Hello, and welcome to the video for the TI Precision Lab discussing electrical overstress, or EOS, part 1. In this video we'll discuss the causes of electrical overstress and introduce several methods that can be used to improve circuit robustness against electrical overstress. All of the examples in this video show op-amp circuits, but the methods used could be applied to other devices as well. Follow up videos will give additional details showing how to select component values as well as test methods used to confirm electrical overstress robustness.

ESD vs. EOS – What's the Difference?

ESD

- Electrostatic discharge
- Short duration event (1-100ns)
- High voltage (kV)
- Fast edges
- Both "in-circuit" and "out-of-circuit"

EOS

- Electrical overstress
- Longer duration event
  - Milliseconds or more
  - Can be continuous
- Lower voltage
  - May be just beyond absolute maximum ratings
- "In-circuit" event only

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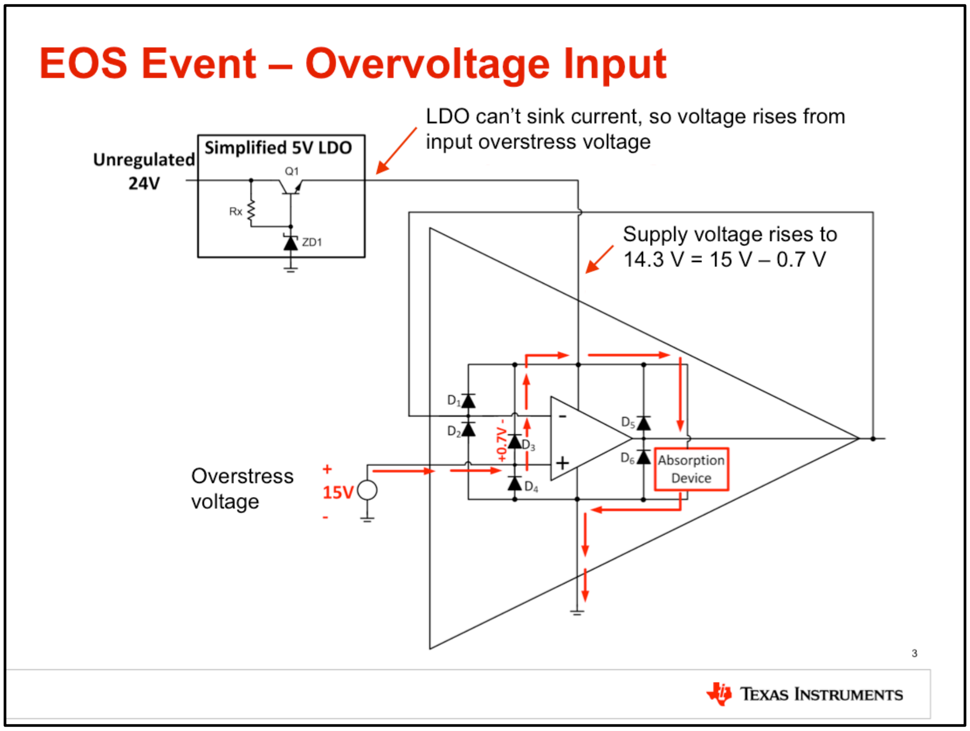
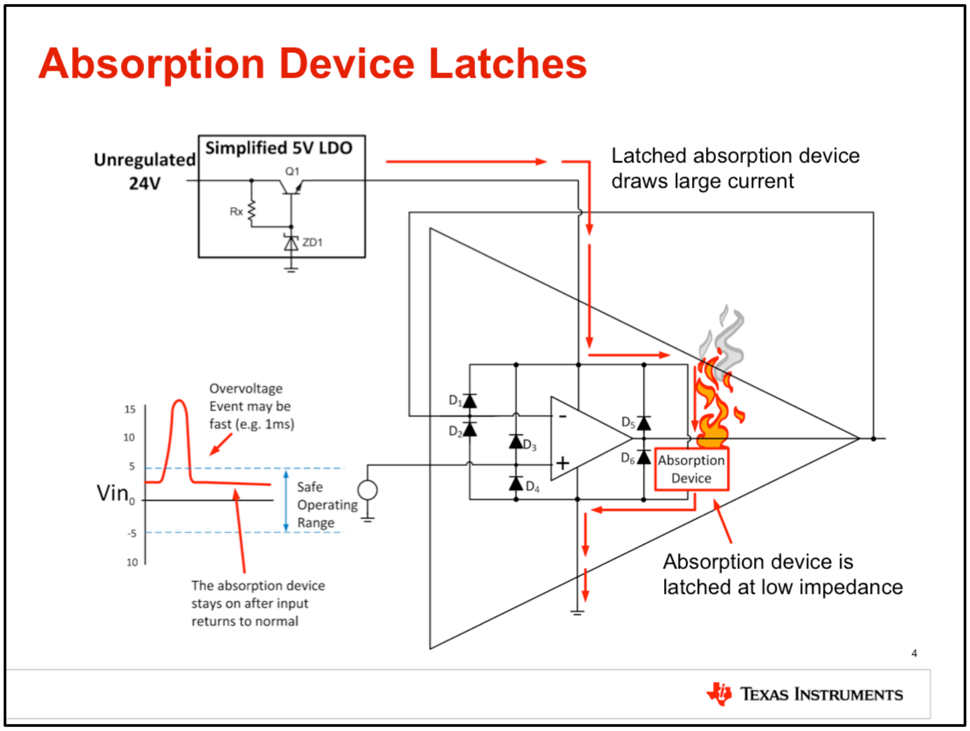
First, lets compare ESD and EOS. We discussed ESD in detail in TIPL 1401. ESD or electrostatic discharge is the sudden flow or discharge of static charge between two oppositely charged objects. ESD is a very short event; typically in the nano-seconds. The voltage of an ESD event can be quite high, in the kilo-volts, and the pulses can have very vast edges. ESD damage can happen both in-circuit and out-of-circuit.

EOS or electrical overstress happens when a voltage is applied that exceeds the absolute maximum rating of the device. An EOS event can be a long duration event. It may be milliseconds, seconds, or even a continuously applied overstress voltage. The voltage level is typically lower than an ESD voltage. In fact, it may be just over the absolute maximum of the device. For example, applying 10V to a device with a absolute maximum rating of 7V will cause EOS damage.



Let's look at an example of an EOS event on an op-amp. The example op-amp circuit is in a 5V single supply configuration. Notice that power is supplied by a 5V low dropout voltage regulator, or LDO. The maximum power supply voltage for this circuit is 5V, but the input of this circuit is connected to a 15V overstress voltage. This EOS voltage causes diode D3 to turn on and direct the current to the power supply pin and the absorption device.

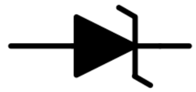
This causes the power supply voltage to rise to 14.7 V, which happens because the LDO cannot sink current and can therefore no longer regulate its output voltage. Effectively, the LDO acts like an open circuit under these circumstances. The power supply voltage of 14.7 V is above the absolute maximum rating for the op-amp, which causes the absorption device to turn on in an attempt to clamp the supply voltage.



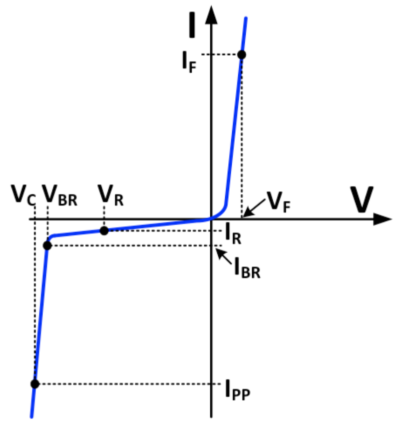
Once the absorption device is on, it will remain on until power for the circuit is cycled. In this mode, the absorption device has a very low impedance and draws excessive current from the LDO. This high current generates a great deal of heat which often destroys the device.

It is important to remember that the absorption device was designed to protect the integrated circuit from “out-of-circuit” ESD events, and is not intended to protect against this kind of electrical overstress event. In fact, it is very important to design EOS protection circuits that prevent the absorption device from ever turning on during an EOS event.

Transient Voltage Suppressor (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



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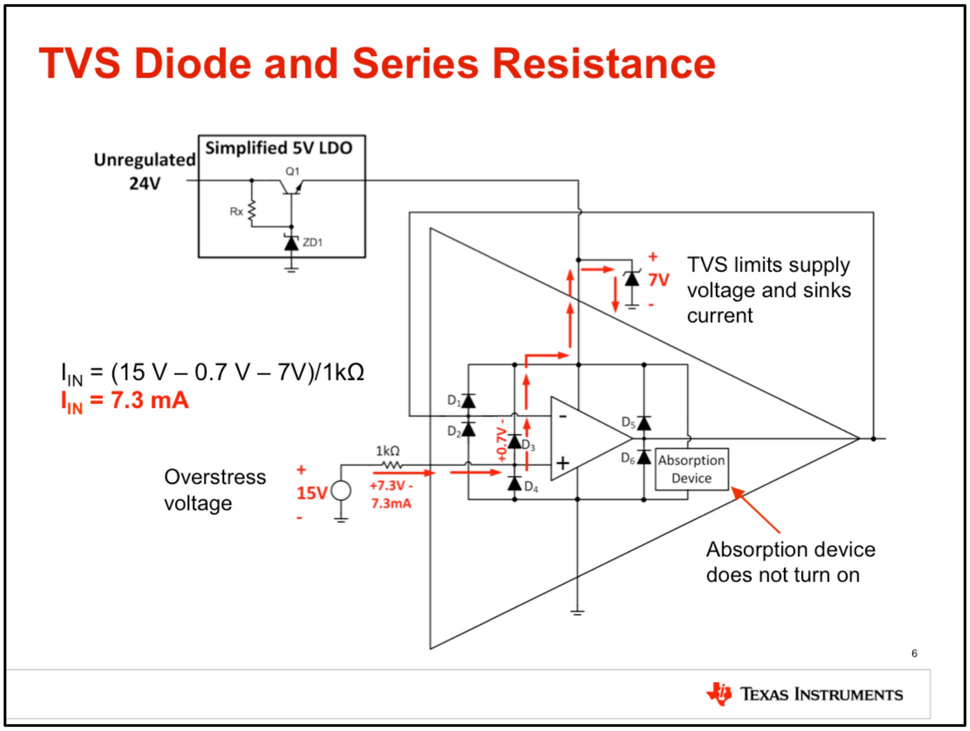
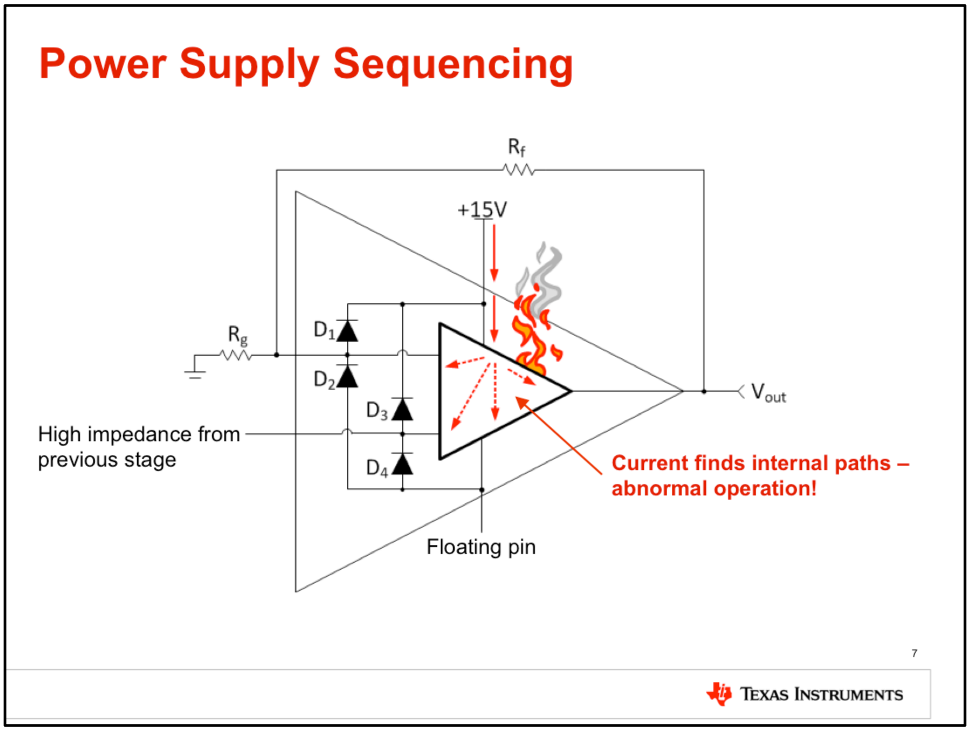
One of the most common devices used to protect circuits from EOS damage is the transient voltage suppressor diode, or TVS diode. A TVS diode is similar to a Zener diode, but is designed for fast turn on and large transient power dissipation.

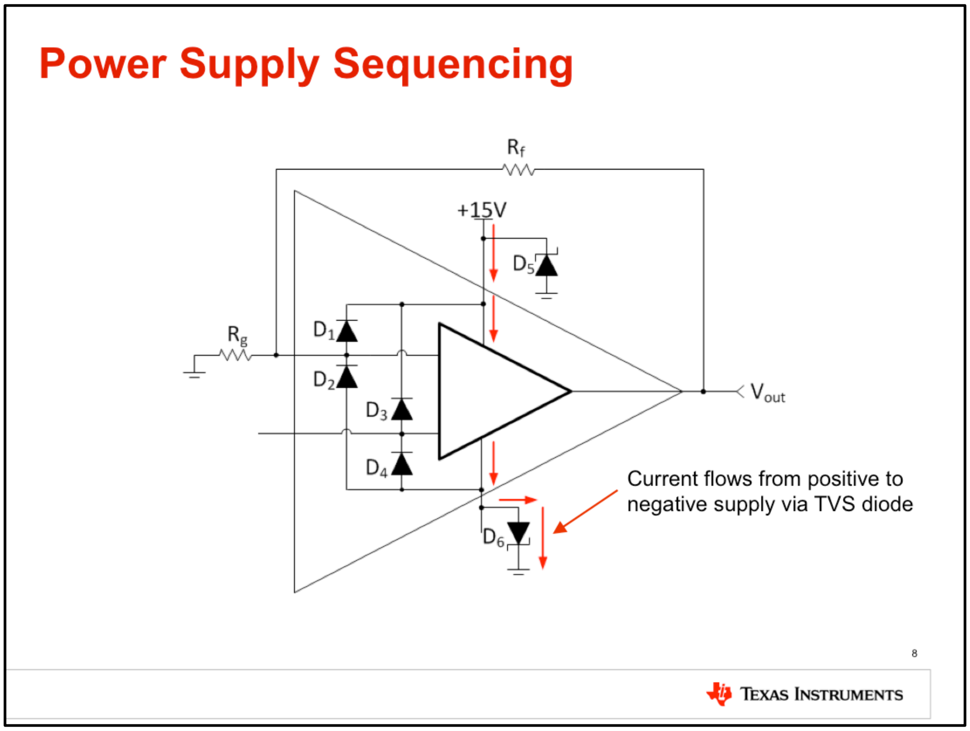
The plot on the bottom-right shows the I-V curve for the TVS diode and points out key locations on the curve. On the right side of the curve the forward voltage, Vf, is defined at forward current If. On the left side of the curve, the reverse standoff voltage, Vr, is shown with its associated reverse leakage, Ir. The reverse standoff voltage is the maximum voltage which can be applied across the TVS diode for it to maintain a low leakage current. This is the “off” state for the TVS diode. The reverse breakdown voltage, Vbr, is the point at which the TVS diode starts to breakdown and limit, or clamp, the voltage. Finally, the clamping voltage, Vc , is the voltage across the TVS diode when the peak pulse current, or Ipp, is flowing.



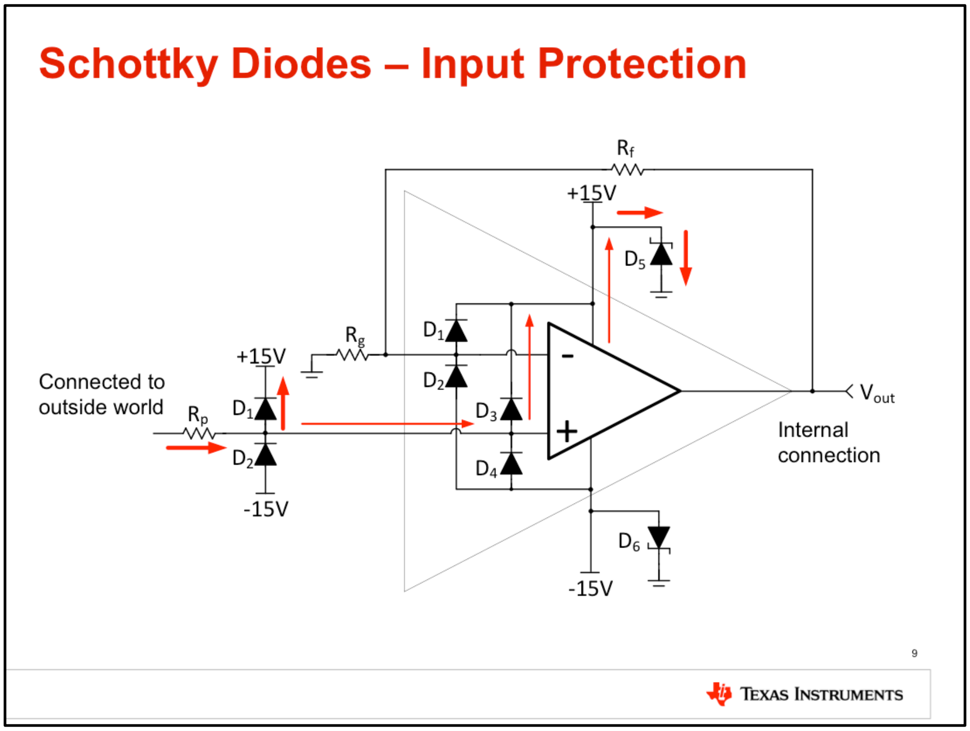
Here we show the same circuit and EOS event from before, but now a TVS diode on the power supply and a series resistance at the input have been added to protect the amplifier from EOS damage. In this case, the 15V EOS voltage is applied to the input and now the ESD diode D3 directs the overvoltage pulse to the TVS diode. The TVS diode limits the supply voltage to 7V, which is below the voltage needed to turn on the absorption device. Also, notice that the series 1kΩ resistor limits the current to less than 10mA to prevent damage. Remember that 10mA is the absolute maximum rating for signal input current. This method of EOS protection is the most common way to protect semiconductor devices.



In some cases, power supply sequencing can actually cause device damage. This example shows a dual supply power amplifier in the process of powering up. In this system the power supply sequence turns on the +15V supply first and the -15V supply second. At this moment in time, the +15V supply is on but the -15V supply has not yet turned on and is floating. There is no proper current path from the positive supply to the negative supply, so the current finds parasitic paths inside the op amp. This can potentially put the device into an abnormal mode, where the device draws excessive current and has unexpected operation.

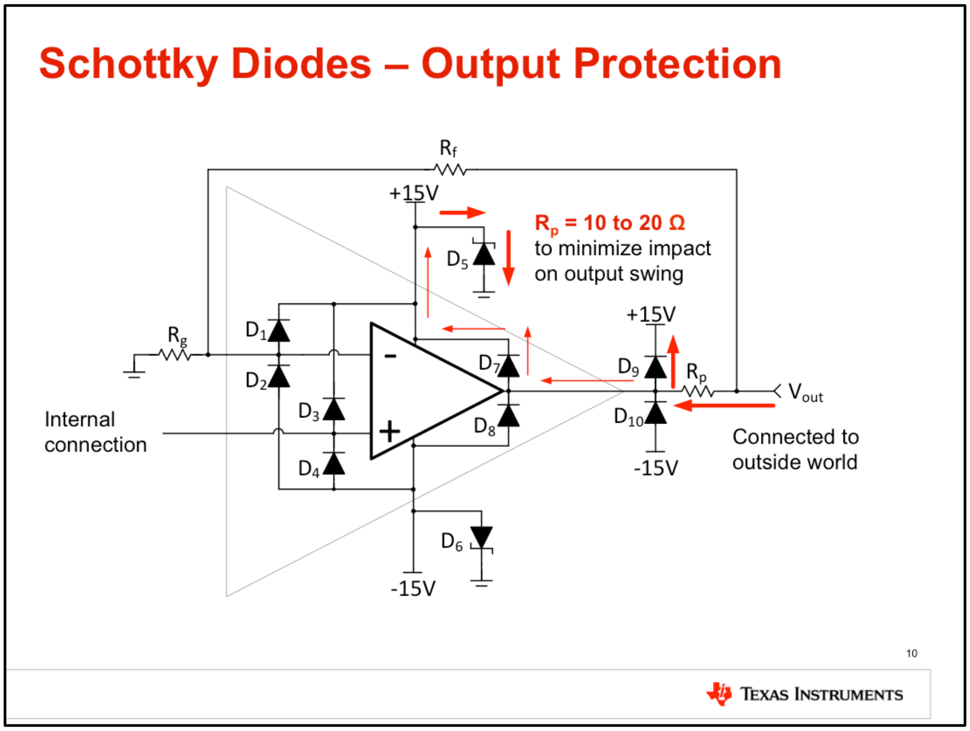


Let's connect TVS diodes across both the positive and negative power supplies. Normally, the TVS diode D6 is reverse biased. However, during power up the TVS diode will become forward biased, providing a direct path for current from the positive to negative supply. This prevents the device from going into an abnormal state. Once the negative supply turns on, D6 becomes reverse biased and the device behaves normally.



Another useful technique which is used to protect the input of a device is to add external protection diodes in parallel with the internal ESD diodes. Ideally, the forward bias voltage drop of the external ESD diodes should be lower than the internal ESD diodes so that the majority of the EOS current flows through the external diodes. For this reason, Schottky diodes are often used as their forward drop is about 0.3V. Unfortunately, Schottky diodes also have very high leakage current, in some cases as high as micro-amps. Thus, it is not always practical to use Schottky diodes and so other silicon signal diodes may be used.

Notice that this example only requires input protection because only the input side is connected to the outside world. The op amp output is connected to an internal circuit on the PCB. For example, the input may connect to a remotely located sensor and the output may connect to an A/D converter or another amplifier stage. In general, external connections are much more susceptible to EOS damage that internal connections. For example, long sensor leads may develop a significant charge that causes an EOS event. Improperly wired external connections and other large induced voltages can also cause EOS damage.



The same Schottky protection circuit can also be used on an amplifier's output, if the output is connected to the outside world. One key point with output protection is that a large series resistance, Rp, will significantly limit the op amp's output swing. This limitation is dependent on the amount of current that the output needs to deliver, so higher power amplifiers will require lower values of Rp. Rp values of 10 to 20 Ω are common for many op amp circuits.

Notice that Rp is inside the feedback loop. This allows an accurate output voltage to be maintained despite the voltage dropped across Rp. Finally, notice that very low current will flow through Rf to the input of the circuit as the value of Rf is generally much larger than Rp.

Thanks for your time!
Please try the quiz.

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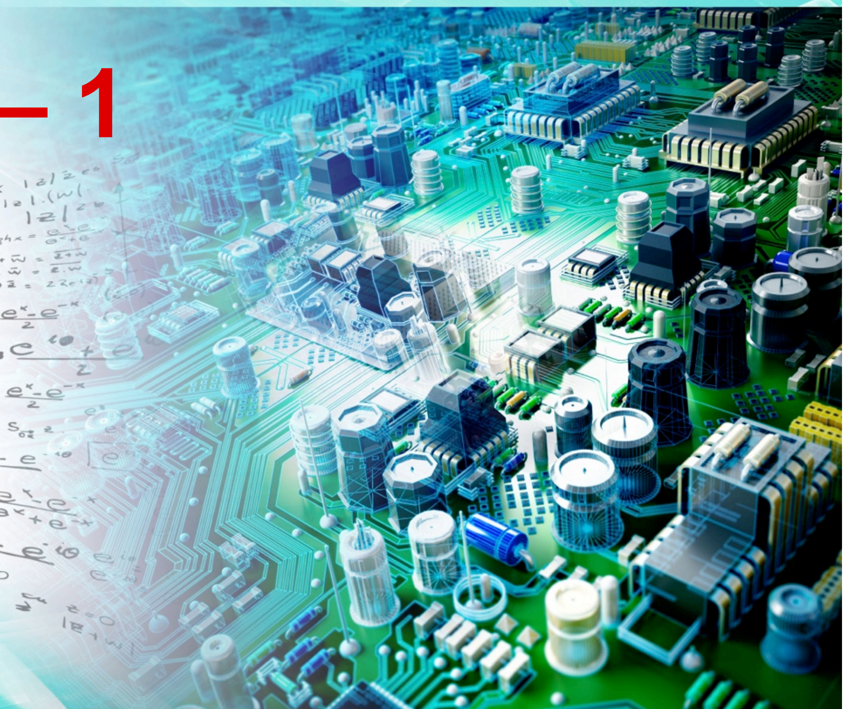
That concludes this video – thank you for watching! Please try the quiz to check your understanding of the video's content.

Electrical Overstress – 1

Multiple Choice Quiz

TI Precision Labs – Op Amps



Quiz: Electrical Overstress – 1

1. EOS damage occurs when you exceed ______.

a. The specified minimum voltage level.
b. Two times the maximum specified voltage level.
c. The absolute maximum voltage rating.
d. The maximum allowable frequency for input signals.

2. (T/F) EOS events are typically longer in duration than ESD events.

a. True
b. False

3. A TVS diode is ___________.

a. A crystal diode used to minimize RF interference.
b. A Zener diode optimized for fast turn on time and large power dissipation.
c. A diode with a low forward voltage that is placed in parallel with ESD diodes.
d. A specialized diode that minimizes leakage over temperature.

Quiz: Electrical Overstress – 1

4. Positive LDO (low-drop-out) linear voltage regulators can _________.

a. Sink but not source current
b. Source and sink current equally
c. Source but not sink current

5. The goal of the TVS diode is to _________.

a. Limit the input current to less than 10mA during EOS events
b. Limit the supply voltage to less than the absolute maximum during EOS
c. Direct EOS energy to an absorption device.
d. Maintain the temperature of the device during EOS

6. What generally limits the resistance which can be connected to the output of an amplifier?

a. The amplifier bandwidth.
b. The amplifier output swing
c. The amplifier slew rate
d. The amplifier offset drift.

Quiz: Electrical Overstress – 1

7. (T/F) Applying an overstress voltage to a device input can cause the absorption device to latch on and draw excessive current.

a. True
b. False

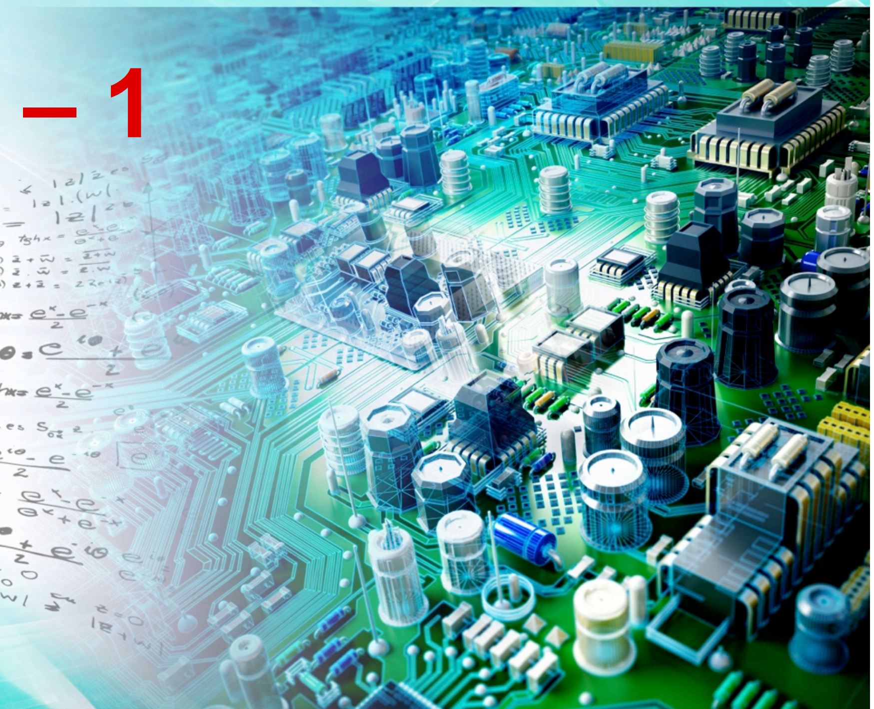
8. Assume than an EOS event turns on the absorption device while the IC is powered on. Once the EOS event ends, the absorption device ______________.

a. Will return to normal operation
b. Will return to normal operation with degraded performance
c. Will continue to draw excessive current until power is cycled.

Electrical Overstress – 1

Multiple Choice Quiz: Solutions

TI Precision Labs – Op Amps



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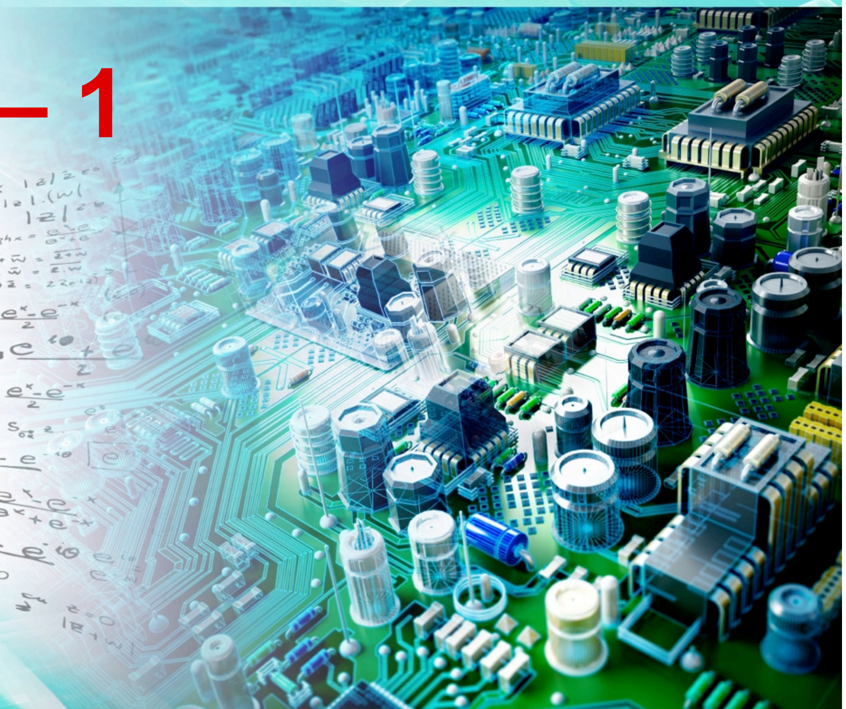
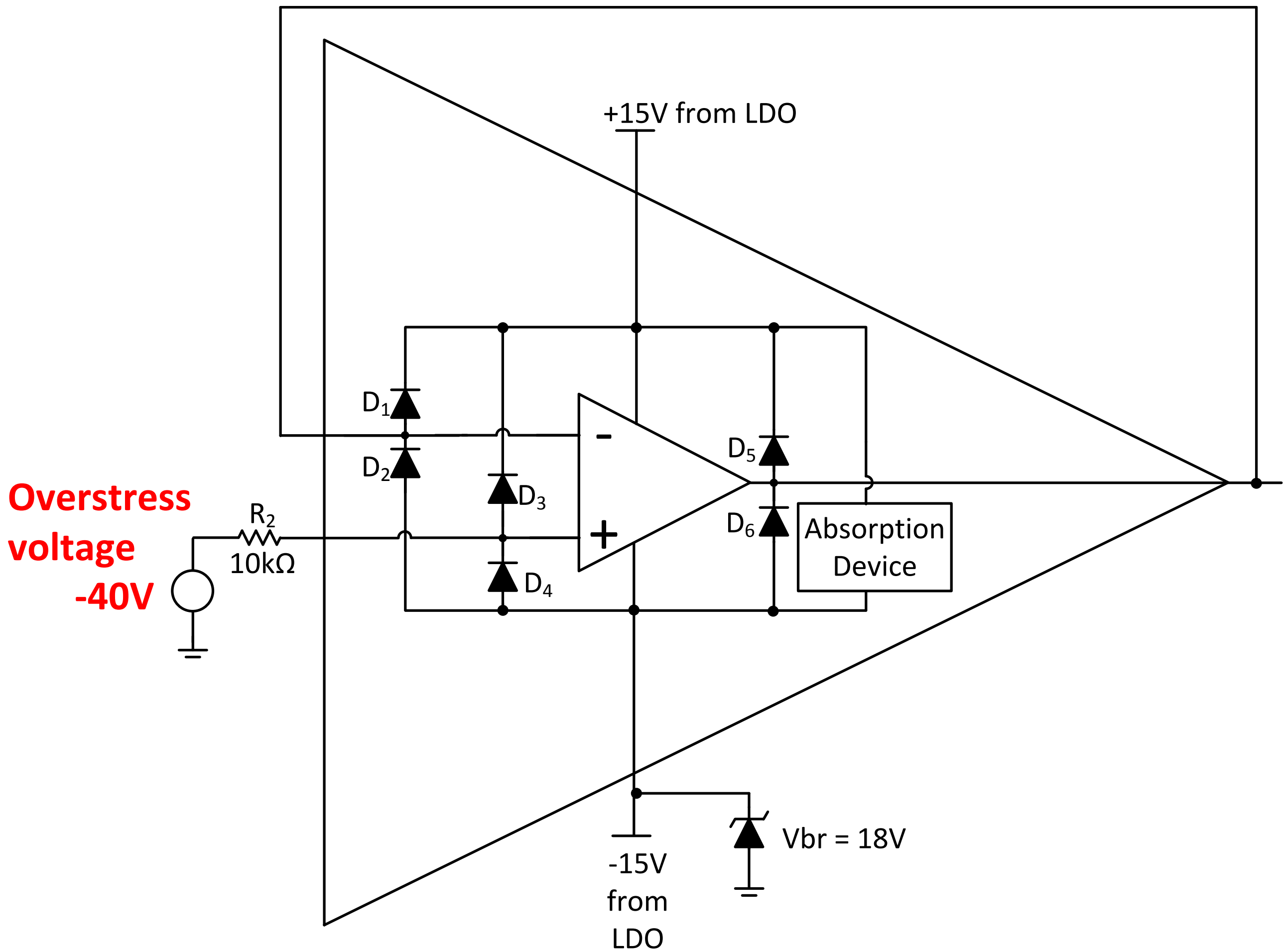
Electrical Overstress – 1

Exercises

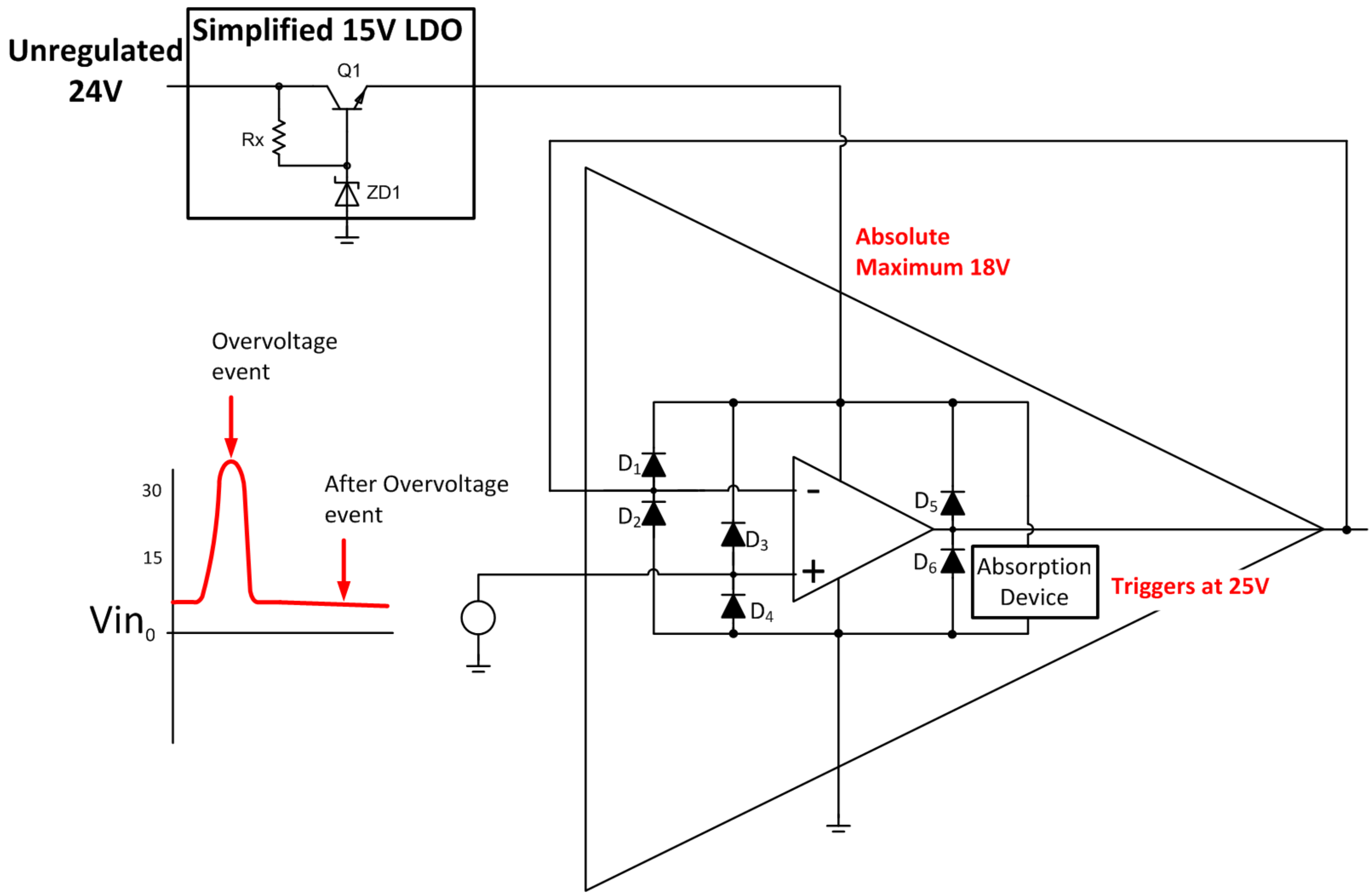
TI Precision Labs – Op Amps



1. For the circuit below: a) Trace the current for the given EOS voltage, b) what is the current level?



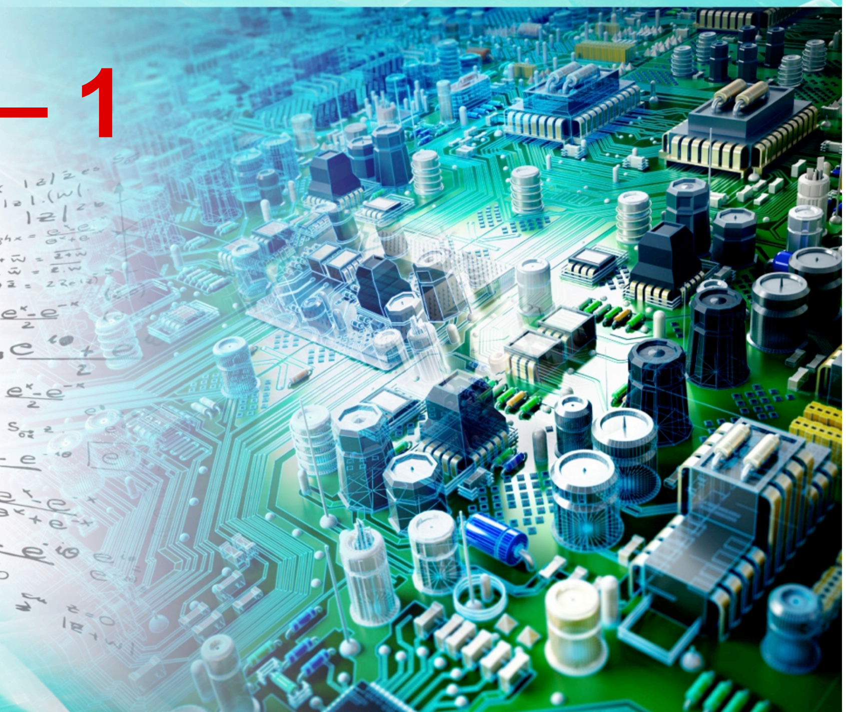
2. For the circuit below: a) What happens during the overvoltage event, *b) what happens after the overvoltage event?*



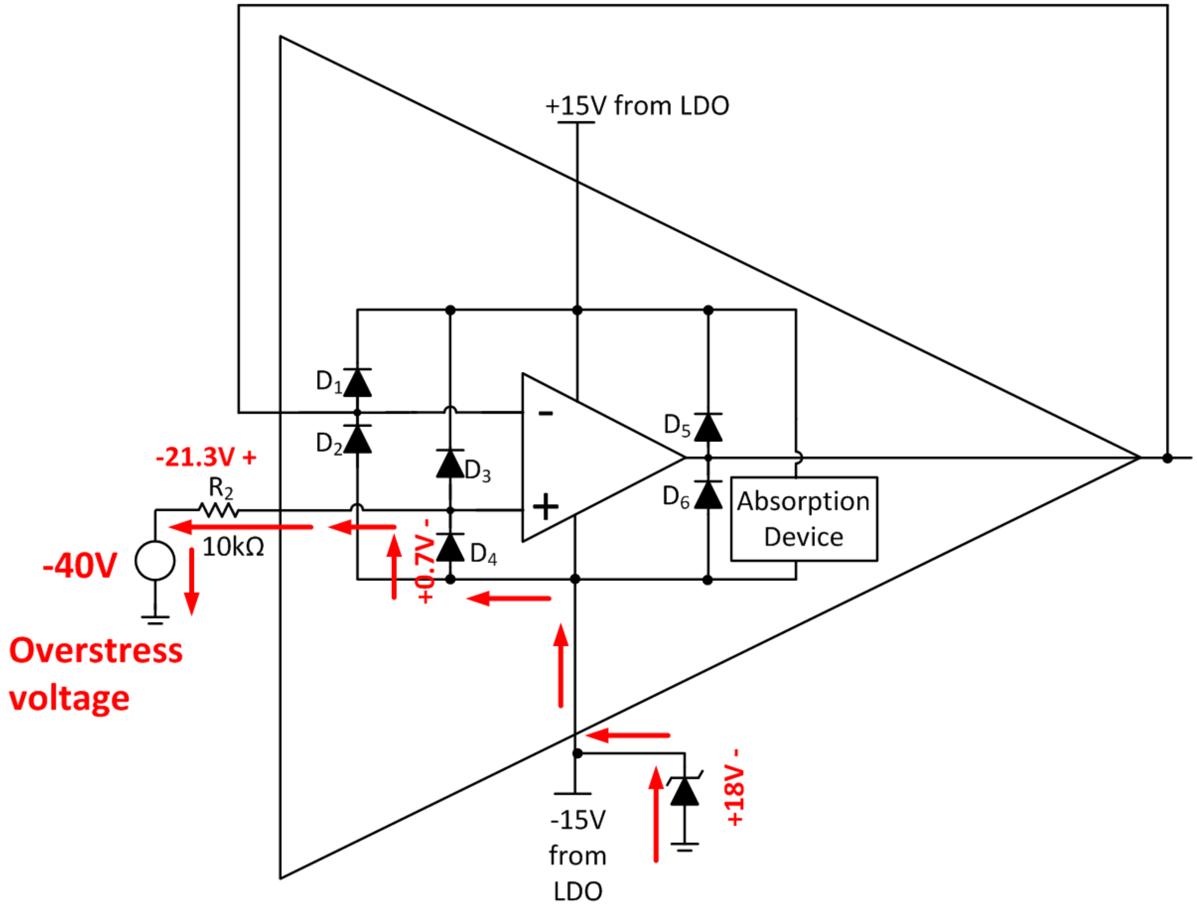
Electrical Overstress – 1

Solutions

TI Precision Labs – Op Amps



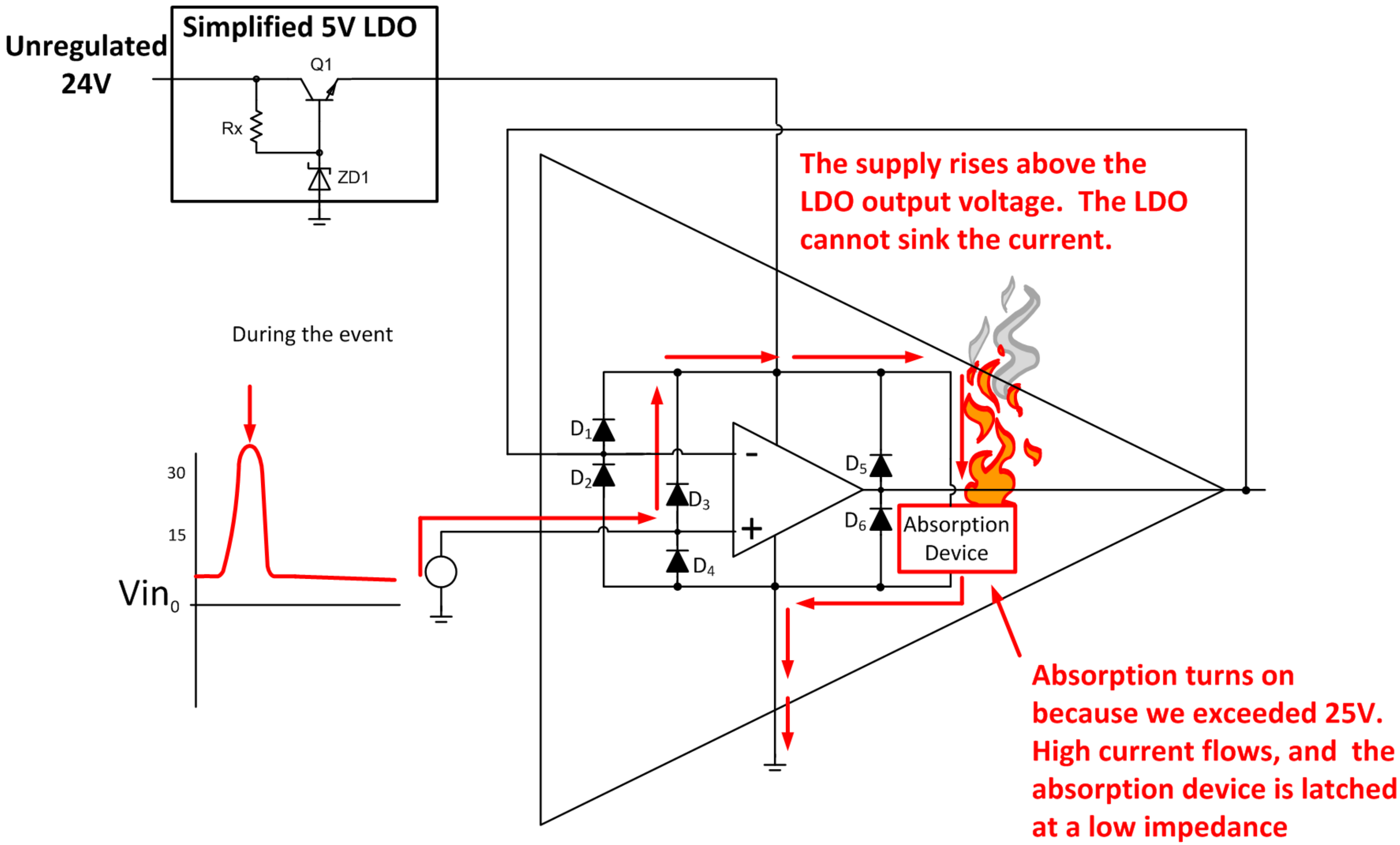
1. For the circuit below: a) Trace the current for the given EOS voltage, b) what is the current level? 2.1mA. Note that the negative supply voltage will rise to about 18V (Vbr for the TVS diode).



I_{fault} = (40 – 18 – 0.7)/10k = 2.1mA

2. For the circuit below: a) What happens during the overvoltage event.

The figure below shows what happens during the event.



2. For the circuit below: b) what happens after the overvoltage event?

The figure below shows what happens after the event.