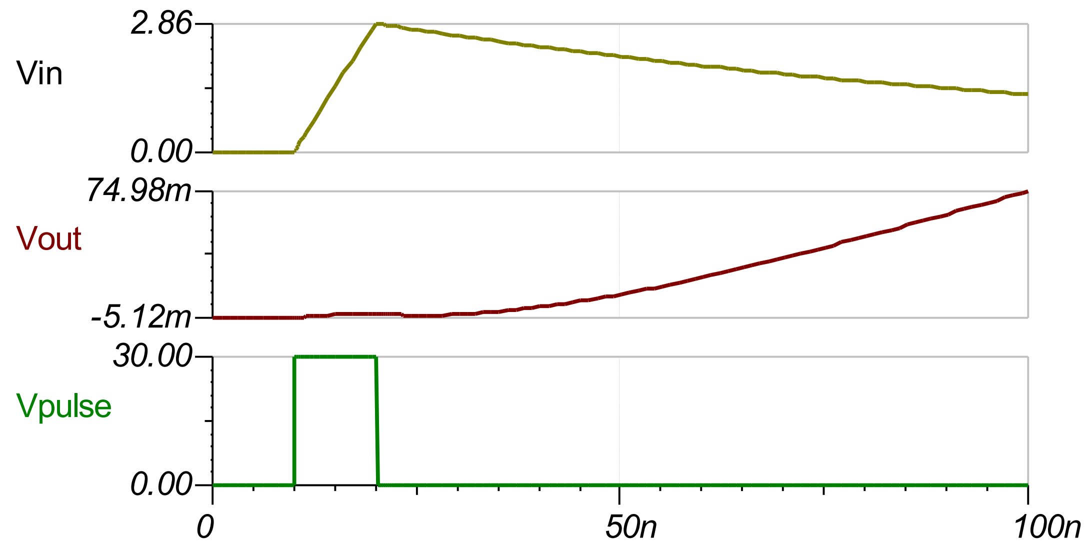
TI Precision Labs – Op Amps



1. **For the circuit below: simulate the response to this pulse. Will the 30V pulse cause EOS damage?**

No. The RC circuit keeps the pulse from reaching overstress levels on the input. RC = 100ns and the pulse is only 10ns.





10ns pulse

1412-EOS2-problem1.TSC

2. **For the circuit below: simulate the response to this pulse. Will the ±5V square wave cause EOS damage?**

Yes. The current flowing into the input is greater than 10mA (about 65mA). This exceeds the absolute maximum input current limit. Increasing the 10Ω series resistance could help protect the amp.

When the input transitions from +5V to -5V the output cannot instantaneously transition. Thus the potental difference between the input and output is 10V. Most of the 10V is across the 10Ω input resistance. This causes a very high current to flow, limited by the op amps short circuit limit (65mA in this case).

I_input_max = (10 – 0.7)/10Ω = 430mA (beyond op amp short circuit limit)
I_input_expected ≈ 65mA from short circuit limit

2. For the circuit below: simulate the response to this pulse. Draw the differential input waveform, the output waveform, and input current waveform. Note that the input current is limited by the short circuit limit of the amplifier and is above the absolute maximum of the amplifier.