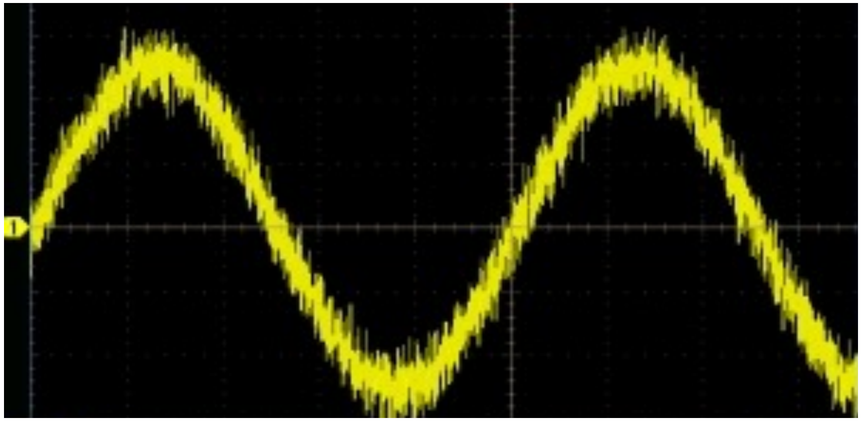
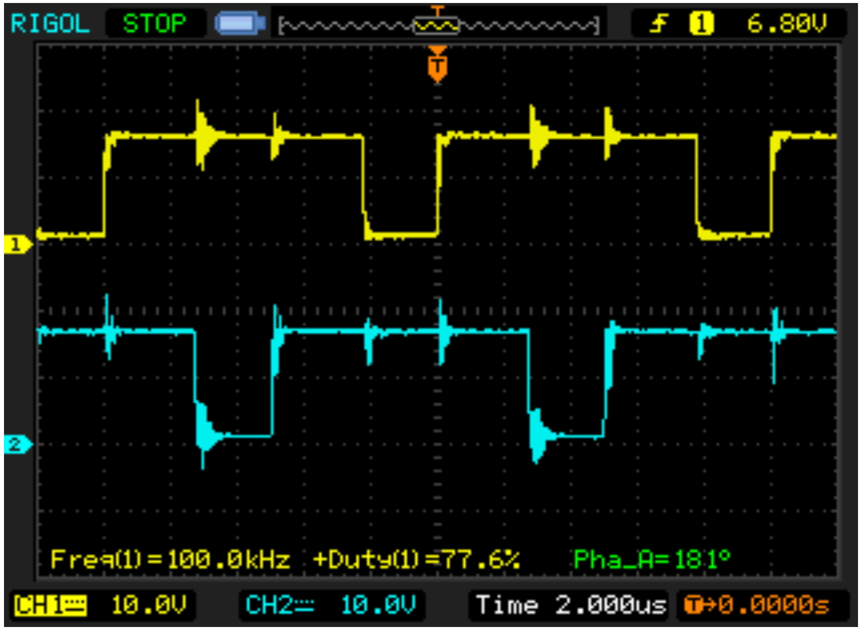
PHYS127AL Lecture 17

David Stuart, UC Santa Barbara

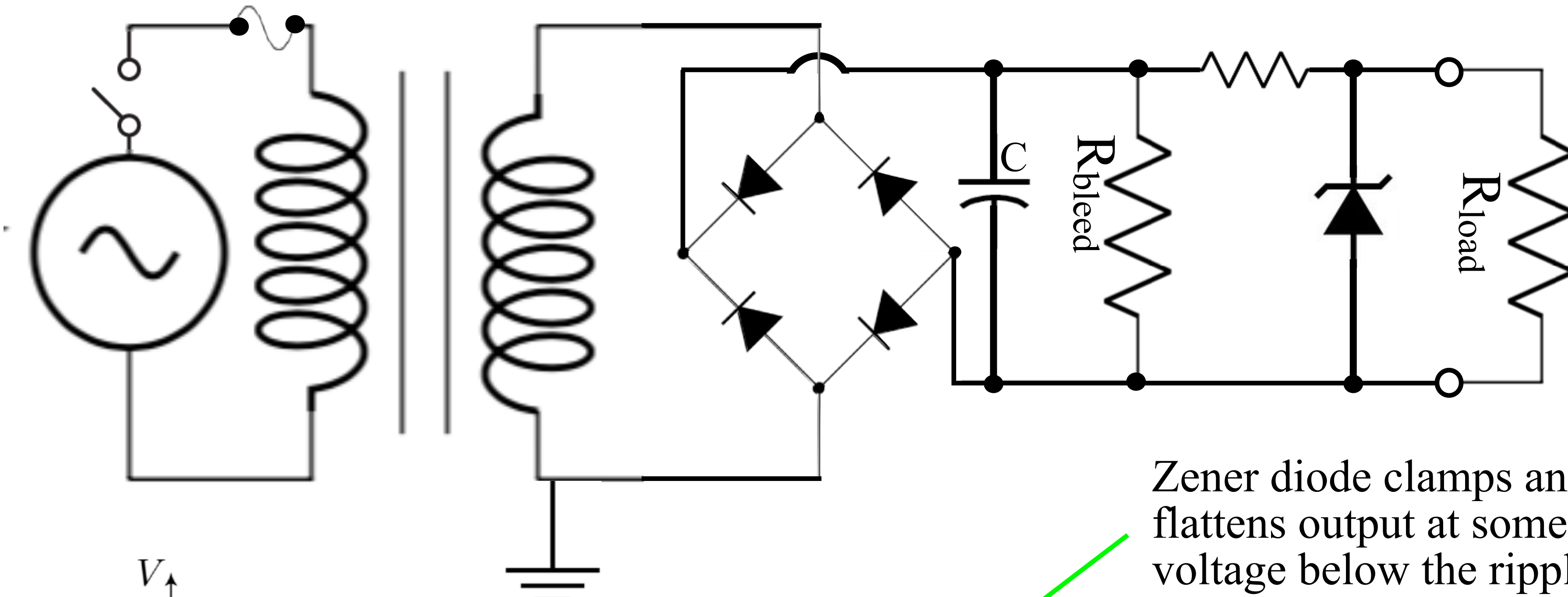
Voltage regulators; Noise



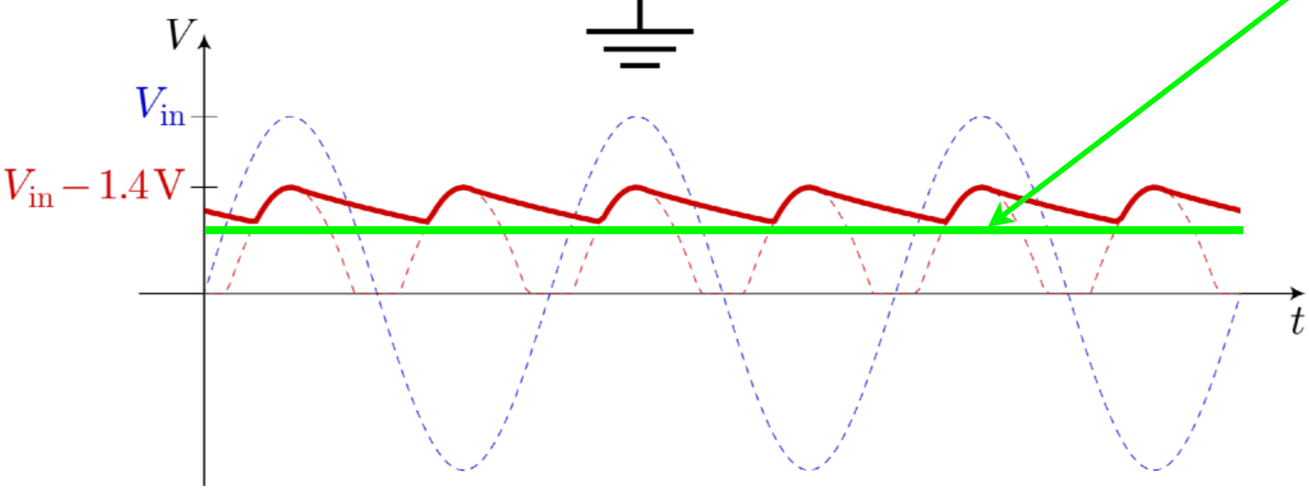


Review: Power supply

We developed an AC→DC power supply with transformer, diodes, C, zener.



Zener diode clamps and flattens output at some voltage below the ripple.



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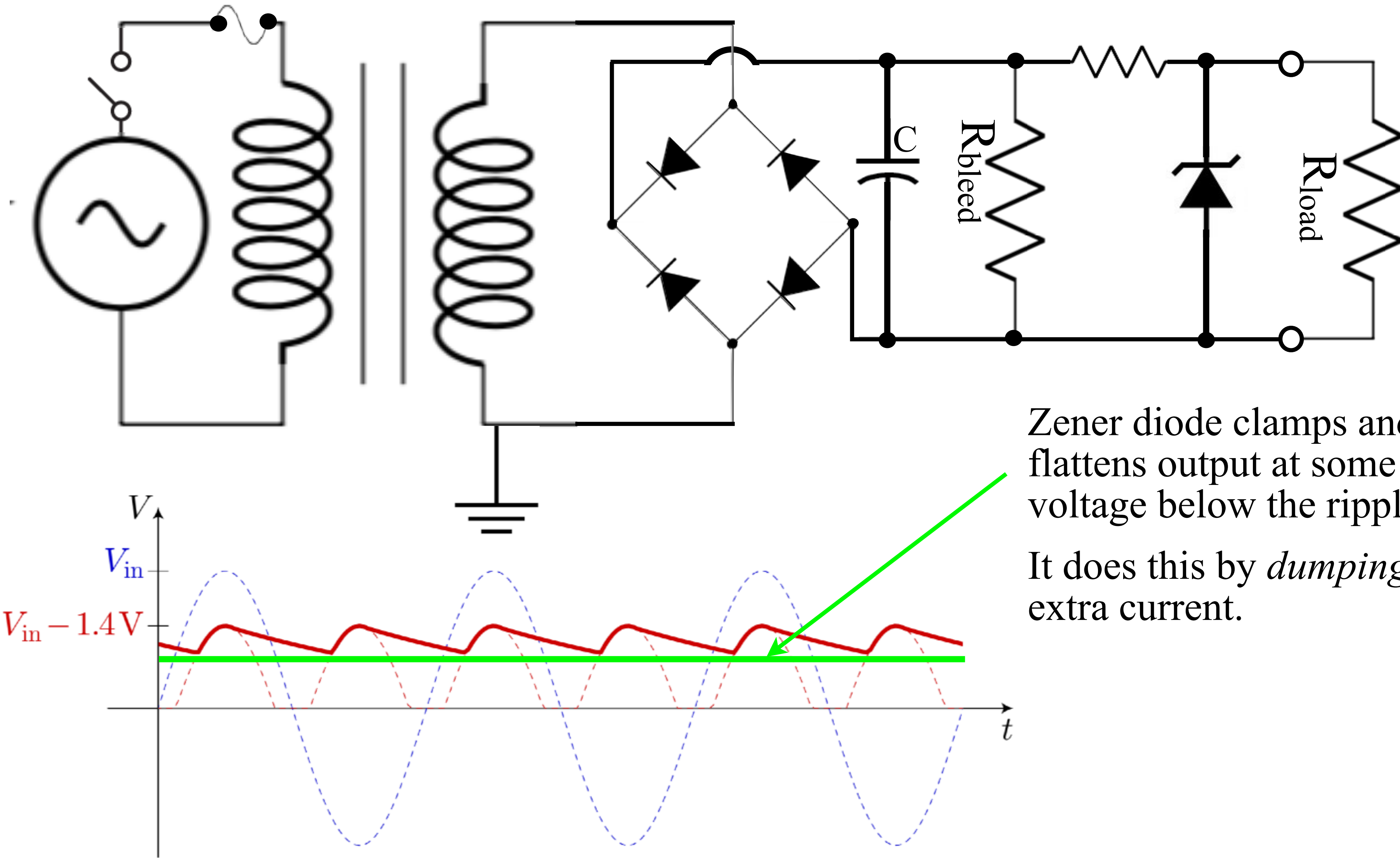
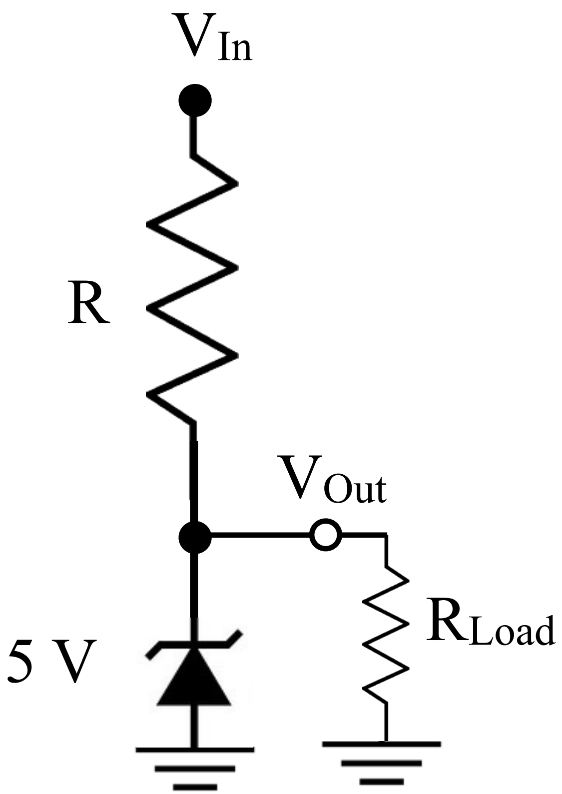


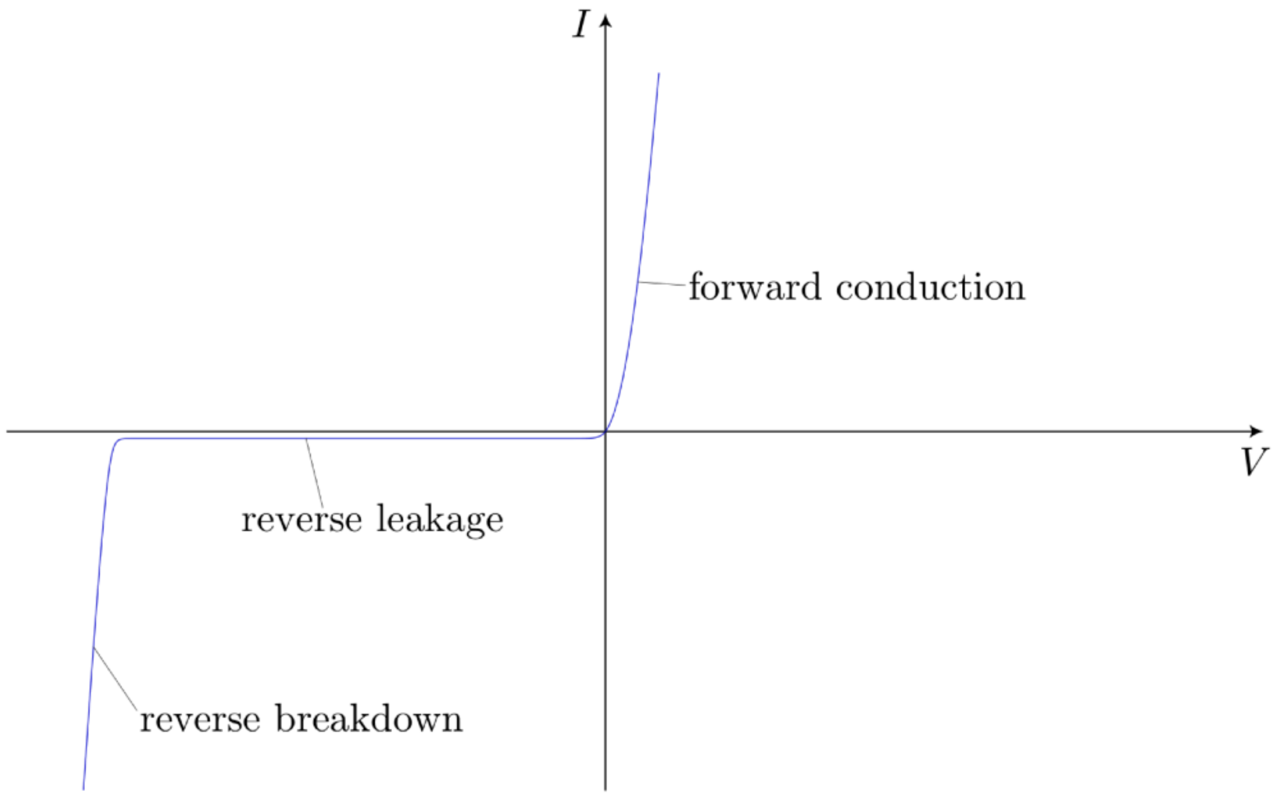
Zener diode clamps and flattens output at some voltage below the ripple.

It does this by *dumping* extra current.

Zener inefficiency

The zener is inefficient because it must dump current to hold voltage.





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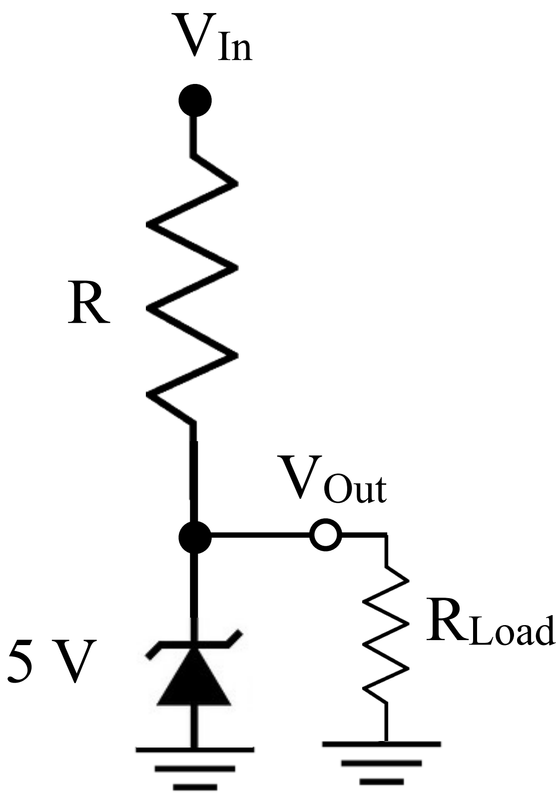

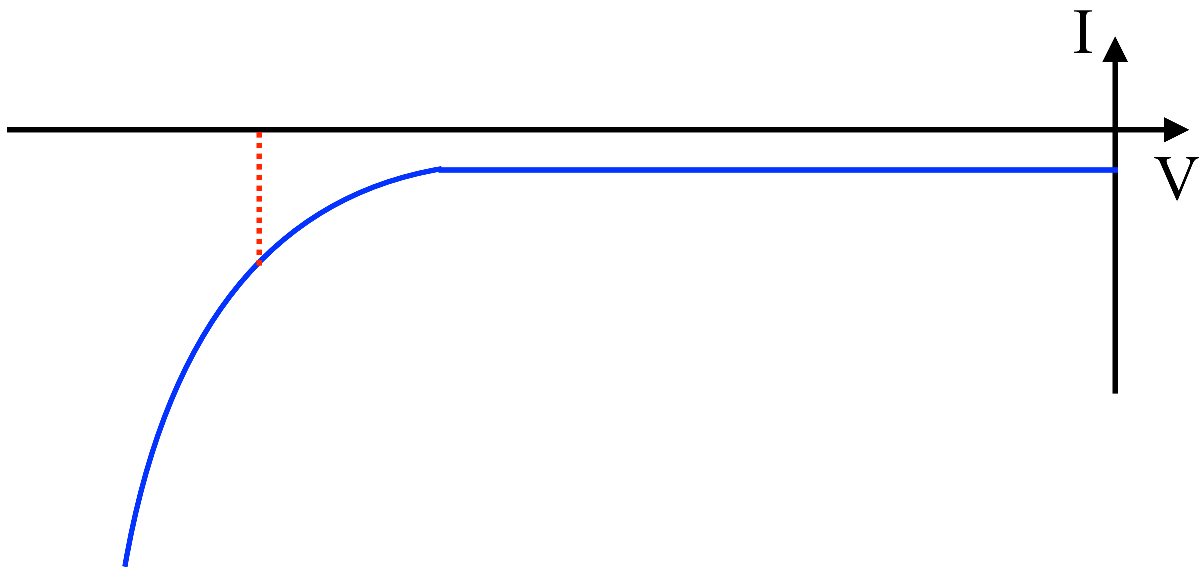

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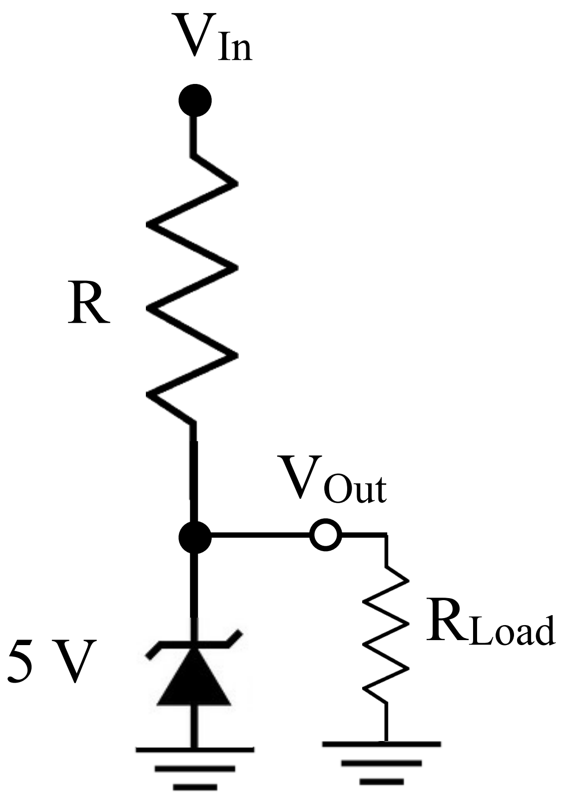
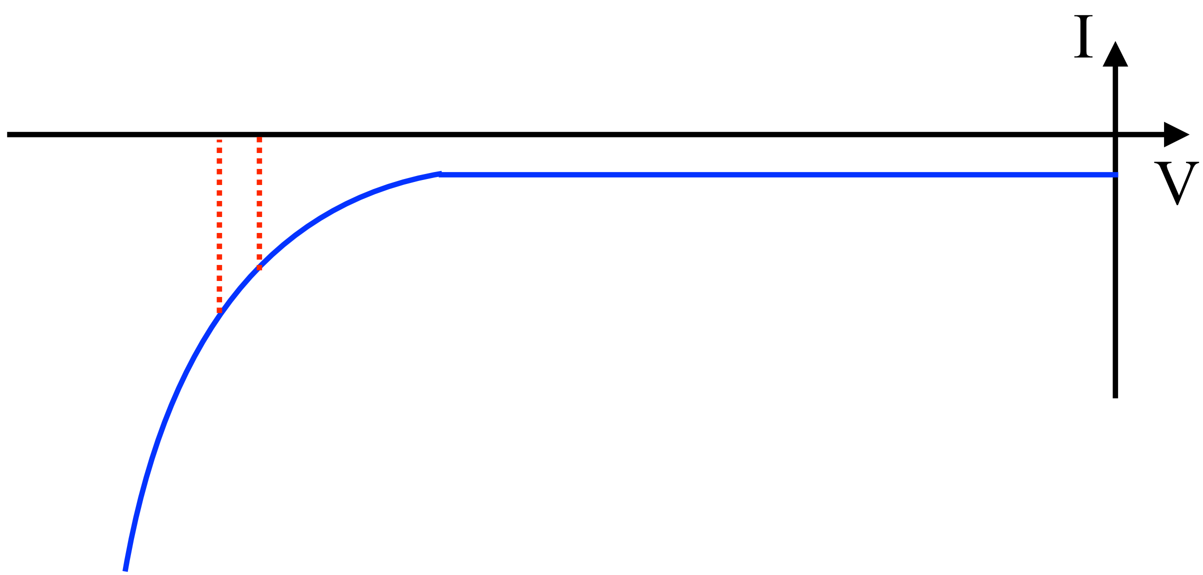




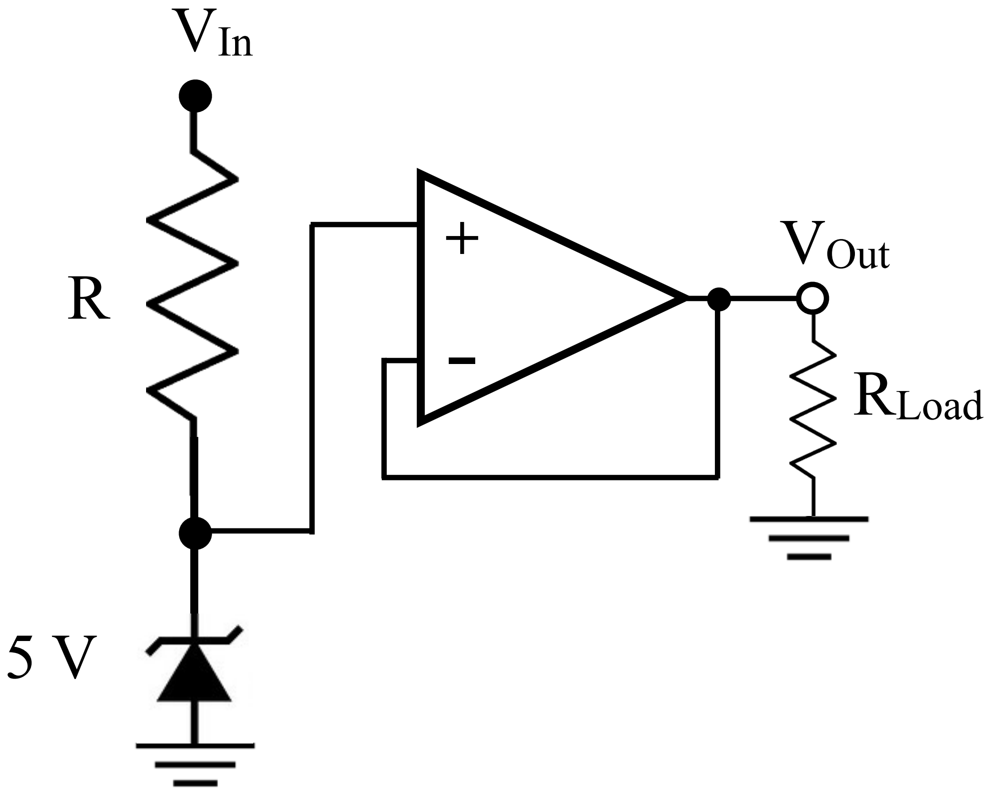
Variations of V_{in} will change the current through the zener diode and hence the voltage across it.

Smaller R makes this less severe, but increases power consumption.

Variations in R_{Load} change the current and hence voltage drop across R. (Standard impedance problem).

An op-amp based voltage regulator

We can remove the R_{Load} dependence with an op-amp follower.



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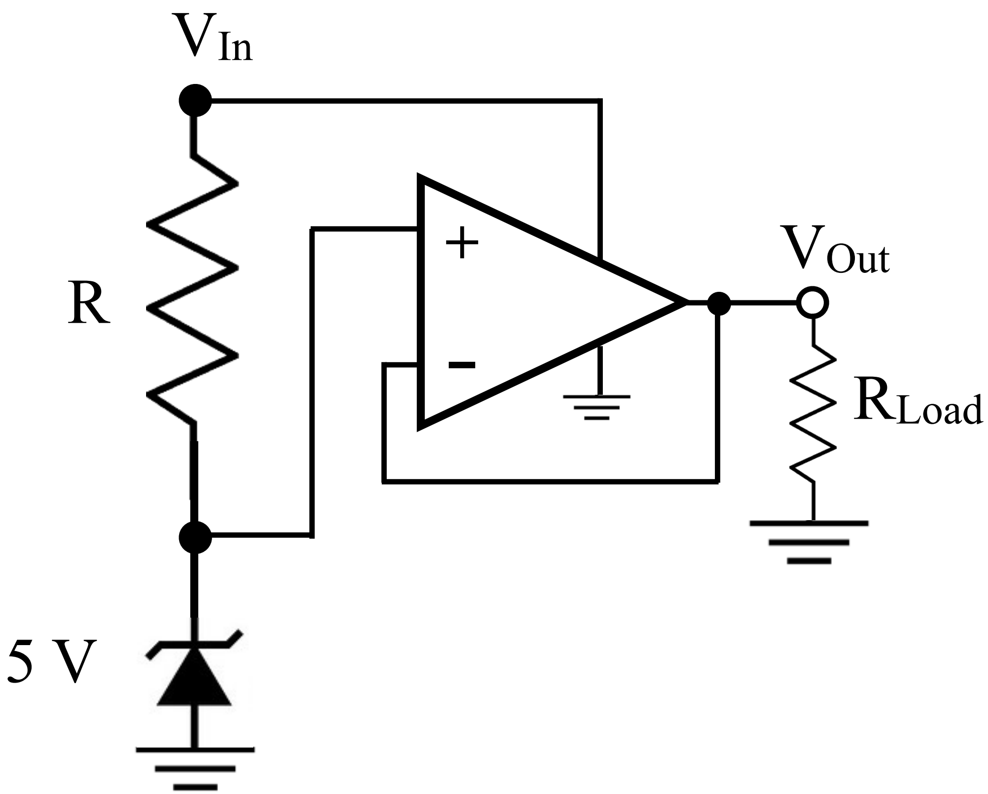

Power the op-amp off the *potentially unstable* input voltage.

The op-amp regulates the V_{Out} to follow V_{Zener}, regardless of V_{In}, as long as $V_{In}>V_{Out}$.

Less wasted power.

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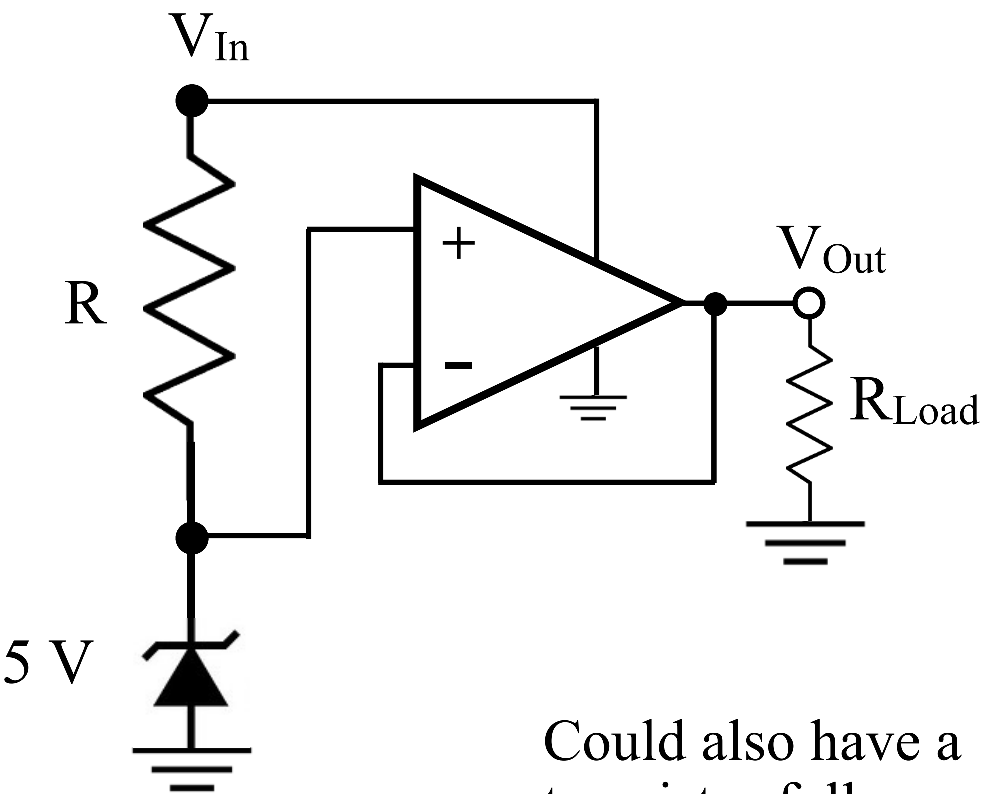

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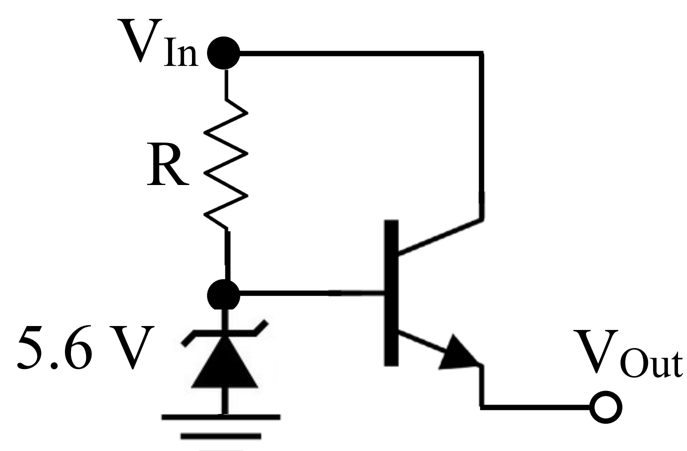
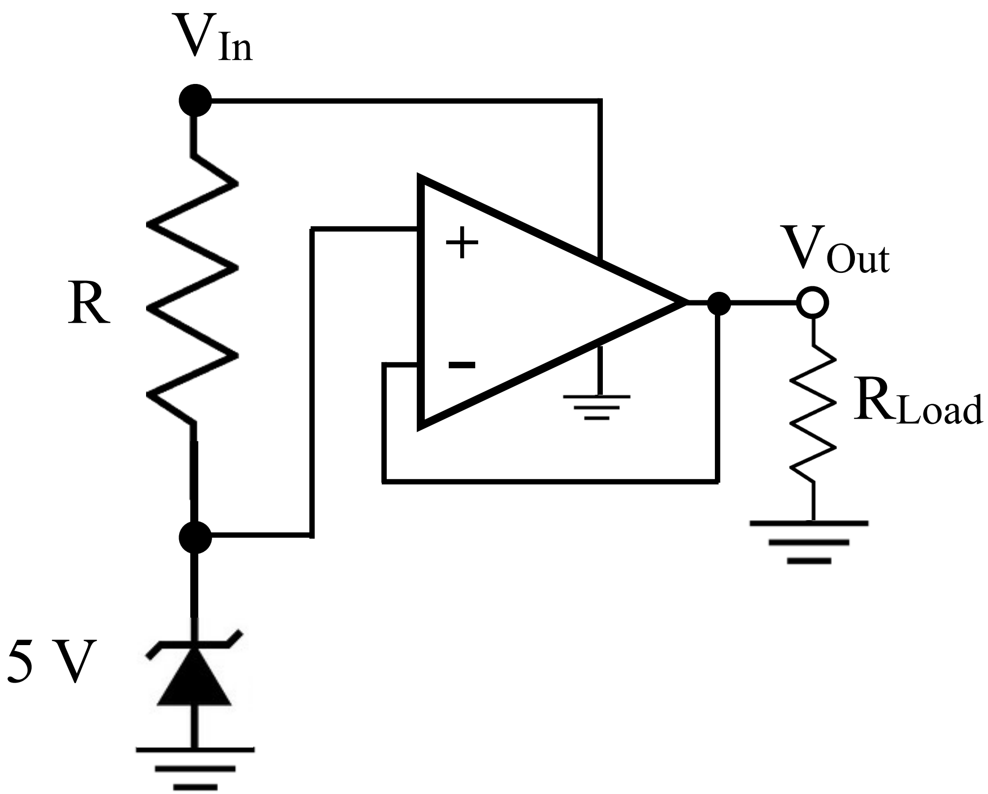
Could also have a transistor follower, but need to add the diode drop and less impedance gain.



An op-amp based voltage regulator

What if we wanted an output voltage other than 5 V?



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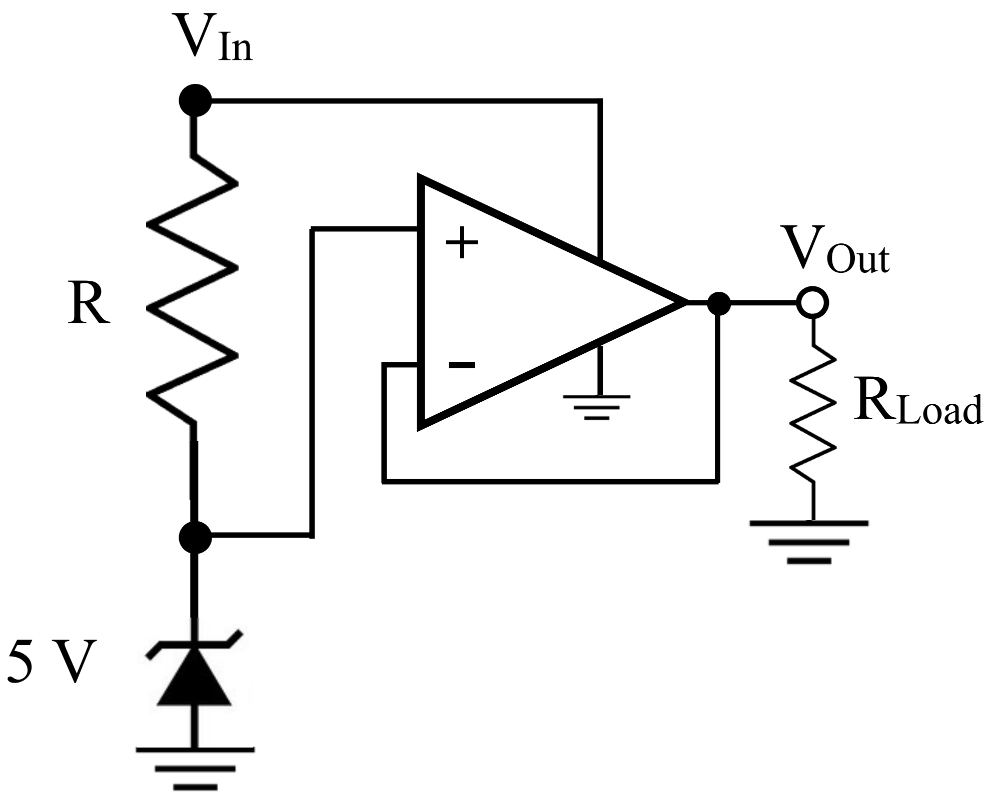

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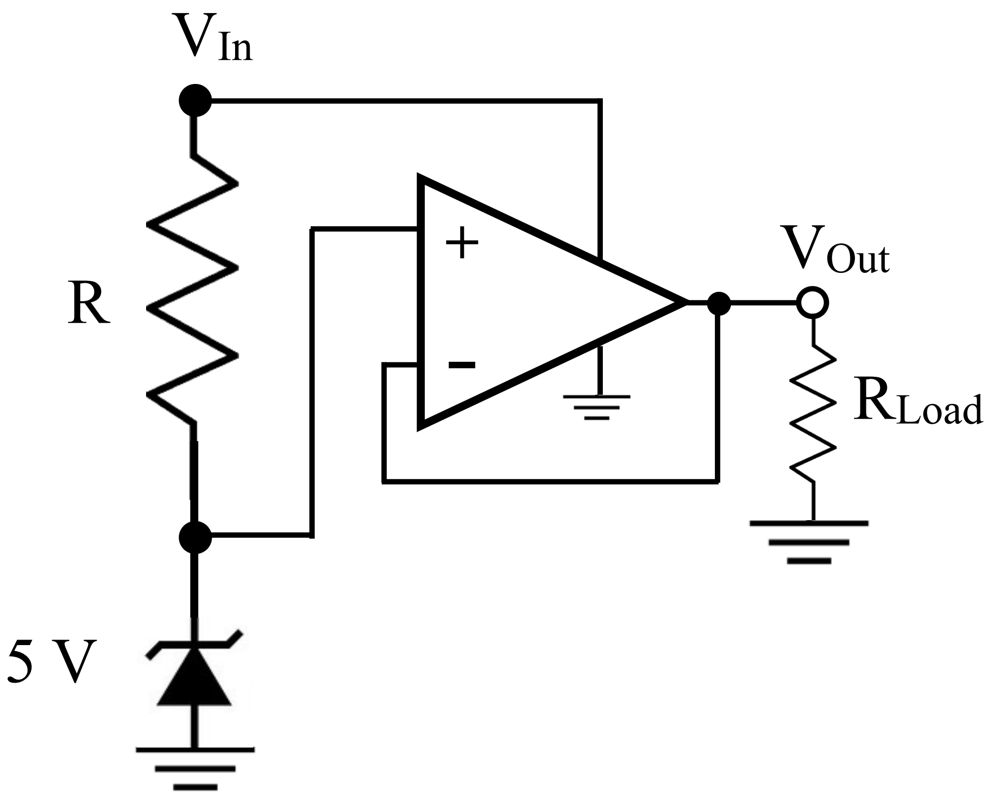
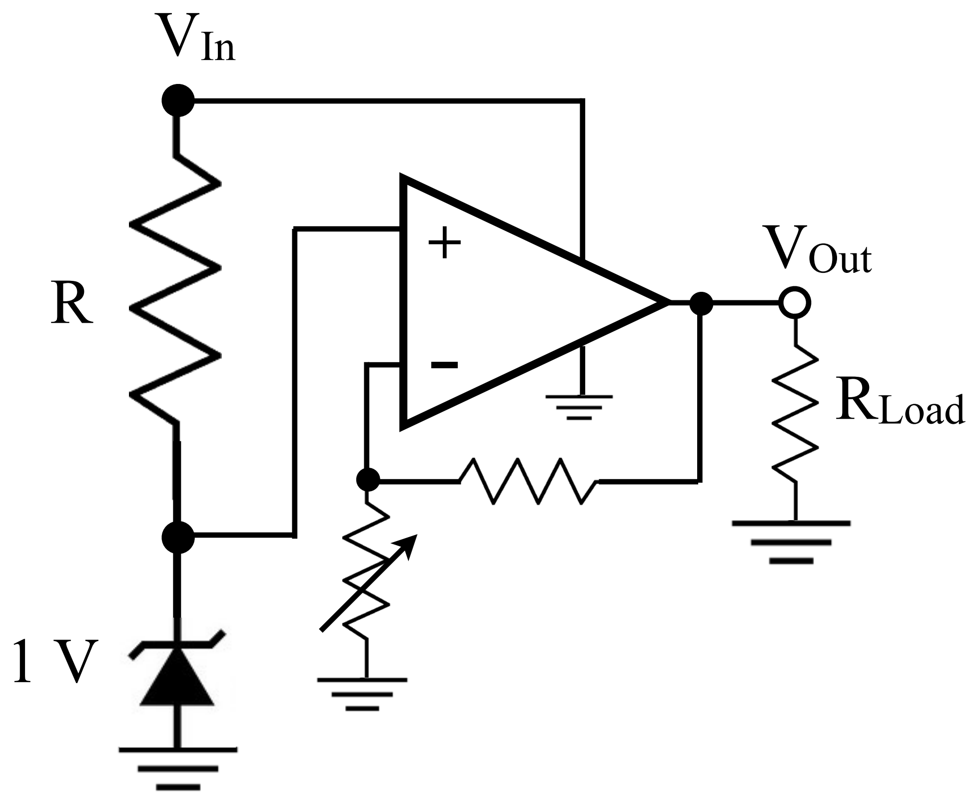


Replace the zener with one constructed for the desired voltage.

Use the op-amp to amplify the diode voltage to some other voltage.

An op-amp based voltage regulator

Amplify the zener's *reference voltage* to get an adjustable output voltage.



Can use a single low voltage zener and adjust the output voltage as desired.

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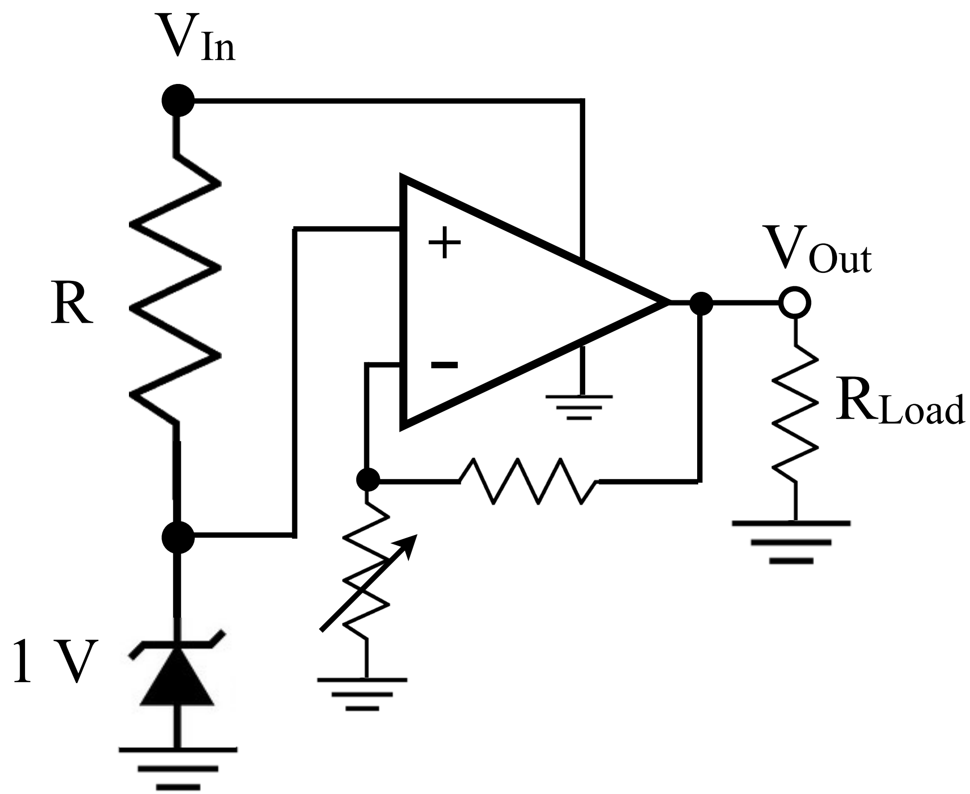

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This fixed the impedance problem but we still have the V_{In} variation changing I_{Zener} and hence V_{Zener}.

Would like to run the Zener off a more stable voltage source.

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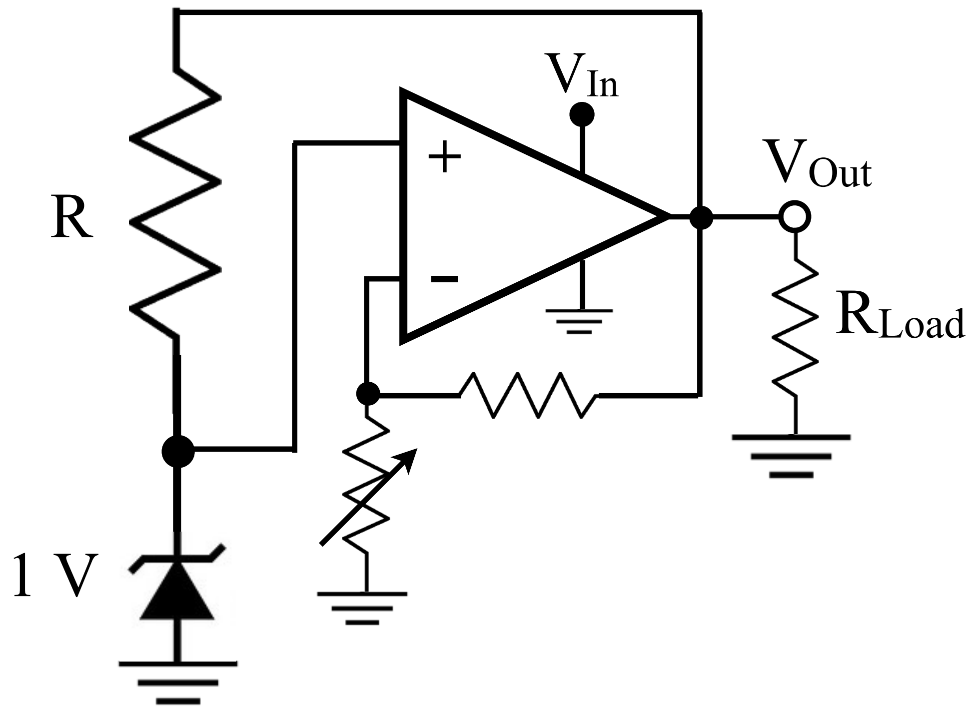

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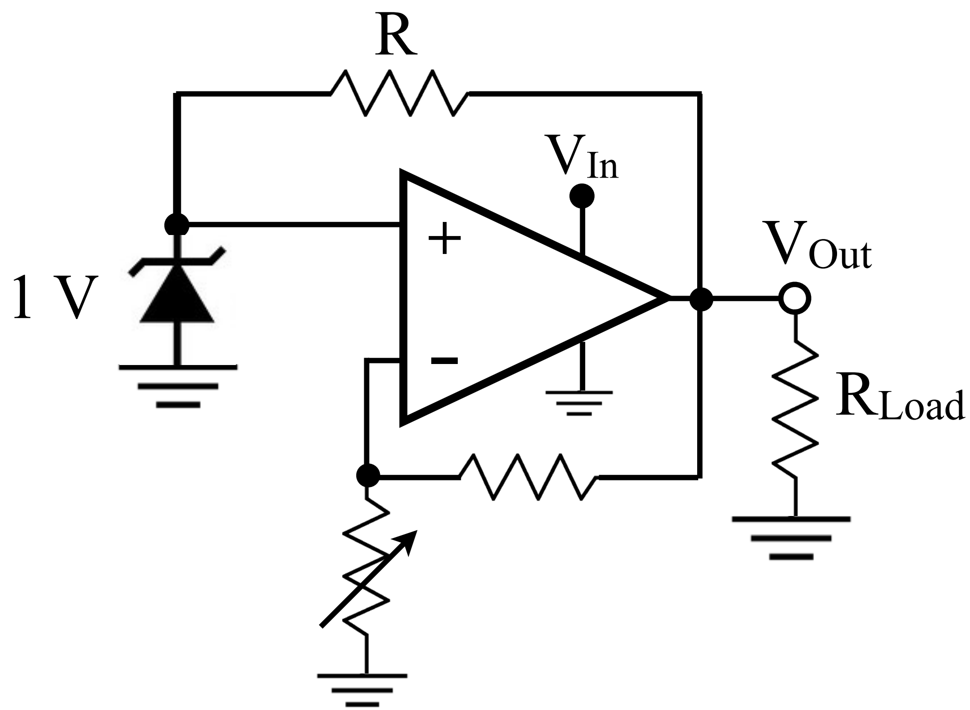
Would like to run the Zener off a more stable voltage source, like V_{Out}.

An op-amp based voltage regulator

Let's simplify the way it is drawn; just a redraw.



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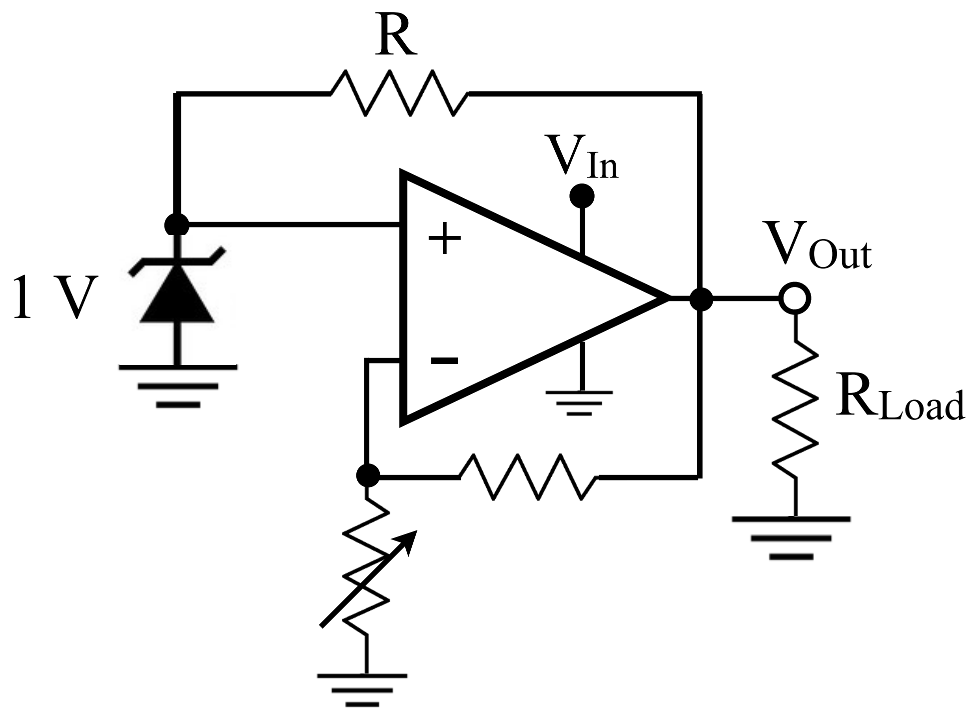
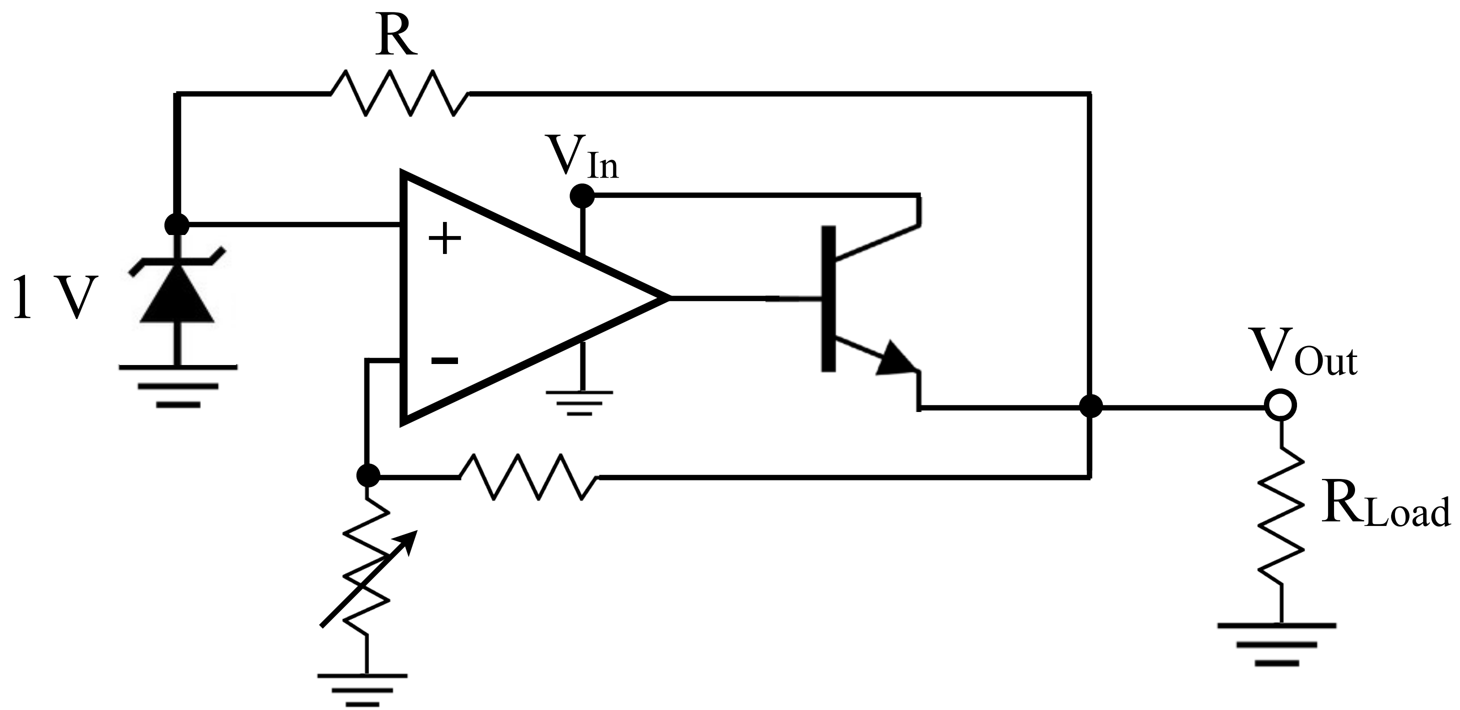


A potential limitation is that op-amp's don't always have high current output capability. Some do, if they have a high power transistor at the output; let's add that explicitly.

An op-amp based voltage regulator

Drive a large current with a power transistor



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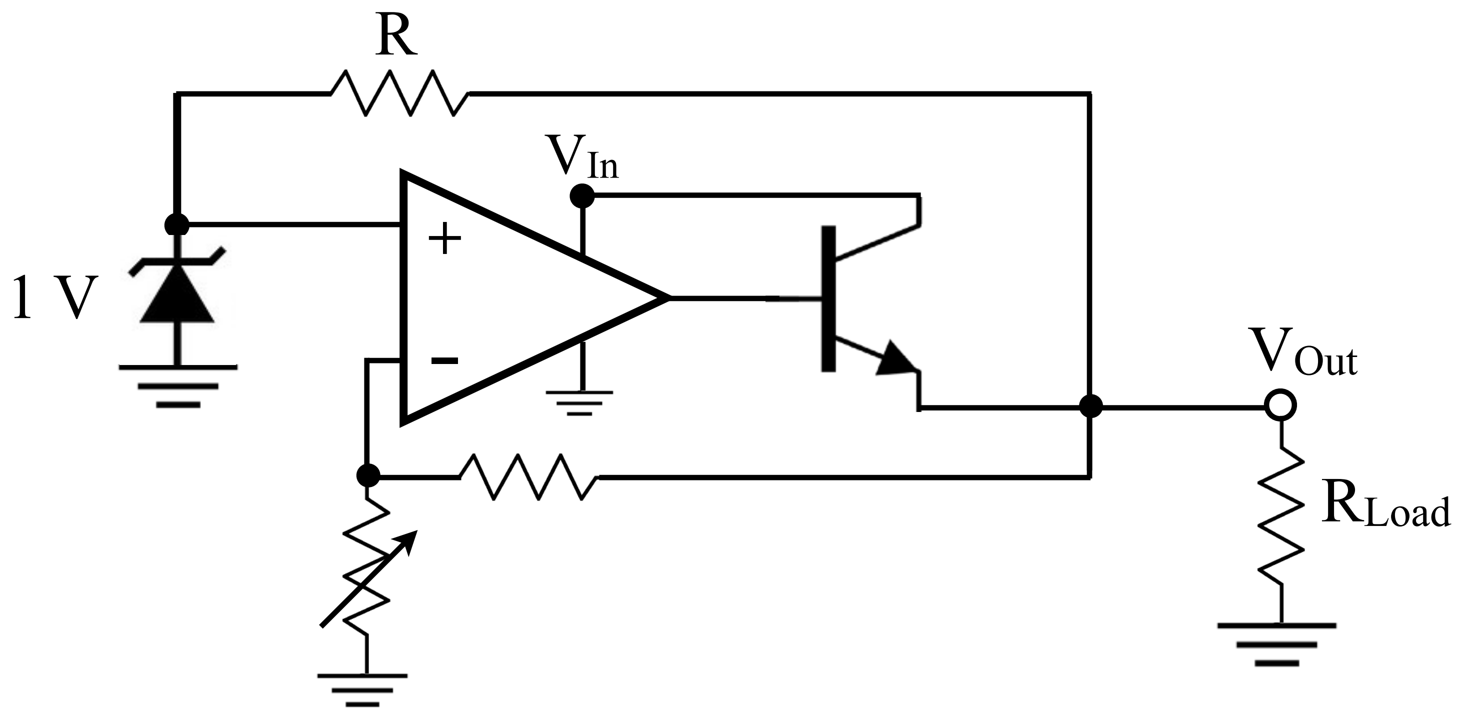

Do you need to compensate for the transistor's diode drop?

An op-amp based voltage regulator

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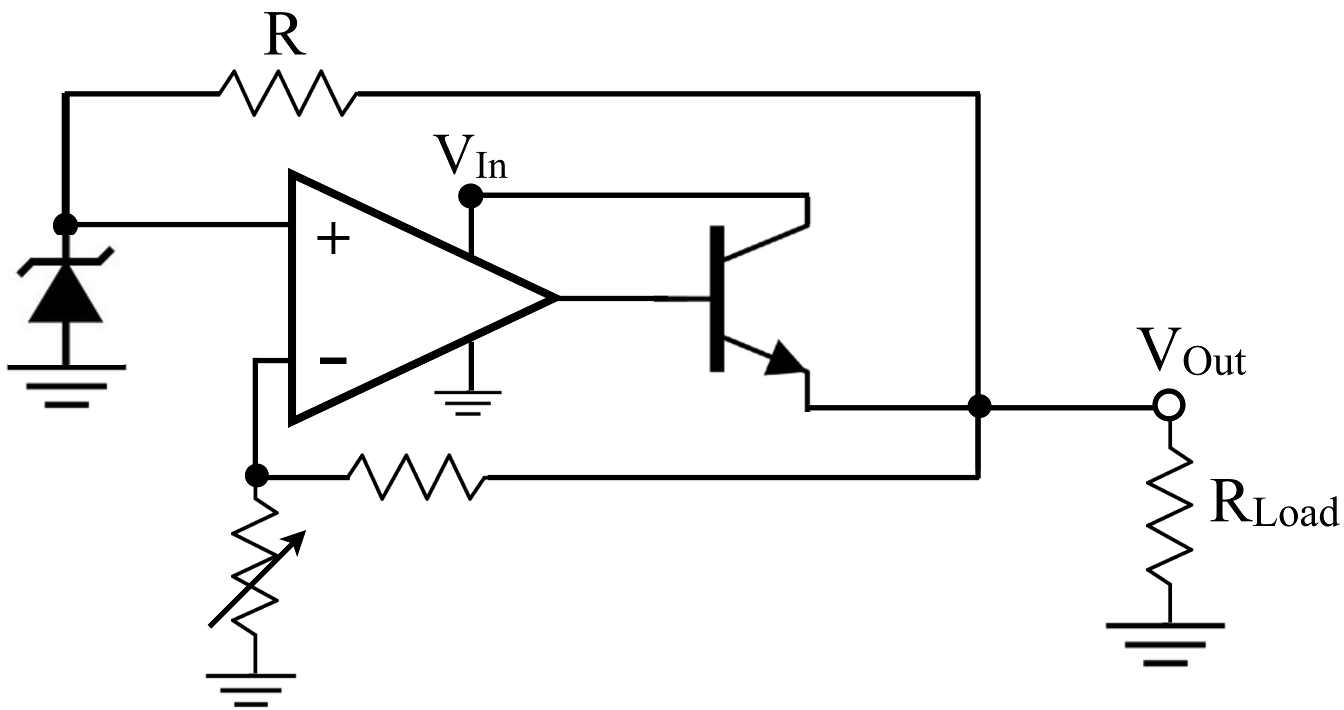
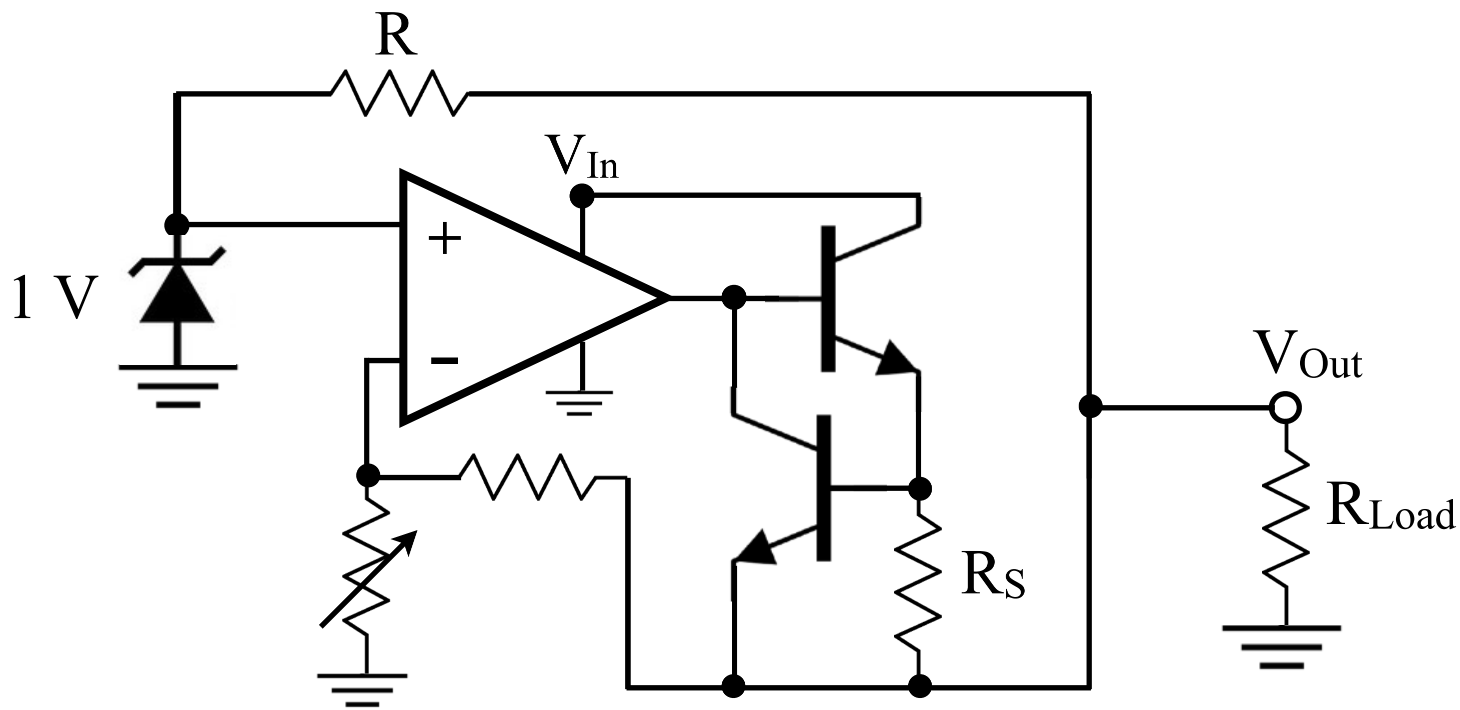


Do you need to compensate for the transistor's diode drop?

What happens if you short the output to ground?

An op-amp based voltage regulator

We can *limit the maximum current* with the feedback trick we discussed before.

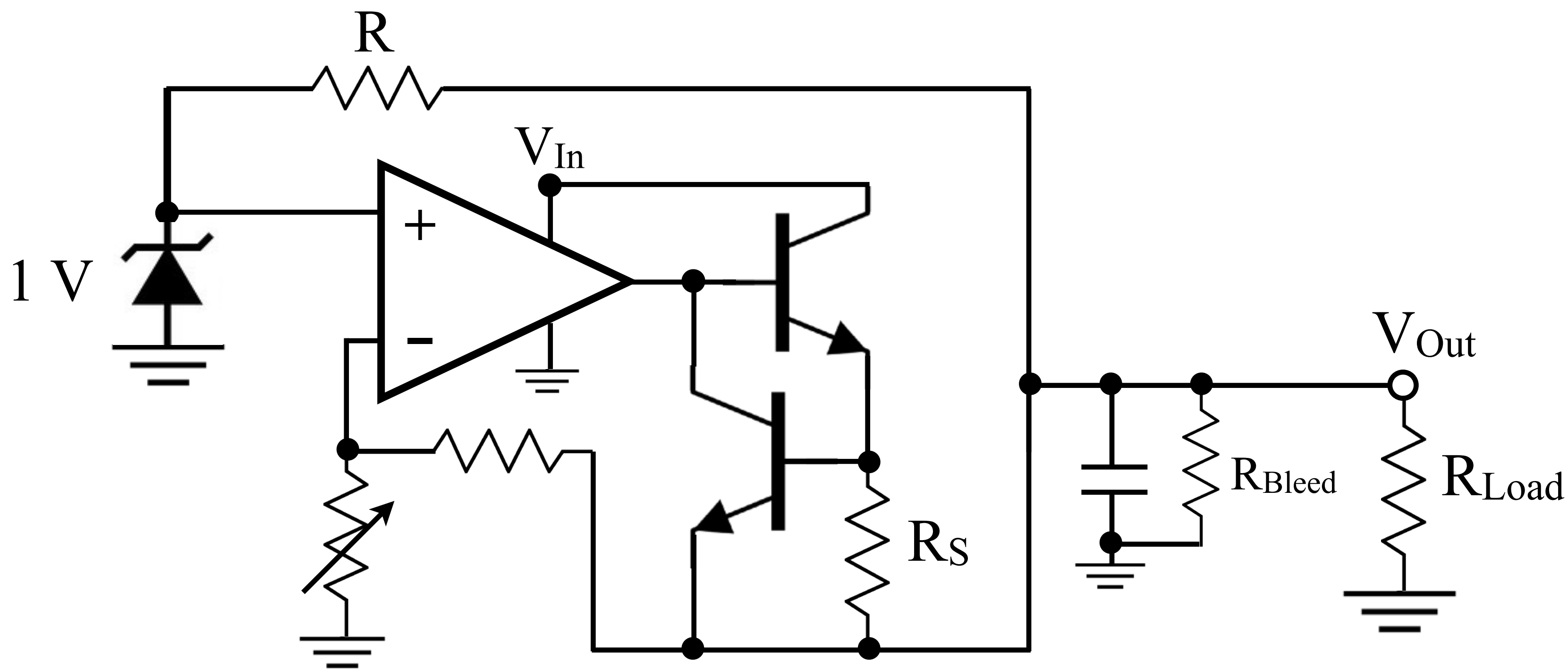


Increasing output current increases the voltage drop across R_S, once that voltage drop reaches 0.6 V, the second transistor turns on and steals base current from the first transistor, dropping its output.

Max current possible is then $I_{Max} = 0.6/R_S$.

An op-amp based voltage regulator

Finally, we add a storage (smoothing) capacitor and bleed resistor.



This is the idea of a voltage regulator that performs better than our original, simple zener diode regulator.

These are packaged as separate voltage regulator ICs.

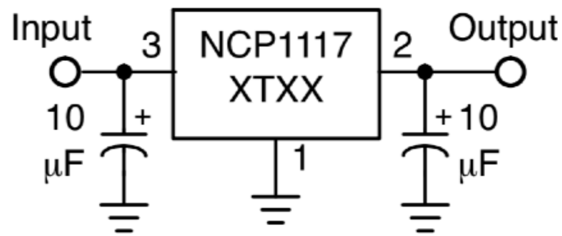
Voltage regulator ICs

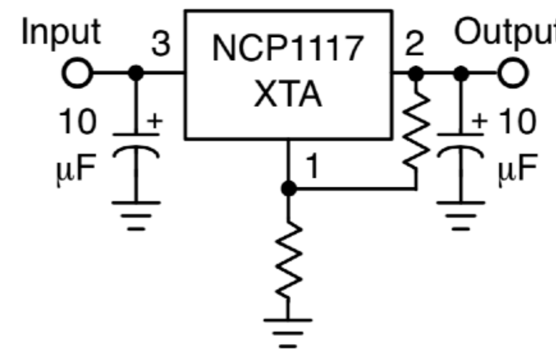
Many options for different fixed voltages and for varying voltages.

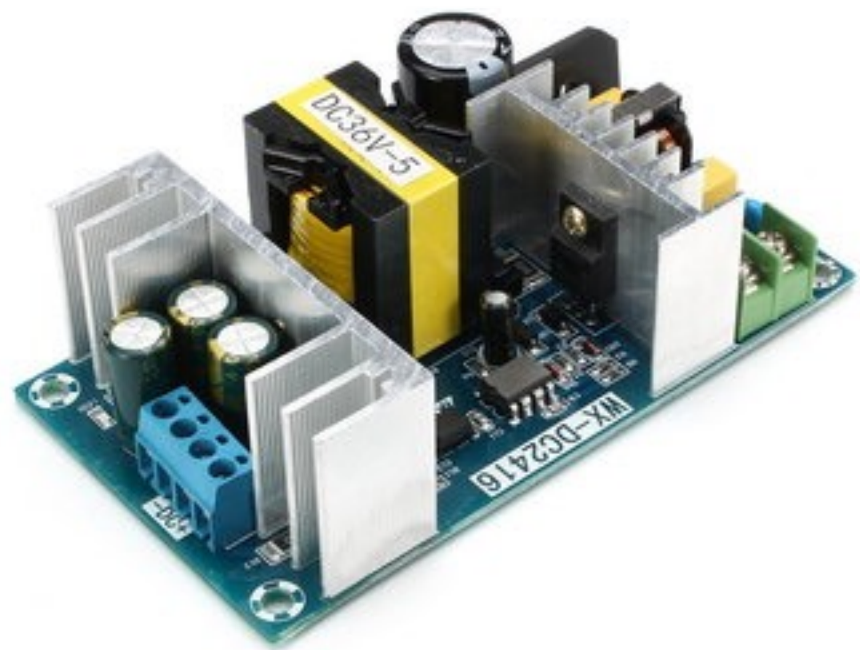
78L05

78L33

78LXX







Voltage regulator ICs

Many options for different fixed voltages and for varying voltages.

Specify the output voltage and the input voltage *range*.

The *dropout voltage* is the minimum additional voltage required at V_{In} for which V_{Out} is maintained at desired regulated voltage.

Many "LDO" options for all the standard DC supply voltages.

NCP1117, NCV1117

1.0 A Low-Dropout Positive Fixed and Adjustable Voltage Regulators

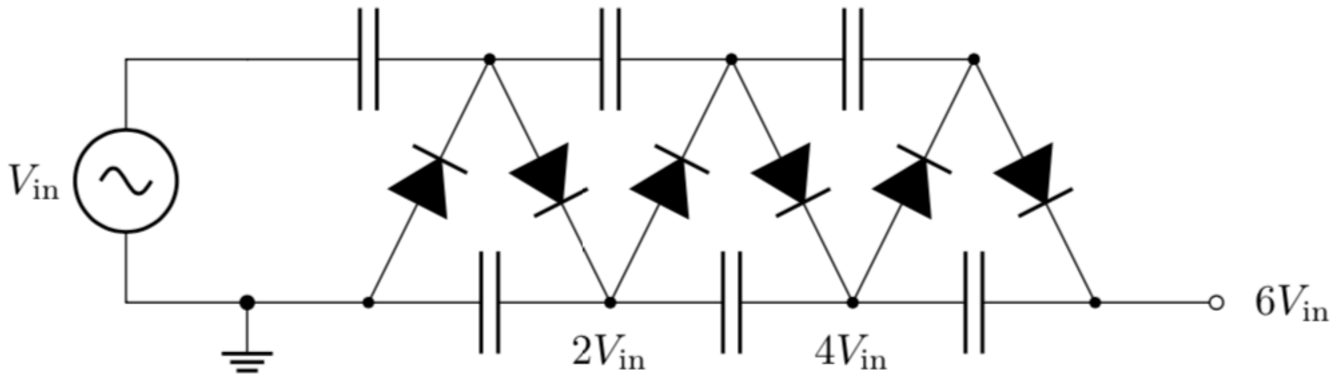
The NCP1117 series are low dropout positive voltage regulators that are capable of providing an output current that is in excess of 1.0 A with a maximum dropout voltage of 1.2 V at 800 mA over temperature. This series contains nine fixed output voltages of 1.5 V, 1.8 V, 1.9 V, 2.0 V, 2.5 V, 2.85 V, 3.3 V, 5.0 V, and 12 V that have no minimum load requirement to maintain regulation. Also included is an adjustable output version that can be programmed from 1.25 V to 18.8 V with two external resistors. On chip trimming adjusts the reference/output voltage to within ±1.0% accuracy. Internal protection features consist of output current limiting, safe operating area compensation, and thermal shutdown. The NCP1117 series can operate with up to 20 V input. Devices are available in SOT−223 and DPAK packages.

Features

- Output Current in Excess of 1.0 A
- 1.2 V Maximum Dropout Voltage at 800 mA Over Temperature
- Fixed Output Voltages of 1.5 V, 1.8 V, 1.9 V, 2.0 V, 2.5 V, 2.85 V, 3.3 V, 5.0 V, and 12 V
- Adjustable Output Voltage Option
- No Minimum Load Requirement for Fixed Voltage Output Devices
- Reference/Output Voltage Trimmed to ±1.0%
- Current Limit, Safe Operating and Thermal Shutdown Protection
- Operation to 20 V Input

DC-DC converters

You can also make $V_{Out} > V_{In}$. For example: Cockroft-Walton voltage multiplier



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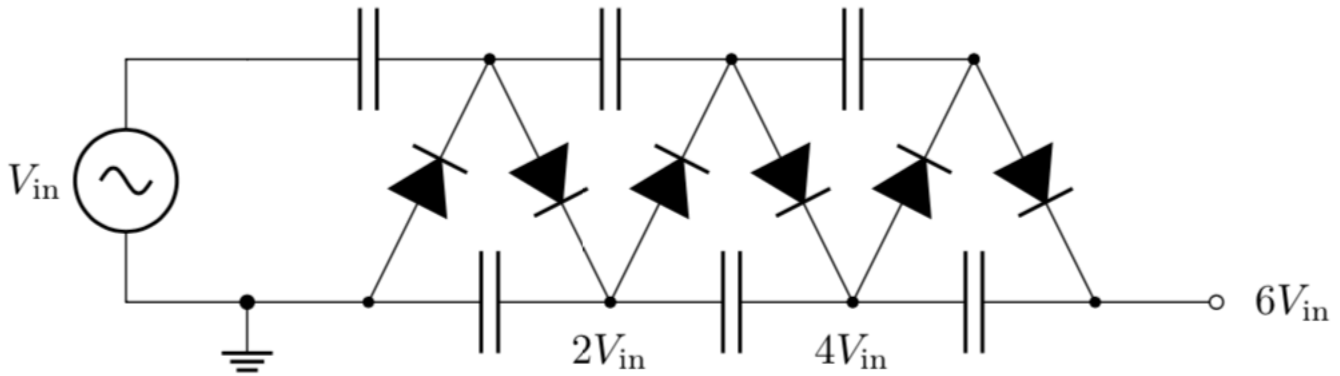

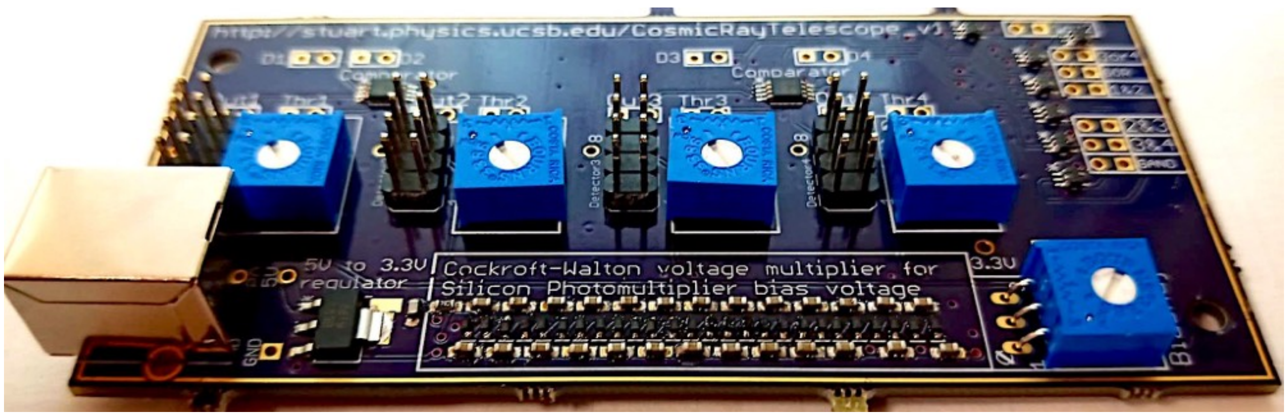

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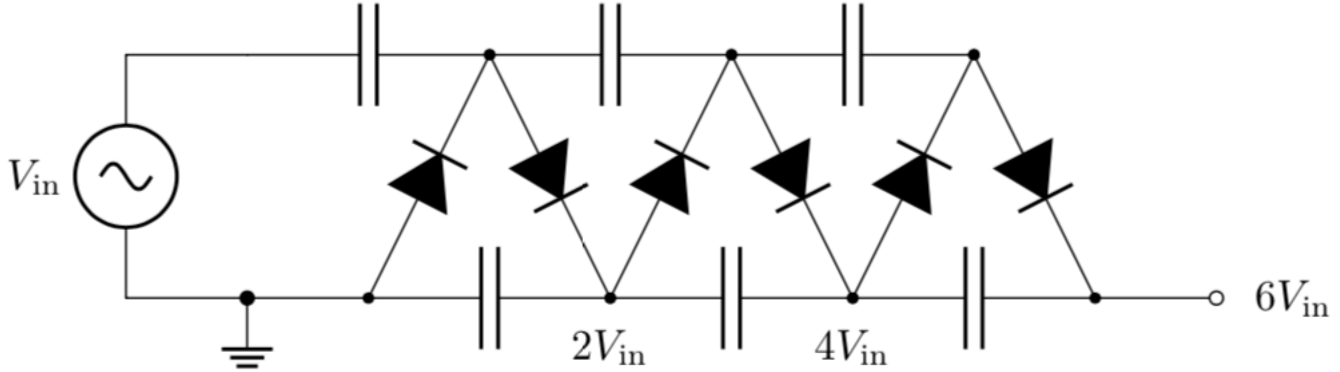
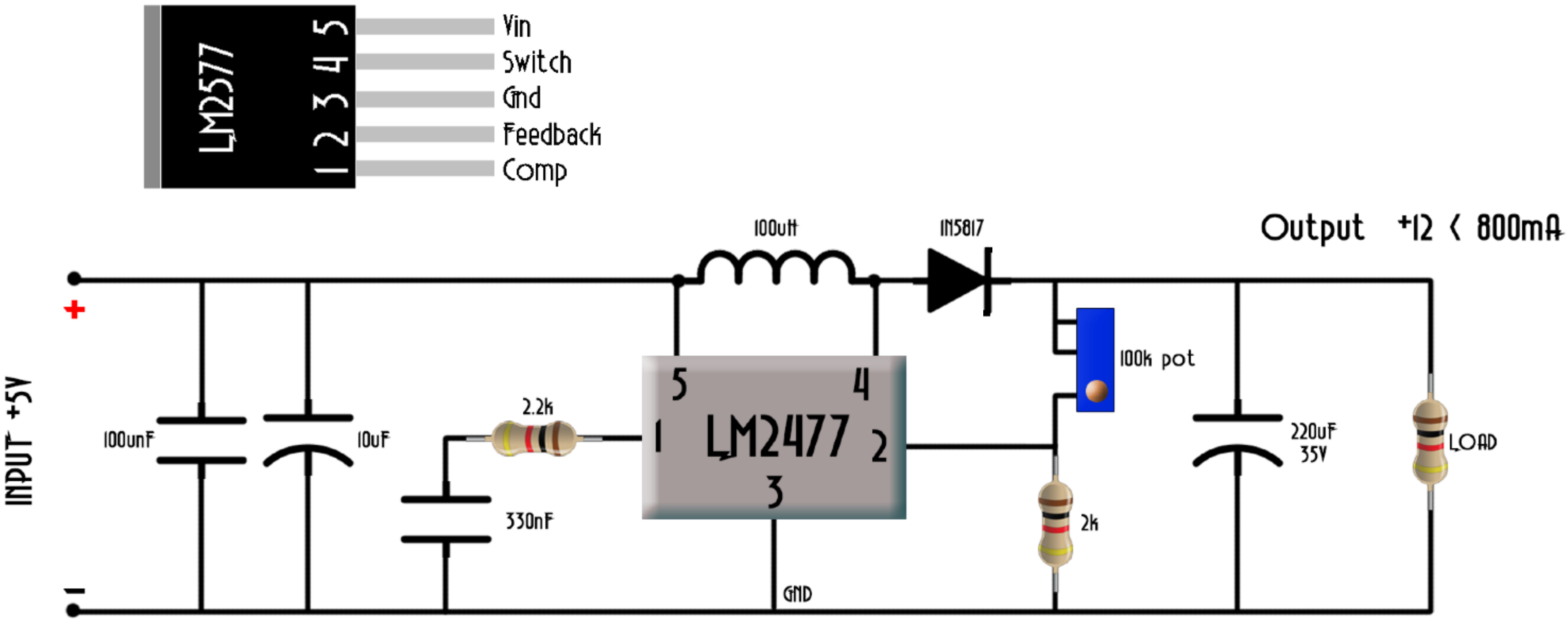


DavidStuart@UCSB.edu

DC-DC converters

You can also make $V_{Out} > V_{In}$. For example: Inductive buck converter.

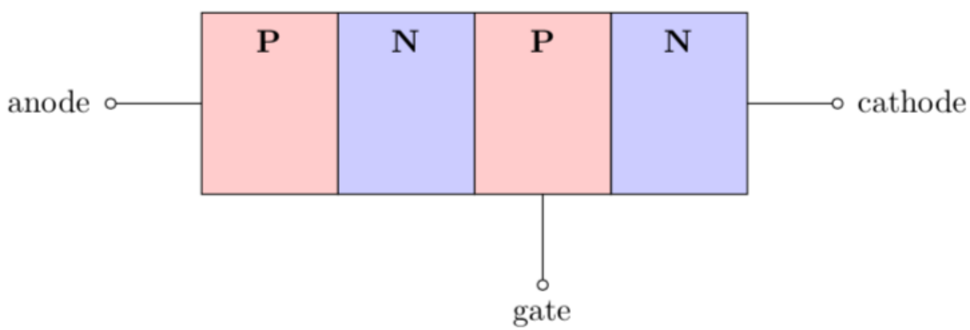


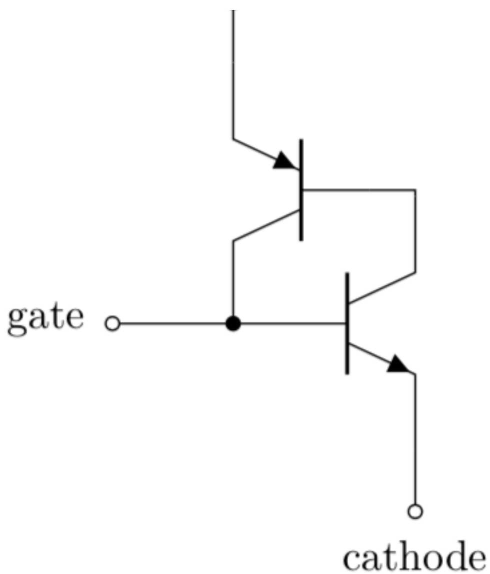
Crowbar

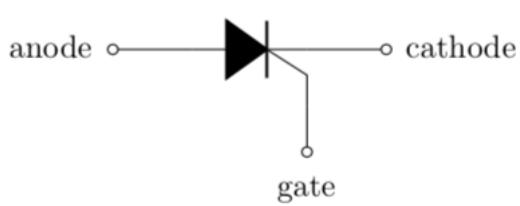
Another useful protection mechanism is called a "crowbar circuit".

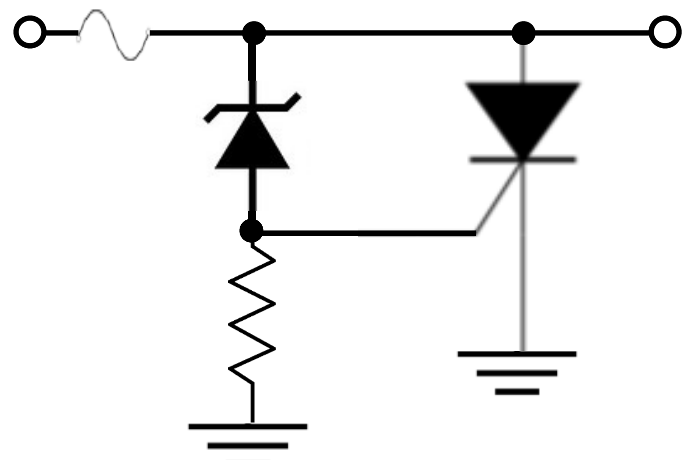
If output voltage exceeds a threshold, throw a crowbar across it to blow a fuse.

This can be done with a silicon-controlled rectifier (SCR)









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Next I want to talk about noise sources.

Next time we'll see how to suppress noise for precision measurements.

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The term "noise" generically means anything that is not *your* signal.

"I can't hear you over the background noise."

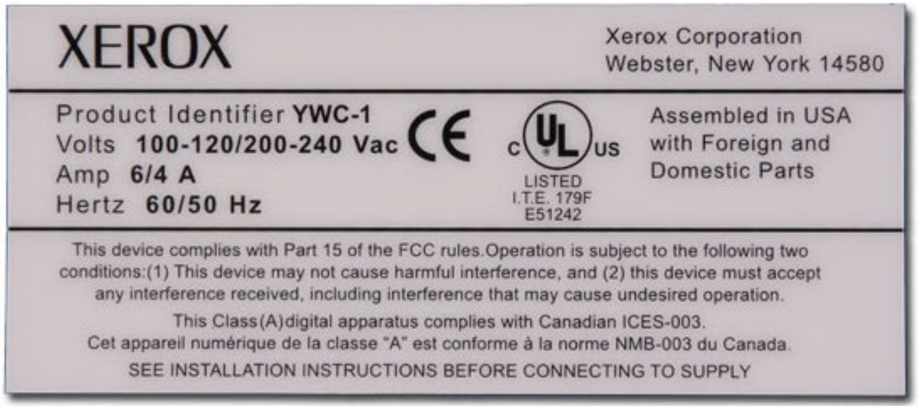
Examples:

The primary star light in our original example of an exoplanet sunset.

Other radio stations leaking into our sidebands.

Uncontrolled transmitters, eg microwave ovens overlap WiFi spectrum.

CMB



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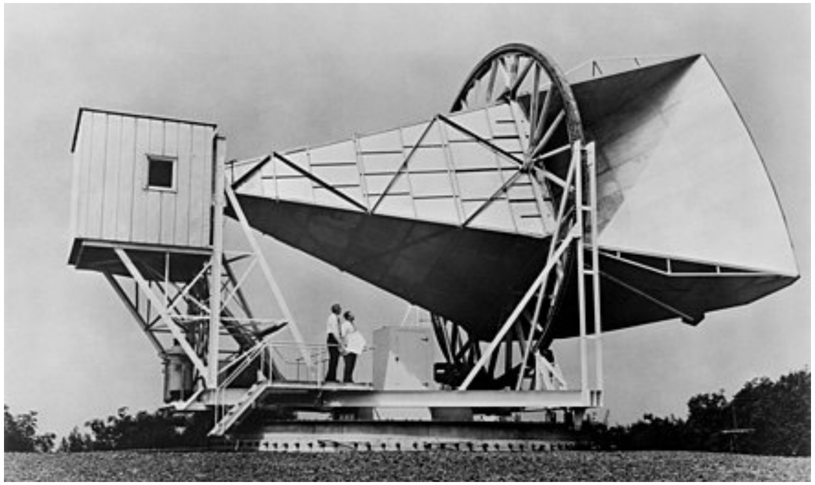

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Rincon Peak Ablaze photo by Mike Eliason / Santa Barbara County Fire Department courtesy of *Noozhawk*

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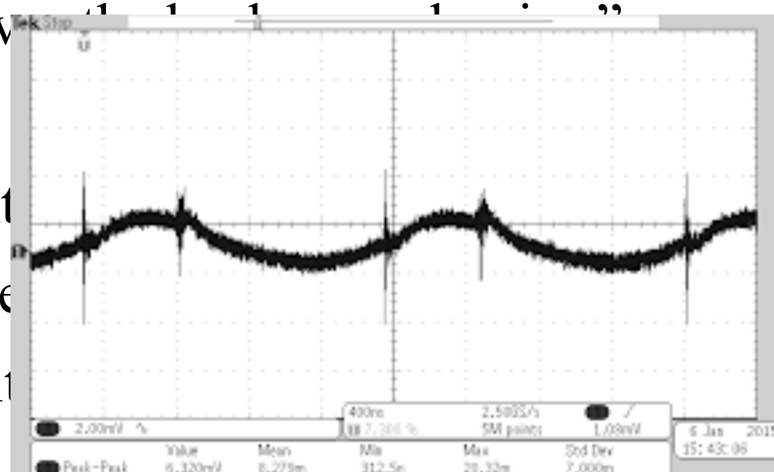

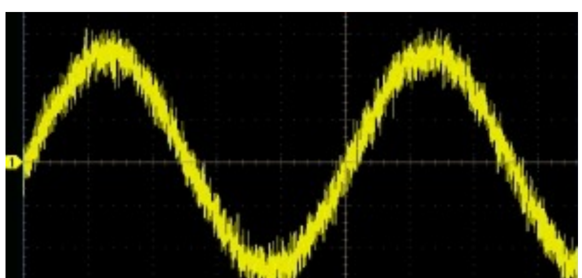

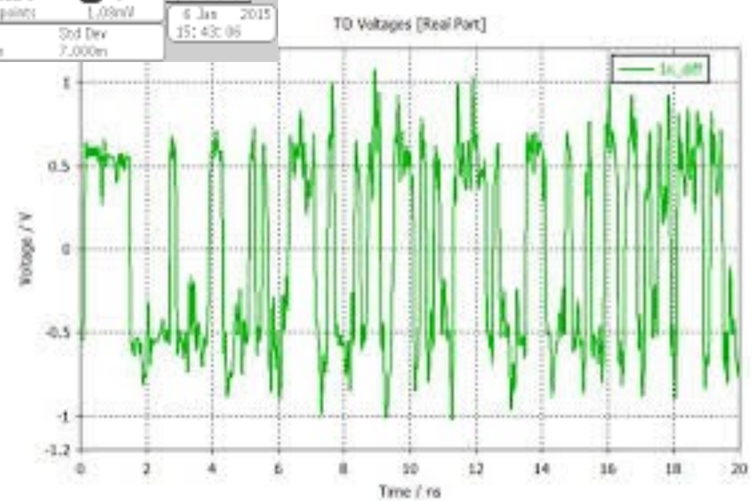

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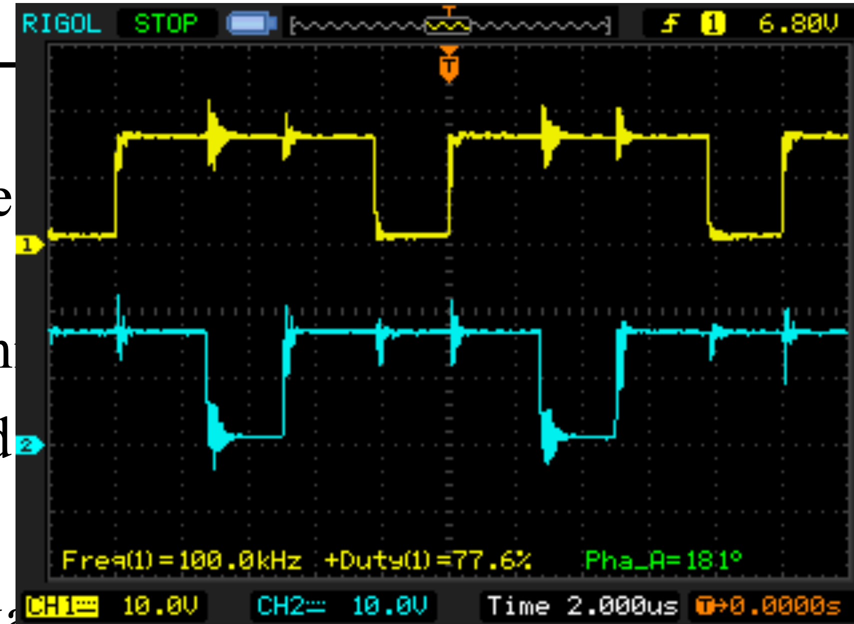
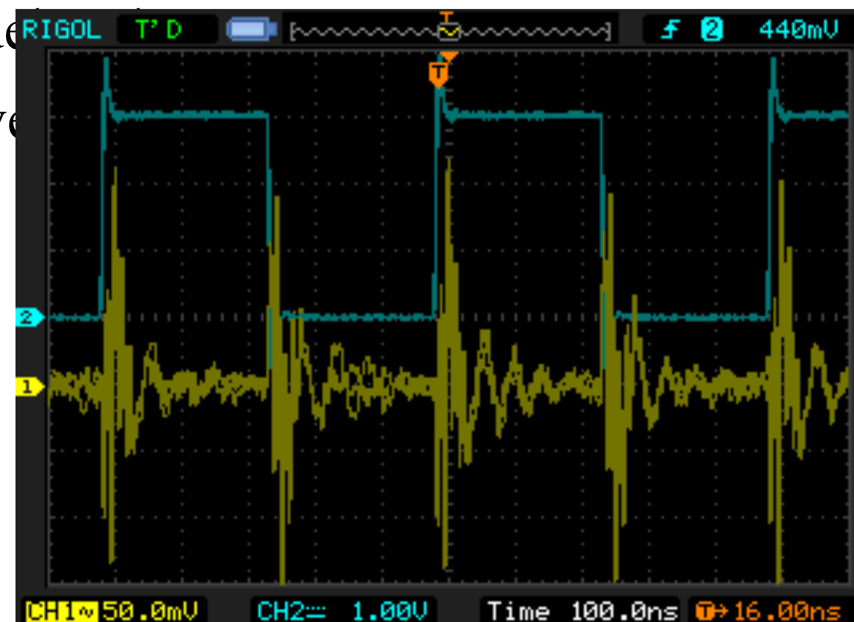
Power supply bounce





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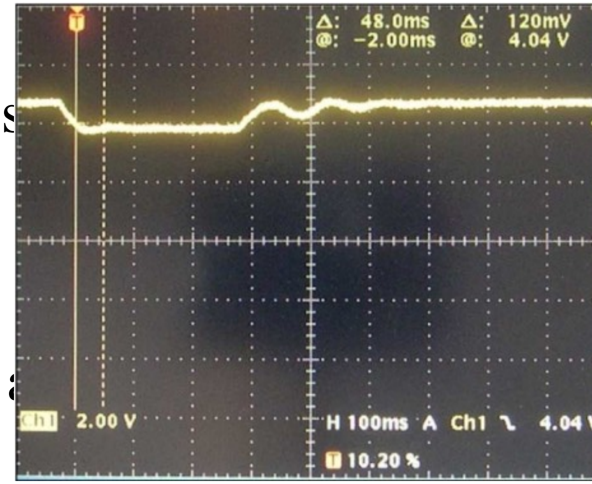

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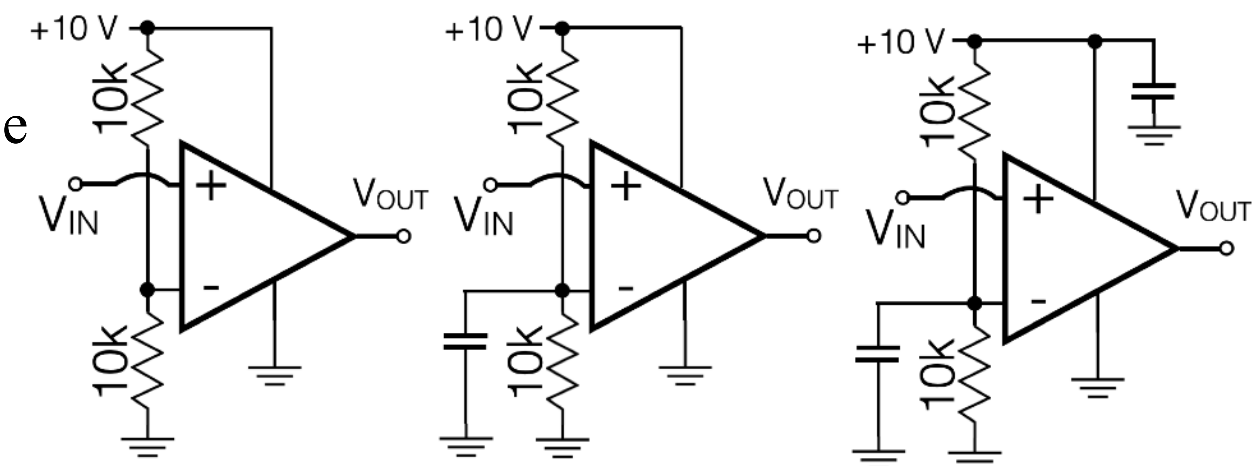

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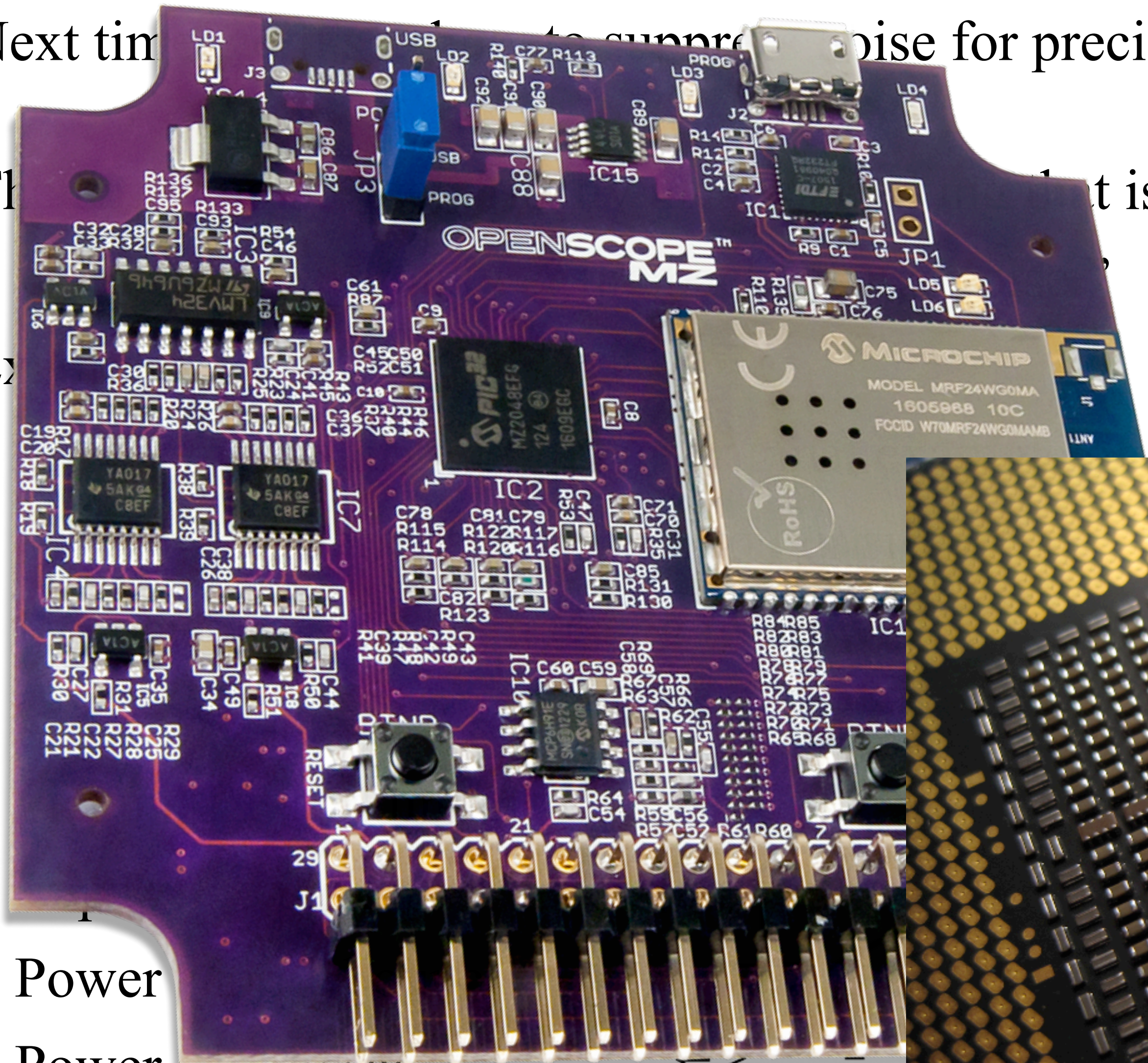
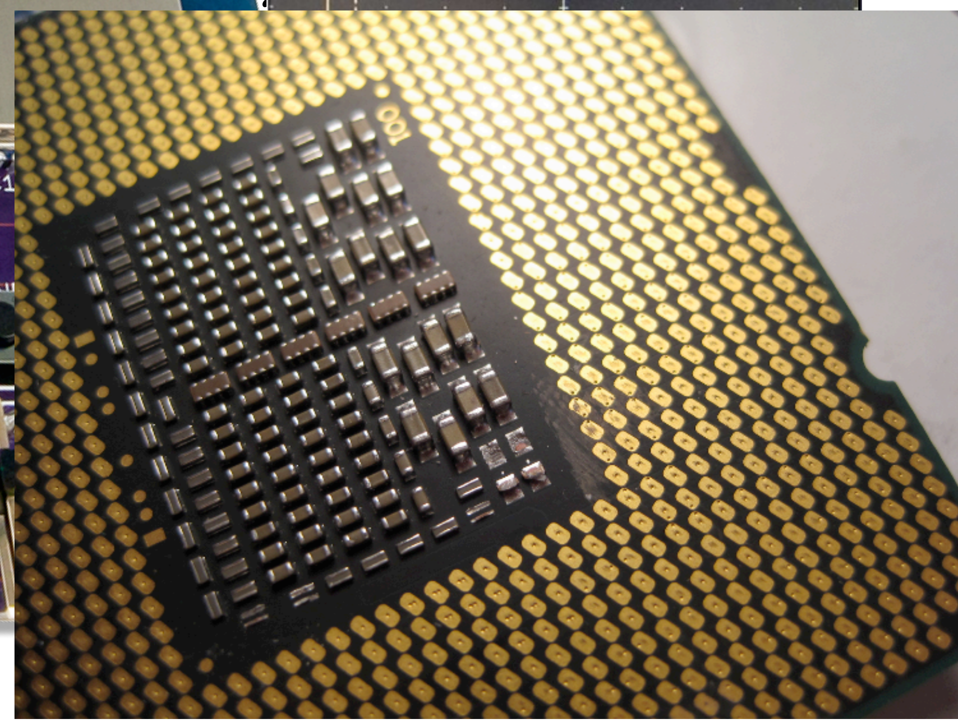




Thermal Noise

There are also thermal noise effects.

Johnson noise is thermal fluctuations that generate RMS current.

That becomes a voltage across a resistor.

Spectral *density* is

$$\overline{v_n^2} = 4k_\text{B}TR$$

So RMS noise in a frequency range is

$$v_n = \sqrt{\overline{v_n^2}}\sqrt{\Delta f} = \sqrt{4k_\text{B}TR\Delta f}$$

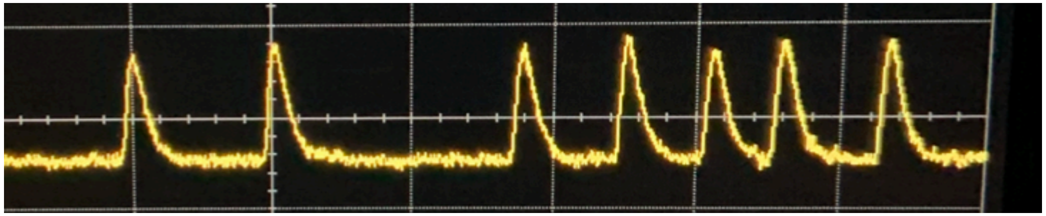
At room temperature, this is a few μV per 10kHz per kΩ.

Using a 10 MΩ input resistor adds a significant, O(10 mV), noise source, so it is best to avoid very large resistors.

Shot Noise

At very low currents, the motion of individual electrons matters.

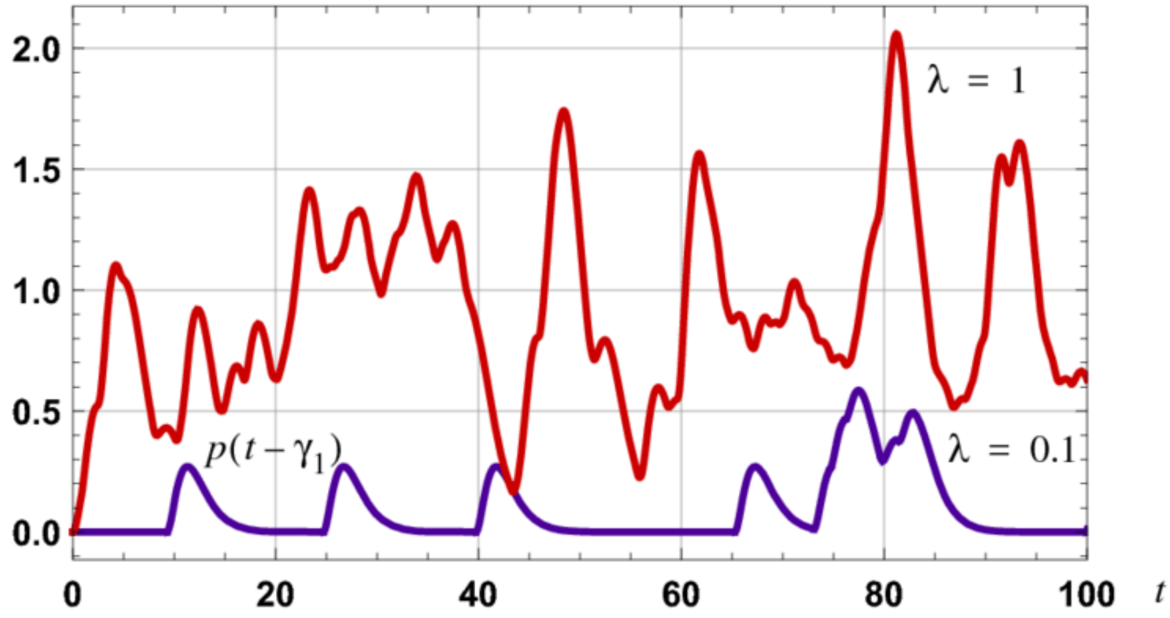
Similarly with low light levels.



Counting N individual events in a time Δt has fluctuations of $\sqrt{N}$.

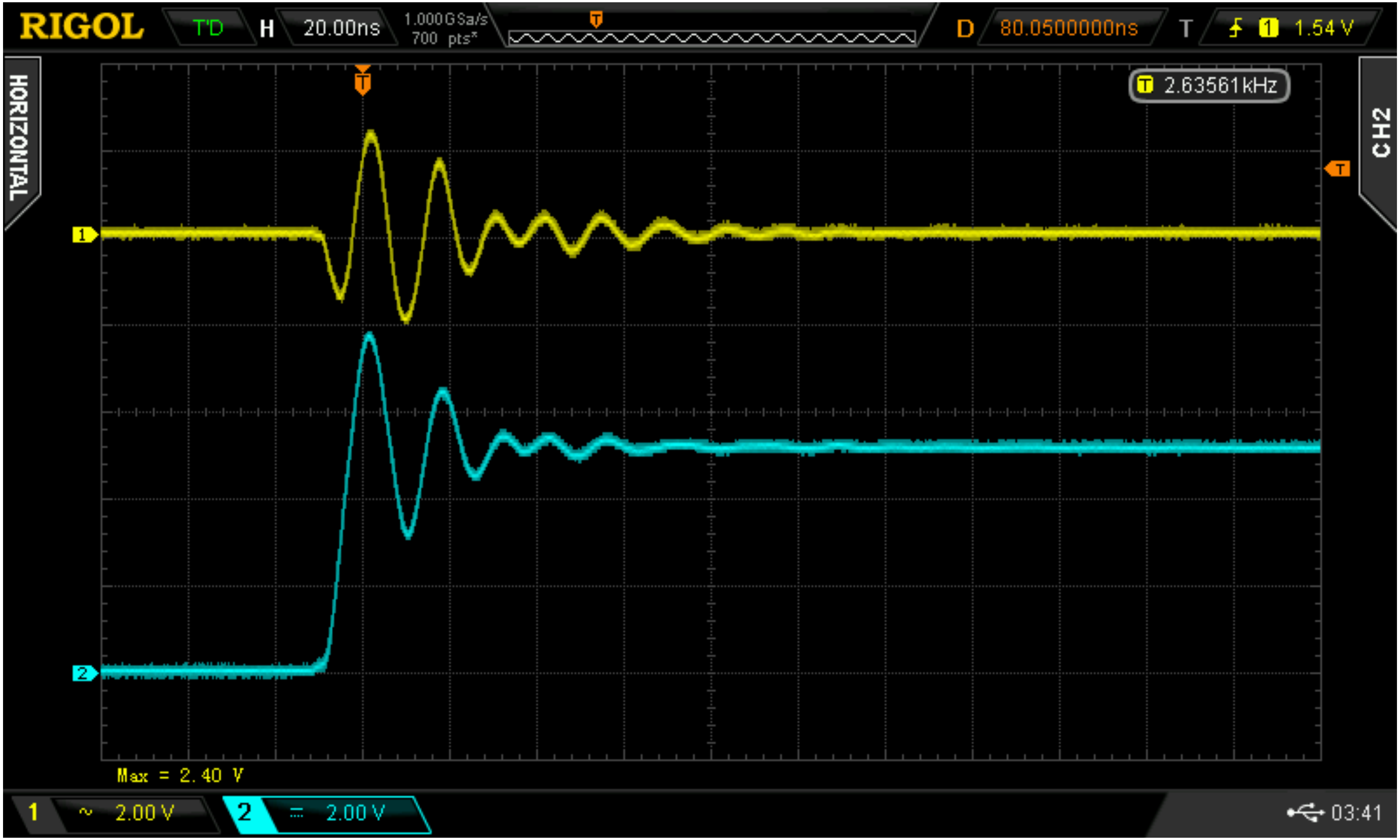
The fractional uncertainty, $\sqrt{N}/N$, reduces at higher currents, but it can dominate for small N.

Best to avoid small I, e.g., i = 10% of I is less noisy if I is larger.



Unwanted oscillations

Often, noise problems are self induced, e.g., unwanted oscillations.

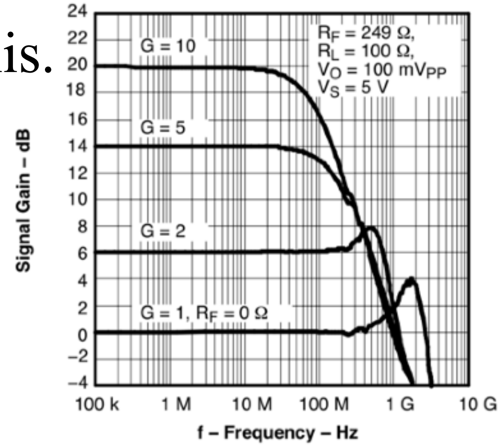


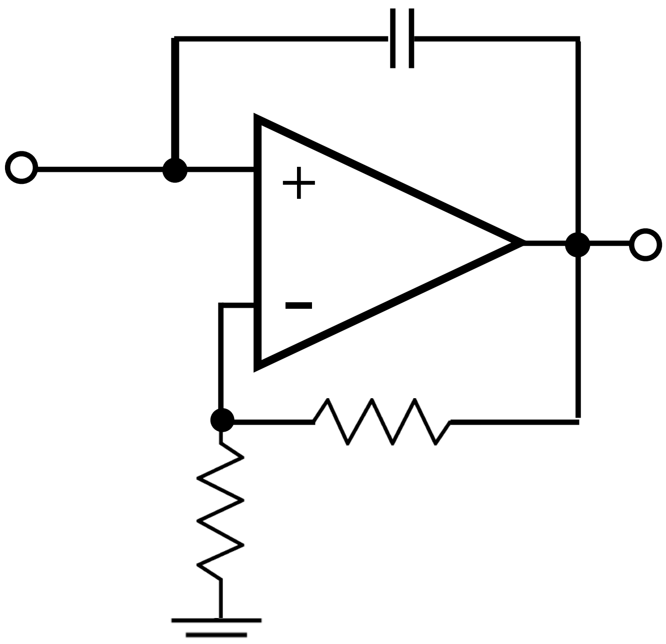
Unwanted oscillations

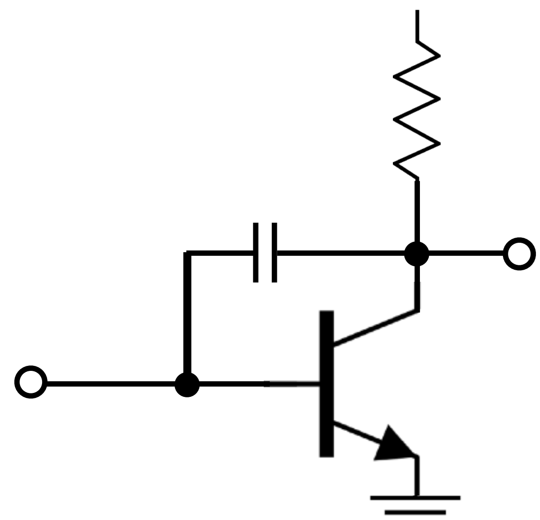
Often, noise problems are self induced, e.g., unwanted oscillations.

Positive feedback through parasitic capacitance can cause this.

- Minimize parasitic capacitance
- Roll off high-frequency gain







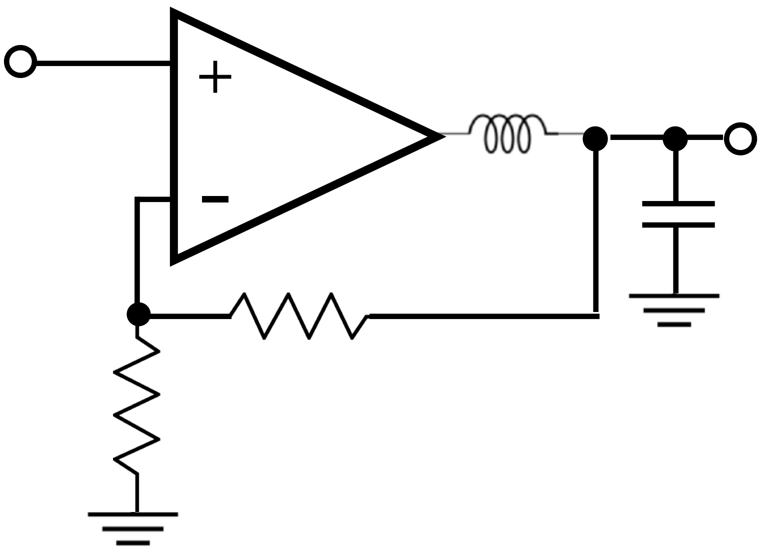
Unwanted oscillations

Often, noise problems are self induced, e.g., unwanted oscillations.

Parasitic inductance and capacitance can cause resonant oscillation.

Parasitic inductance from thin wires

Capacitance from cables.

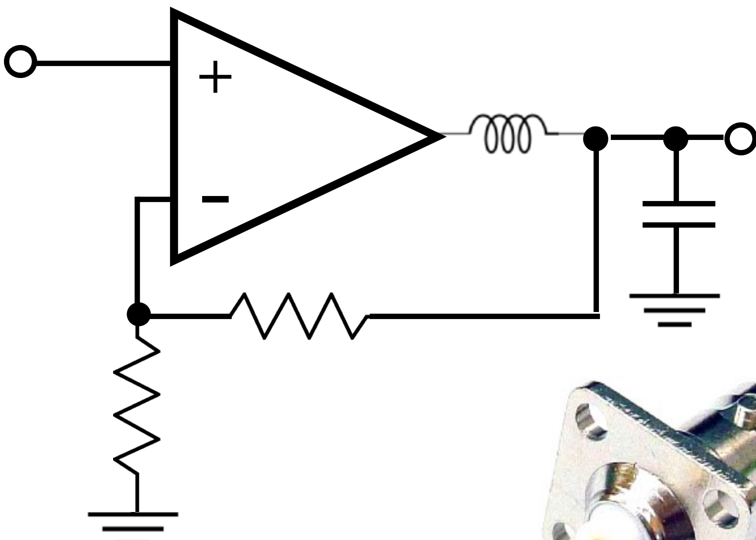


Unwanted oscillations

Often, noise problems are self induced, e.g., unwanted oscillations.

Parasitic inductance and capacitance can cause resonant oscillation.

- Parasitic inductance from thin wires
- Capacitance from cables.
  - ~ 30 pF/foot

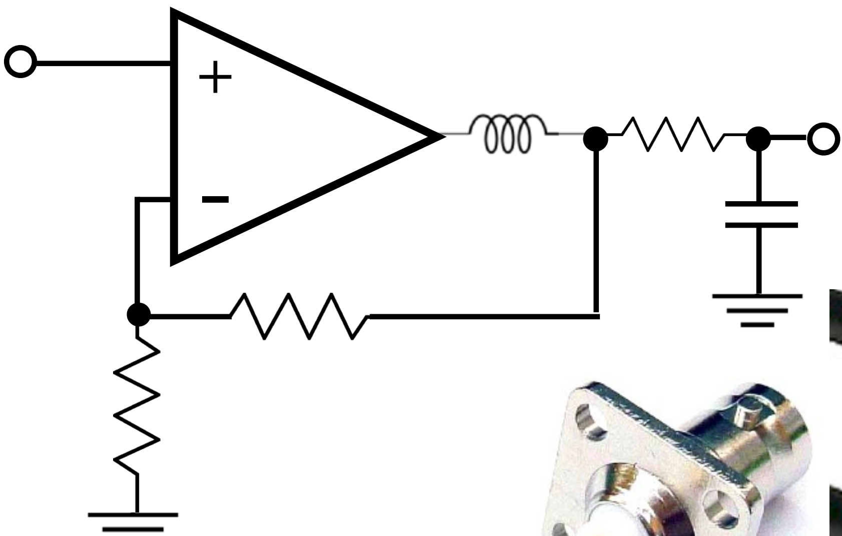


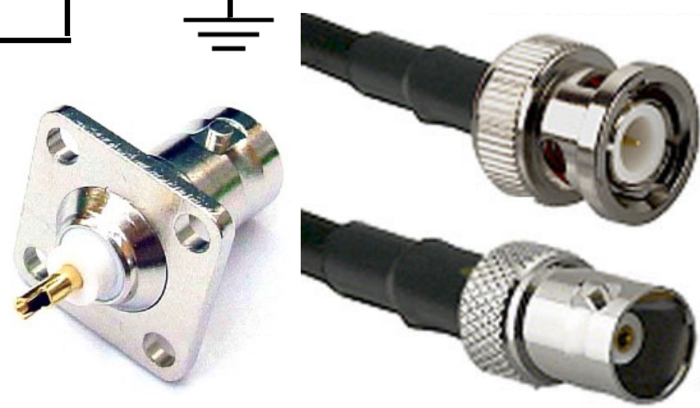
Unwanted oscillations

Often, noise problems are self induced, e.g., unwanted oscillations.

Parasitic inductance and capacitance can cause resonant oscillation.

- Parasitic inductance from thin wires
- Capacitance from cables.
  - ~ 30 pF/foot
- Suppress resonance with small R.





Unwanted oscillations

Often, noise problems are self induced, e.g., unwanted oscillations.

Also have parasitic inductance and capacitance at inputs.

Your breadboard wires are long and would cause problems at high frequency

For > 1 GHz, need *differential* scope probes.