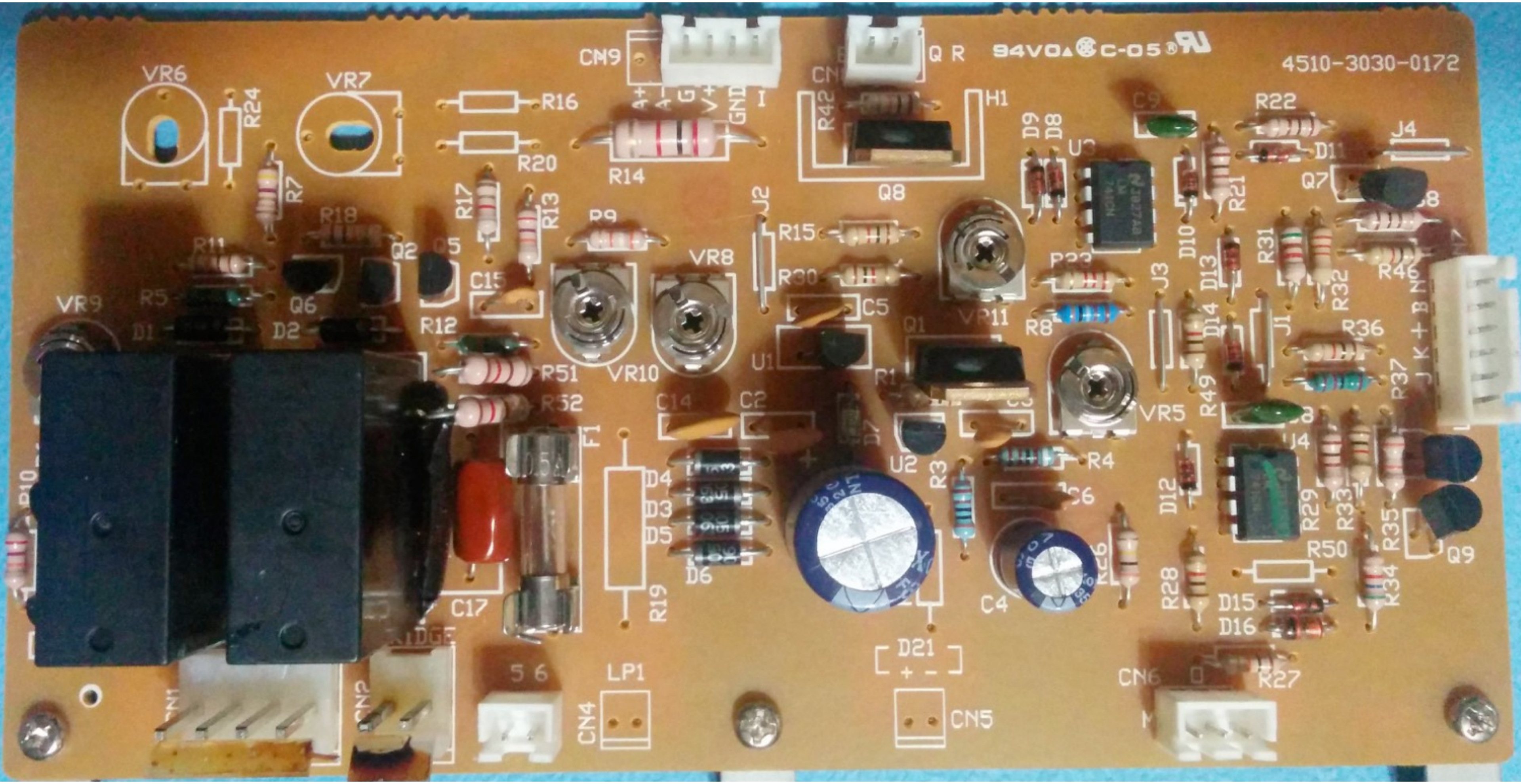
PHYS127AL Lecture 5

David Stuart, UC Santa Barbara

More diodes; Transistors



Review

Diodes:

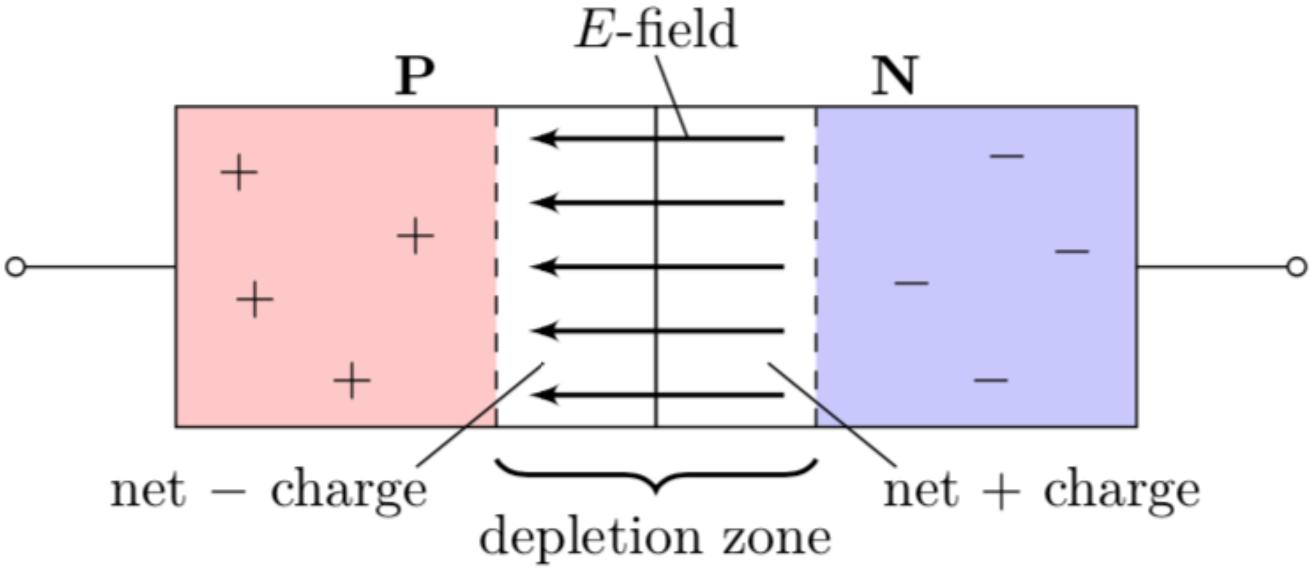
Current proportional to charge carrier density, *n*

Doping n-type or p-type impurities in a silicon crystal changes *n*

A junction between n-type and p-type causes a depletion region

Reverse bias increases depletion region without current flow

Forward bias reduces depletion region; large current once overcome.



Outline

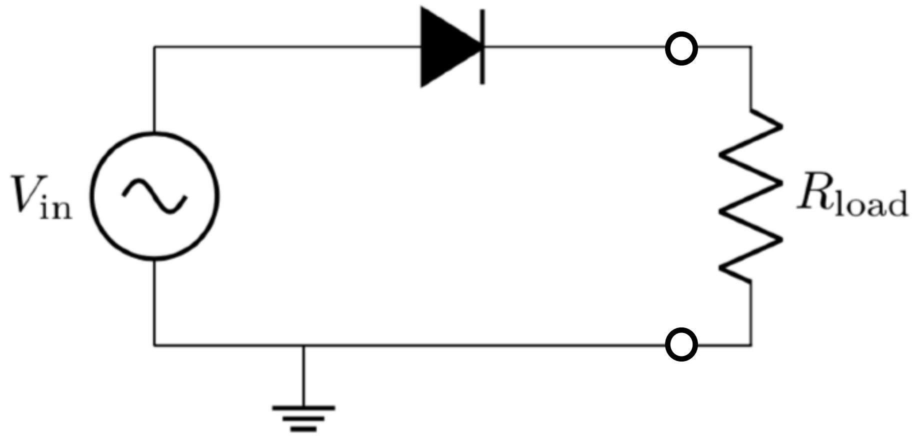
- More diodes:
  - Power supply
  - LEDs
  - Battery backup circuit
  - Photodiodes

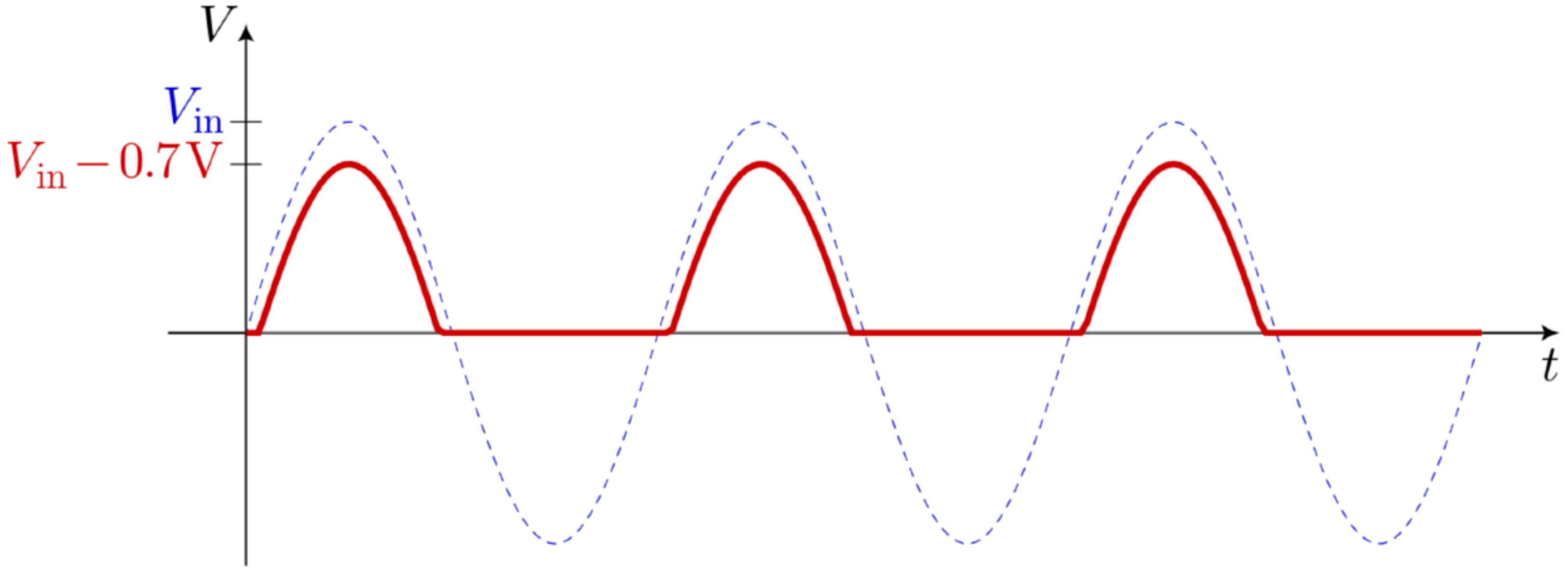
- Transistors
  - Basic idea of operation
  - General rules for circuit analysis
  - First example circuits

DavidStuart@UCSB.edu

Diode circuits

If diodes are in-line, they just drop 0.7 Volts — if current is flowing—otherwise they act like an open circuit. “Rectifier circuit.”





When V_{in} goes negative, diode is reverse biased ⇒ open circuit.

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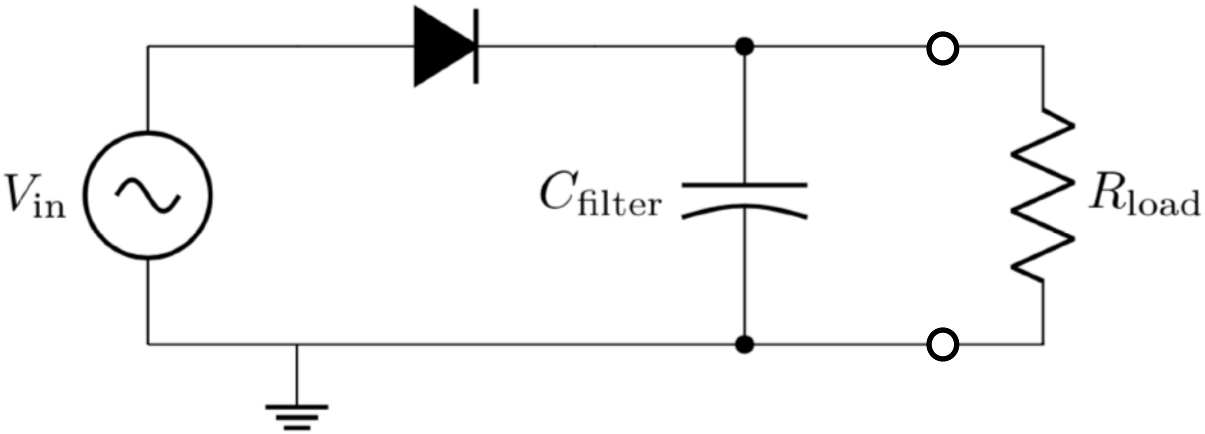
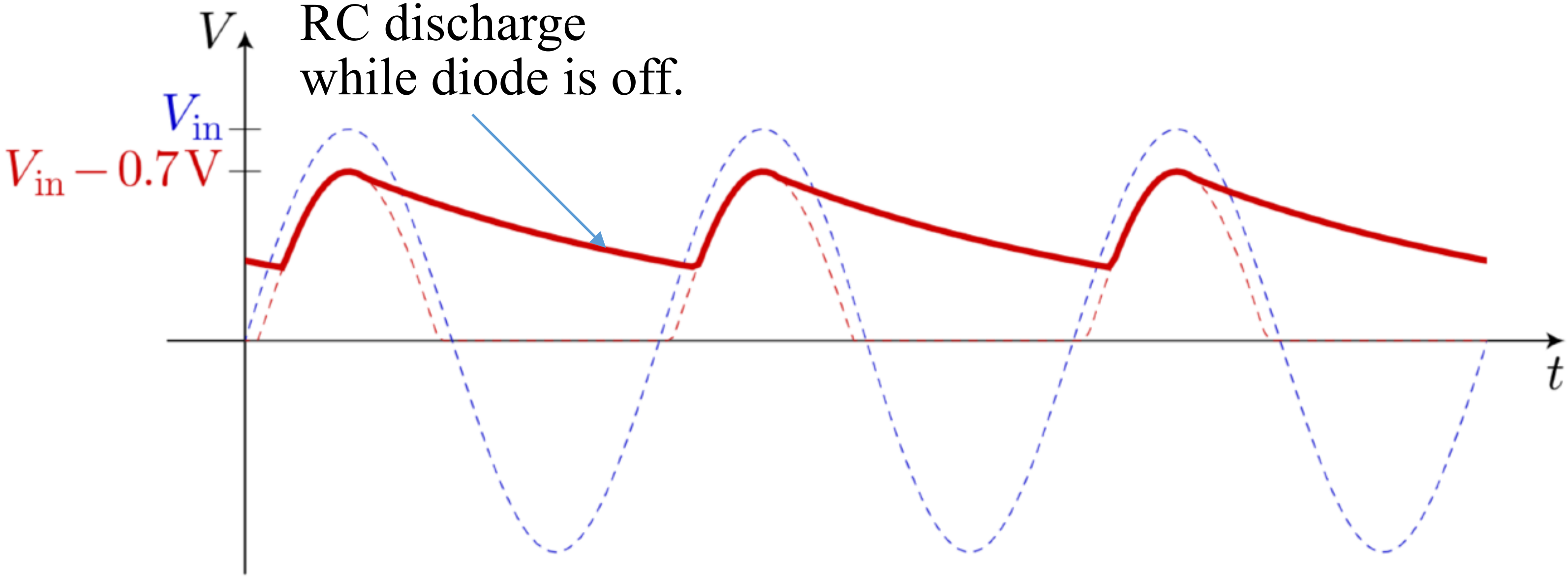
Diode power supply circuits

Can use this to convert an AC signal to a DC signal, e.g., in a power supply, with a capacitor to provide current between swings.





RC discharge while diode is off.

Diode power supply circuits

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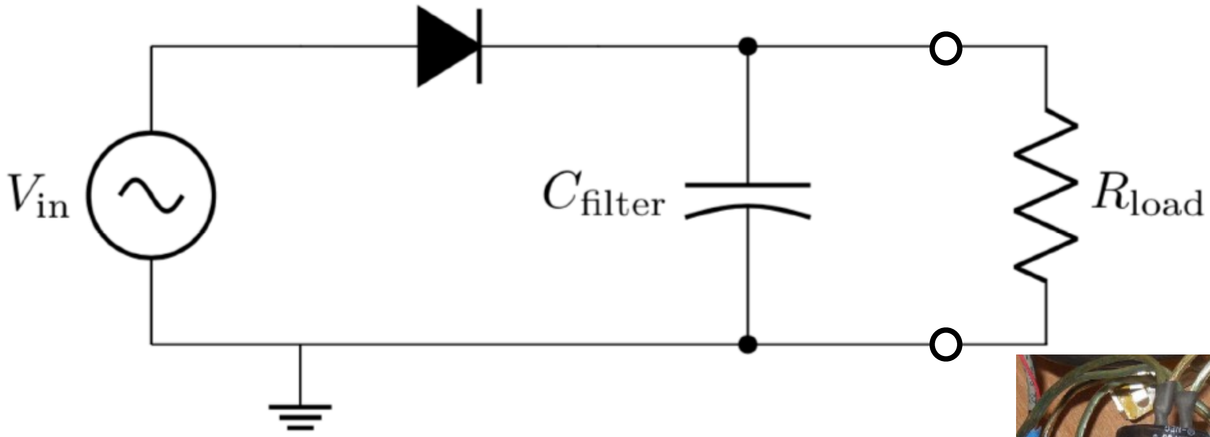
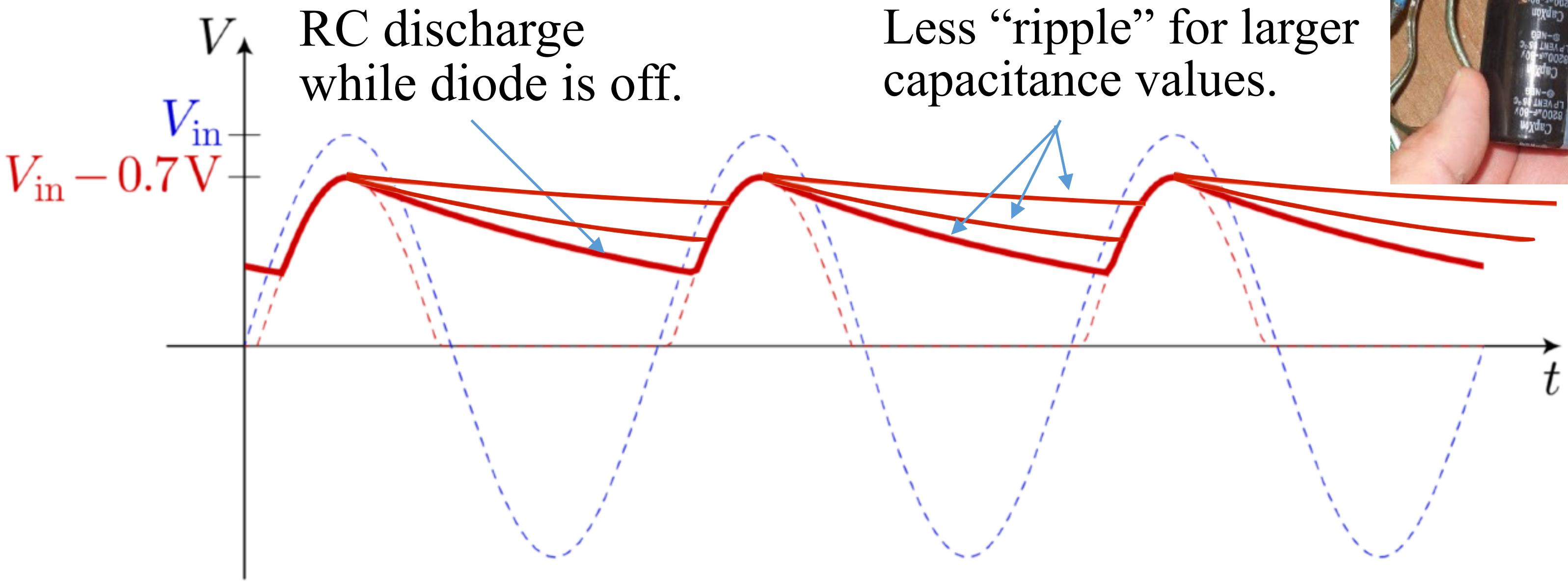
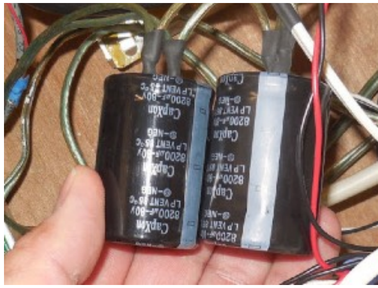




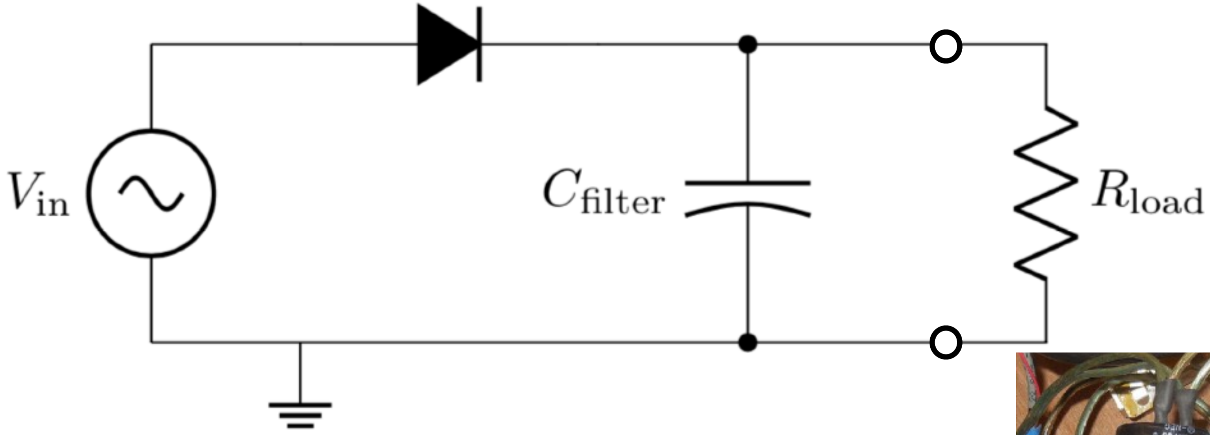
RC discharge while diode is off.

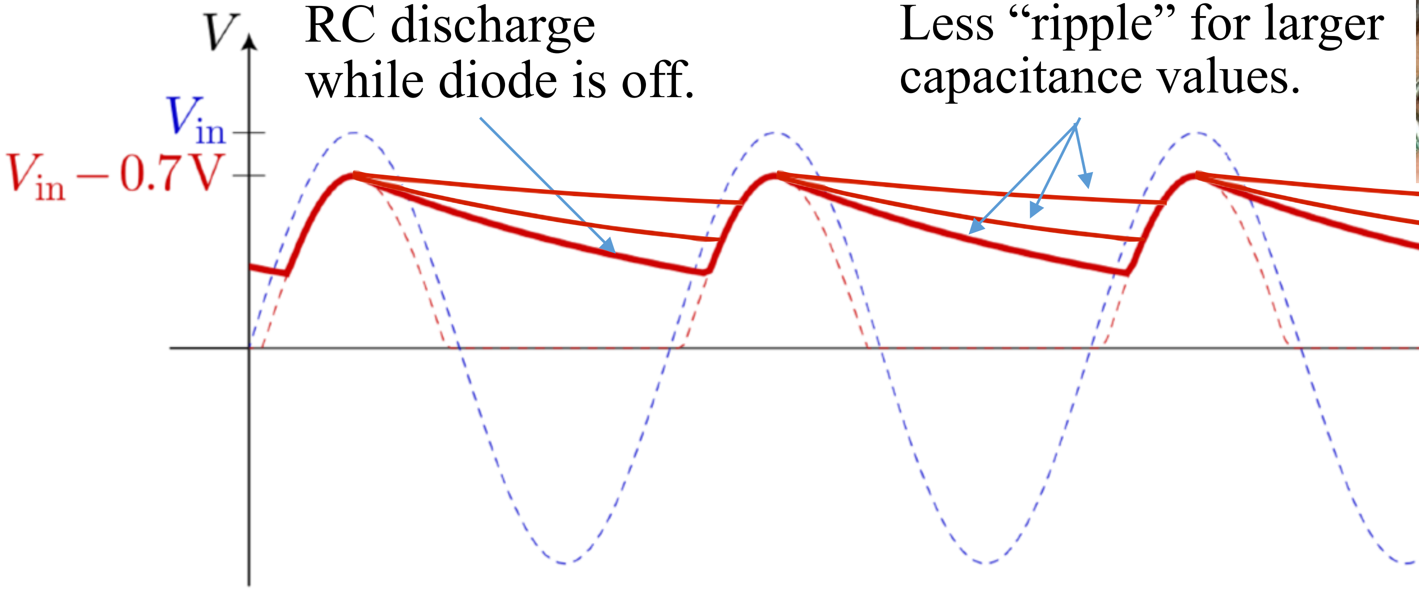
Less "ripple" for larger capacitance values.



Diode power supply circuits

Can use this to convert an AC signal to a DC signal, e.g., in a power supply, with a capacitor to provide current between swings.





RC discharge while diode is off.

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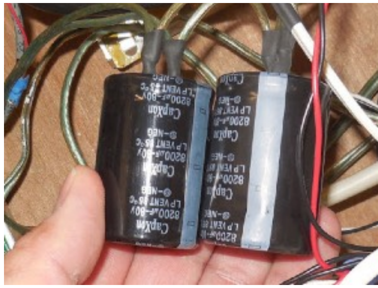

But the negative swings are wasted. This is called a "half-wave rectifier".

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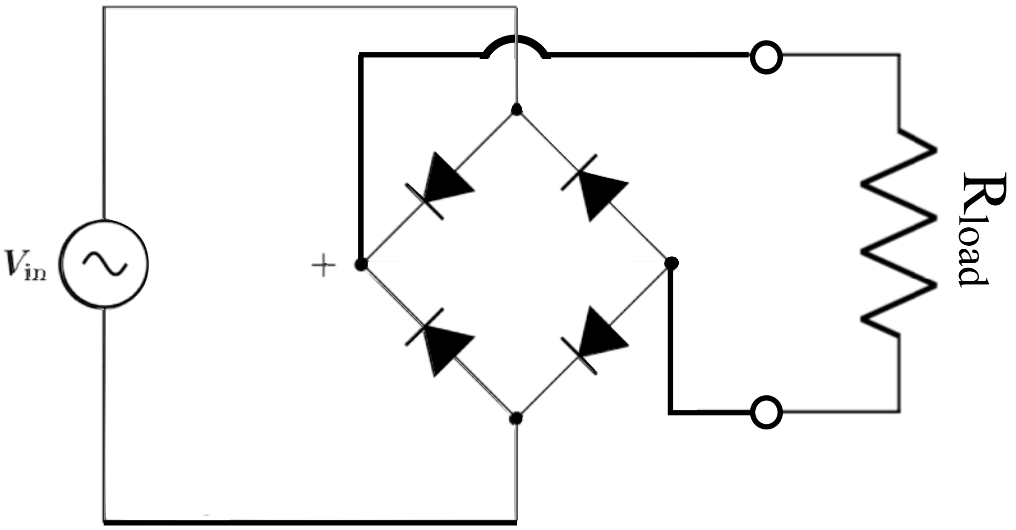
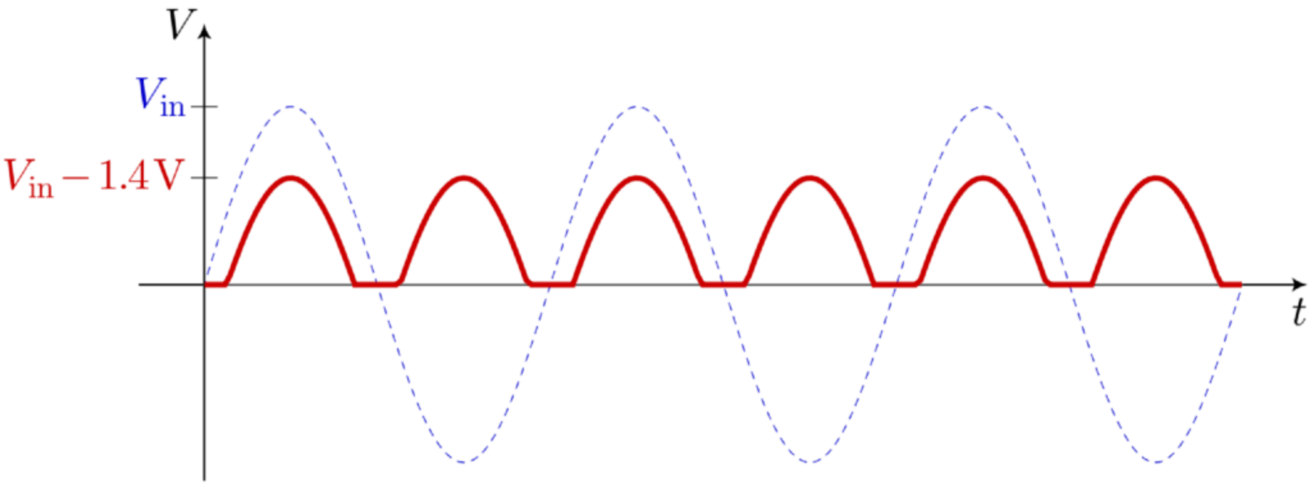
Diode power supply circuits

Can use the negative swing with four diodes in a “full-wave rectifier” circuit.

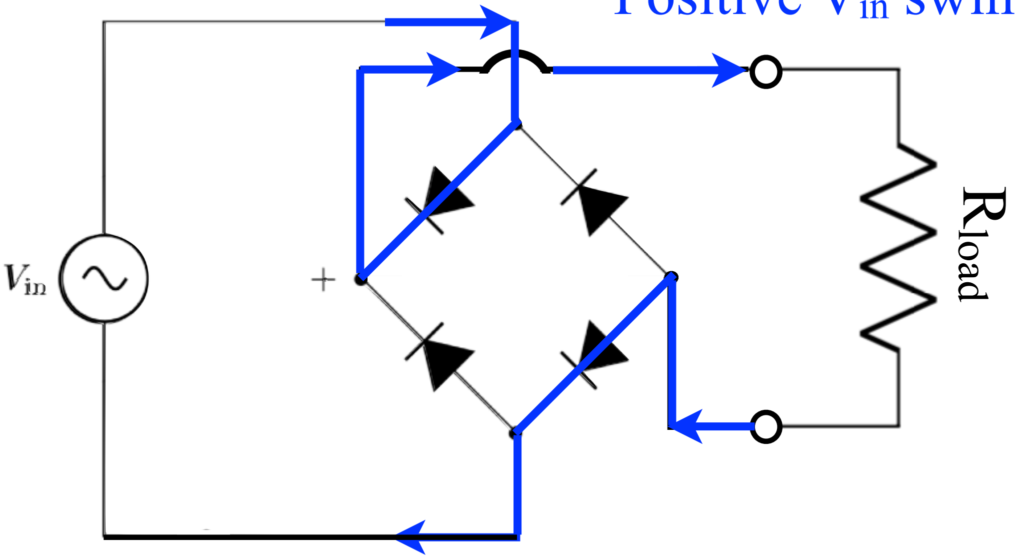


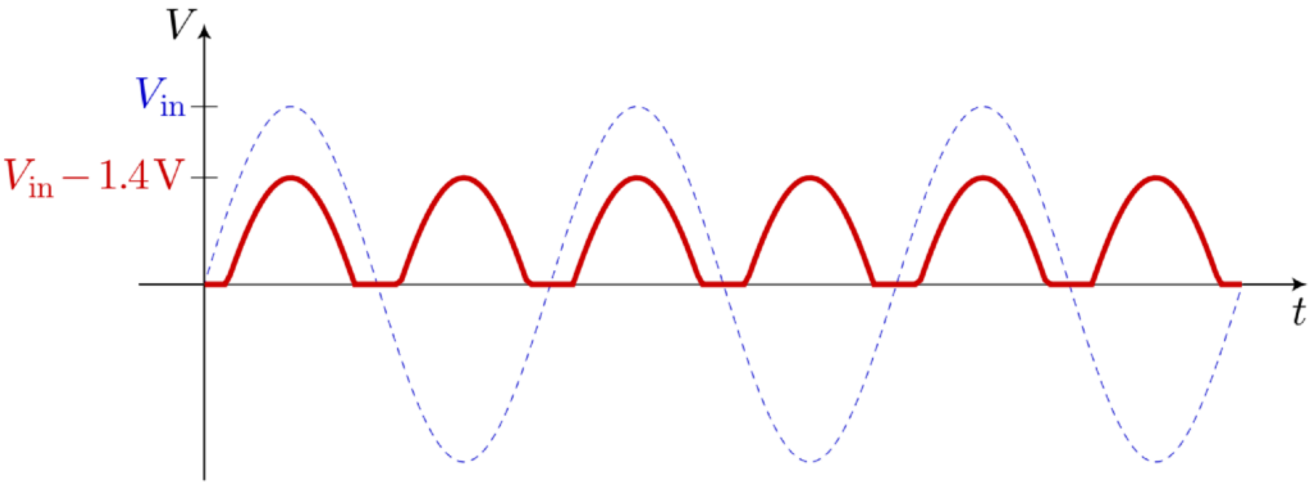


Diode power supply circuits

Full-wave rectifier circuit uses the positive and negative swings

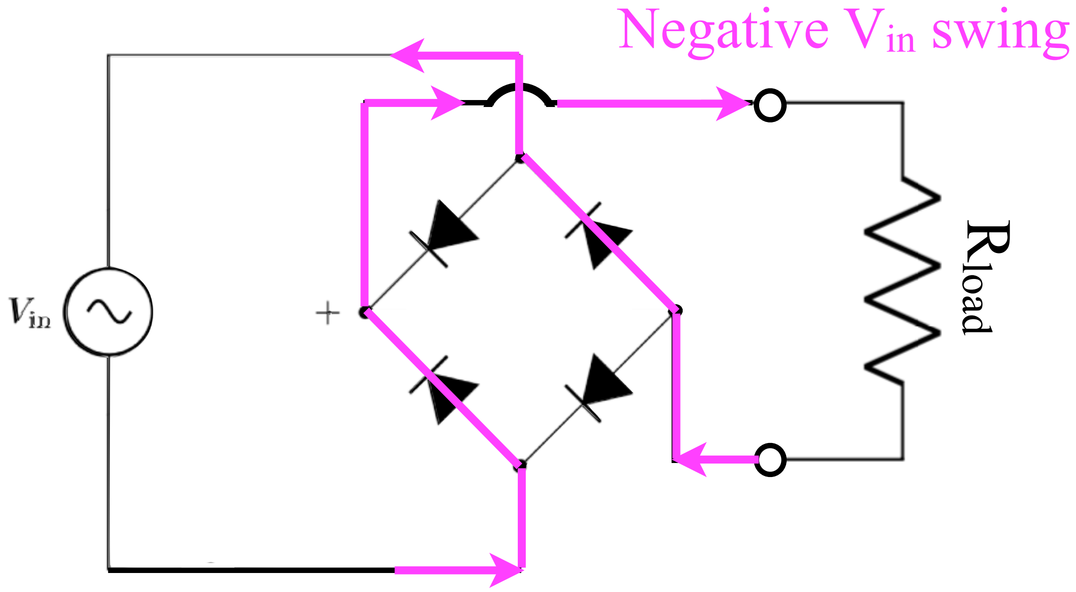
Positive V_{in} swing

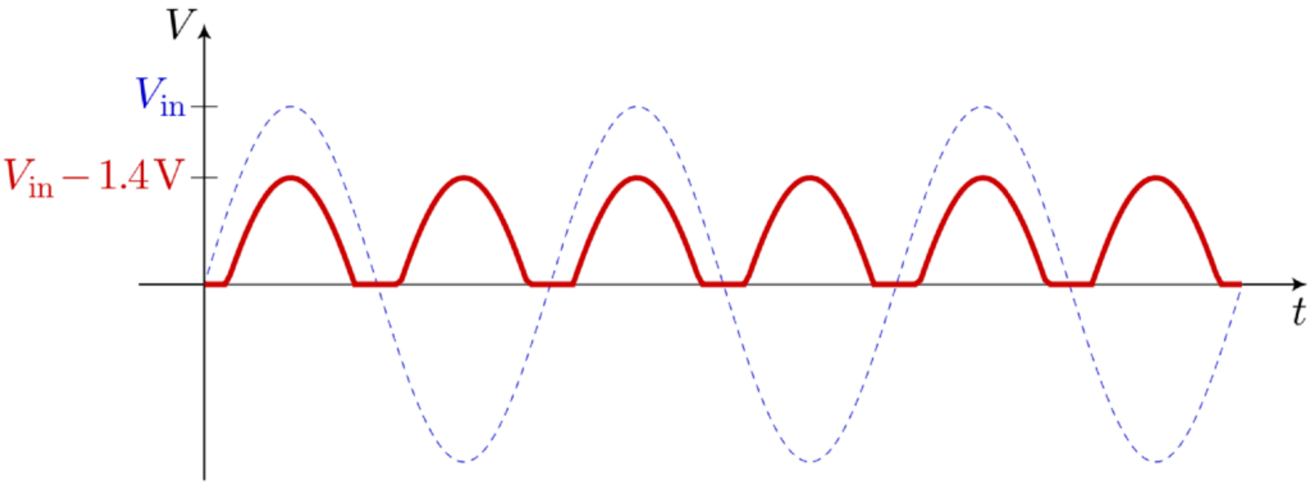




Diode power supply circuits

Full-wave rectifier circuit uses the positive and negative swings

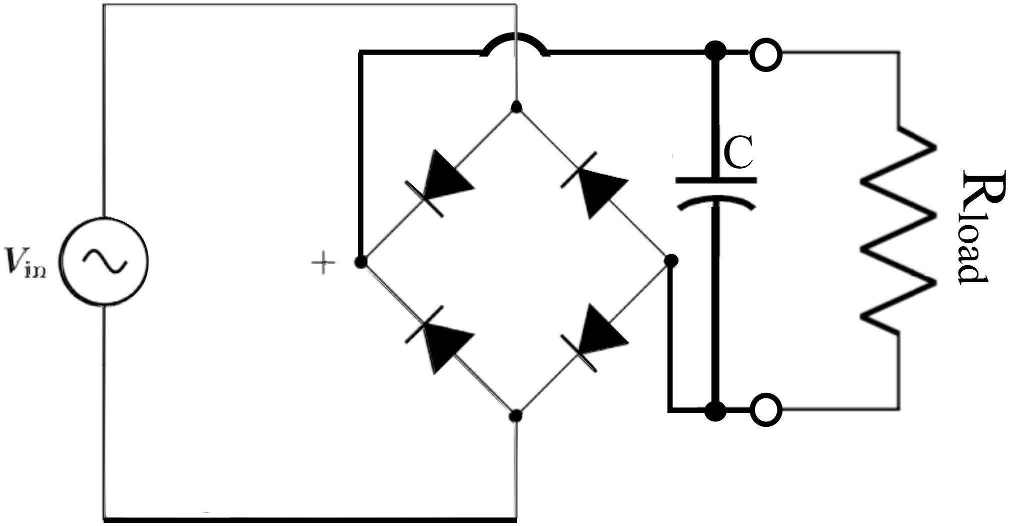


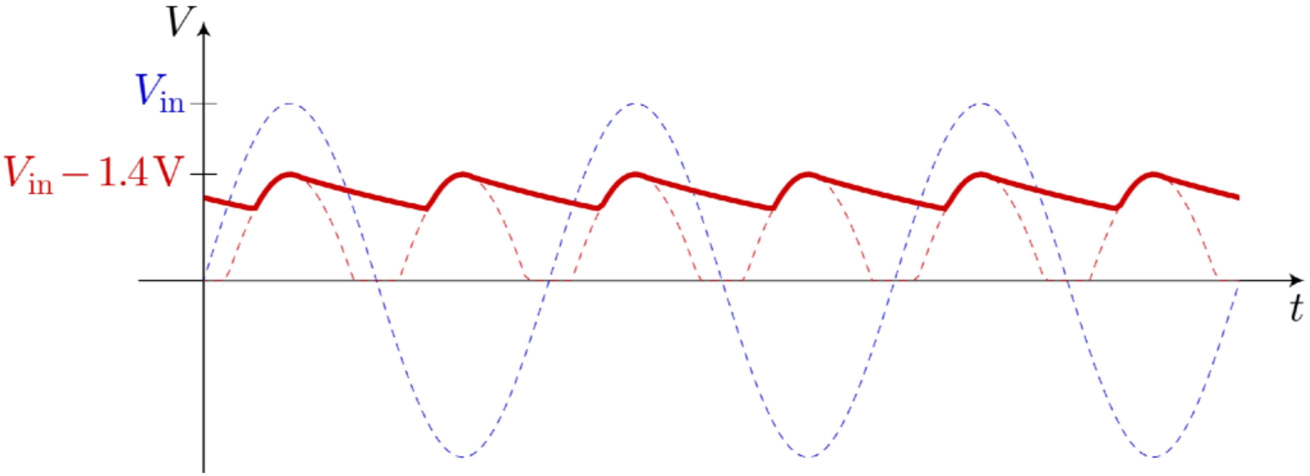


Voltage across R_{load} is positive for both half-cycles, but we have two diode drops, 1.4 V, given up in the rectifier.

Diode power supply circuits

Full-wave rectifier circuit uses the positive and negative swings



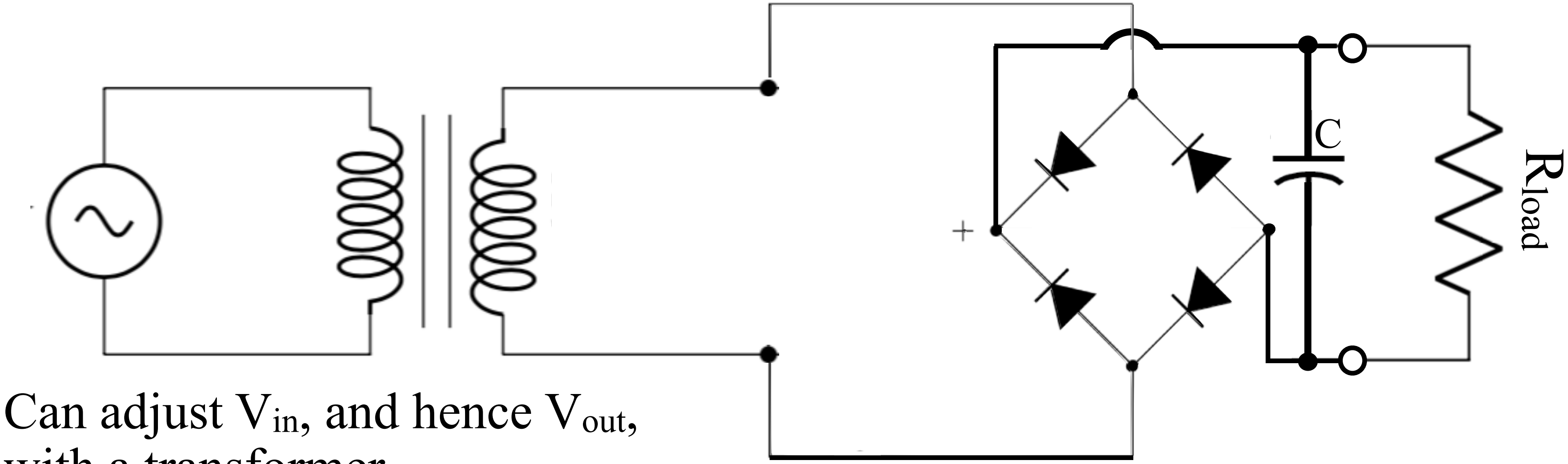


Again, a capacitor can smooth the ripple between peaks.

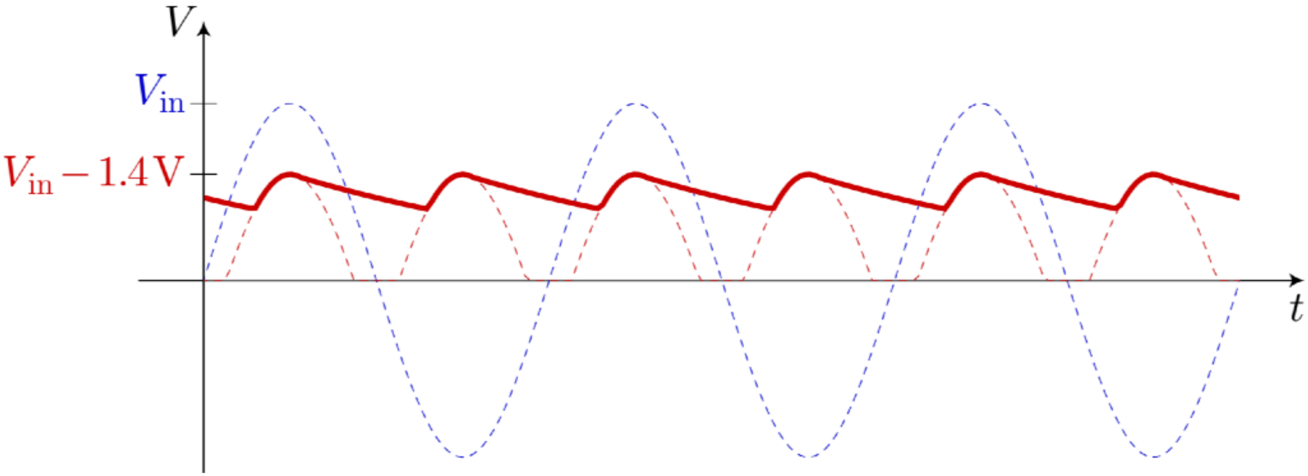
Note use of electrolytic cap here.

Diode power supply circuits

Full-wave rectifier circuit uses the positive and negative swings



Can adjust V_{in}, and hence V_{out}, with a transformer.



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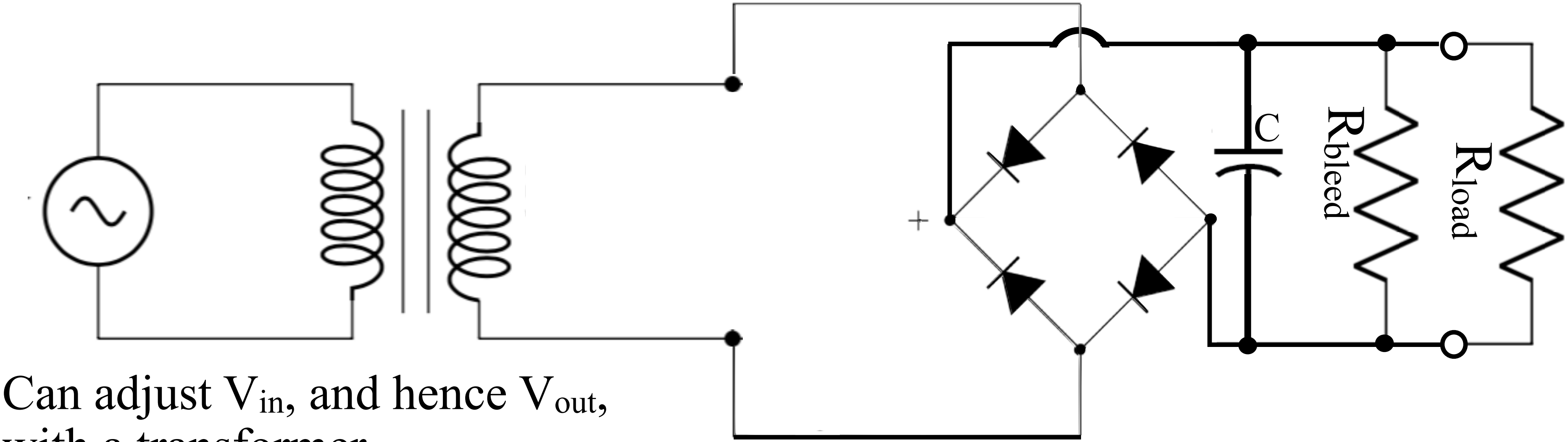
Diode power supply circuits

Full-wave rectifier circuit uses the positive and negative swings



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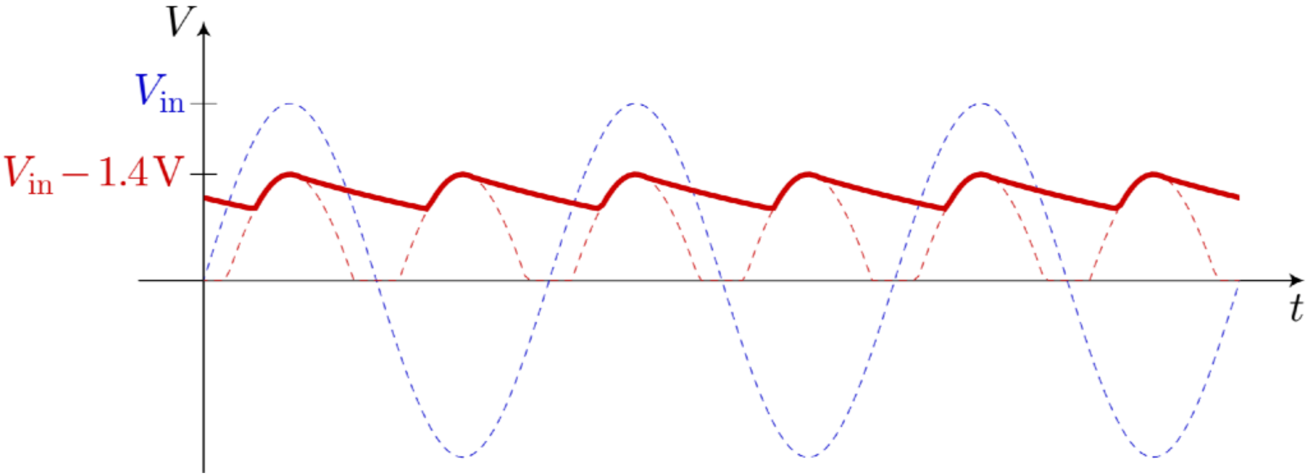

Add a “bleeder resistor” to discharge the large capacitor and avoid a shock if load is disconnected and power turned off.

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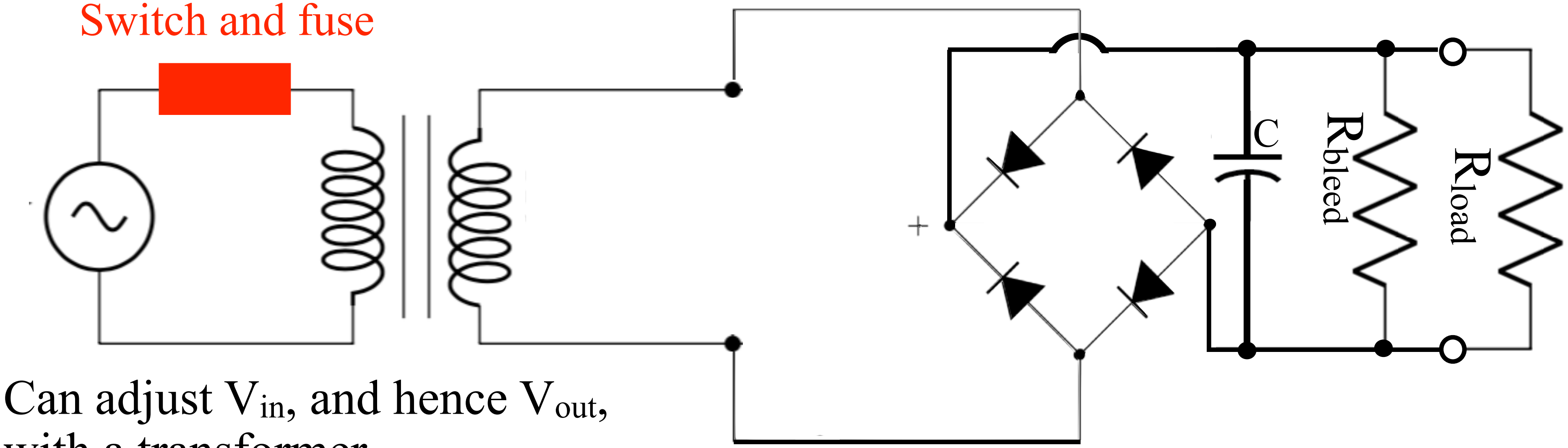
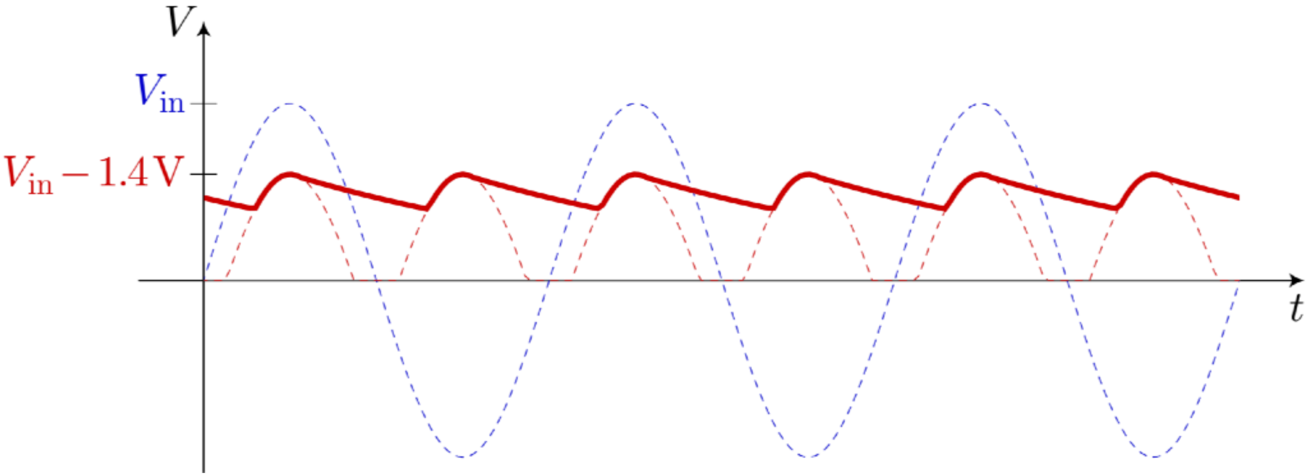
Diode power supply circuits

Full-wave rectifier circuit uses the positive and negative swings



Switch and fuse

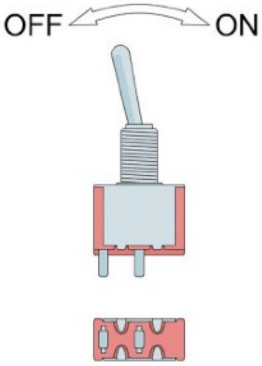
Can adjust V_{in}, and hence V_{out}, with a transformer.



Add a “bleeder resistor” to discharge the large capacitor and avoid a shock if load is disconnected and power turned off.

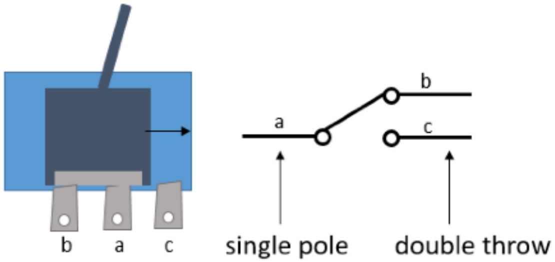
Digression on switches

Many kinds of switches available.



SPST
single-pole single-throw

SPDT toggle switch

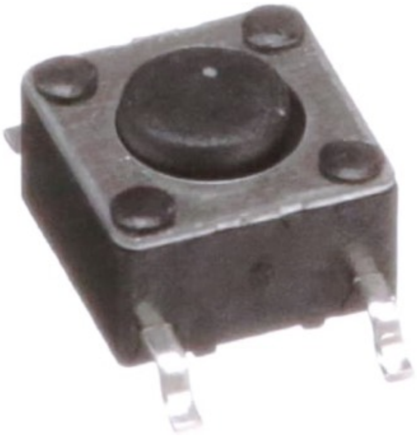


Slide switch

Toggle switch

Double pole - double throw

Momentary (push-button) switch



Digression on fuses

Many kinds of fuses; usually a thin wire that melts at a specific current.

Typically used in car fuse boxes

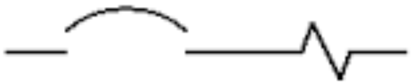
Digression on fuses — resettable fuses

“Resettable fuses” are usually just thermistors that have their resistance increase dramatically with temperature. Turning off the power and waiting a minute will reset them by letting them cool down. If the source of the high current problem is gone, re-powering after cool down will return the circuit to functionality.

DavidStuart@UCSB.edu

Digression on fuses — circuit breaker

For a house or building, the AC power is separated into about a dozen circuits, with circuit breakers that limit current to 15 or 20 A.



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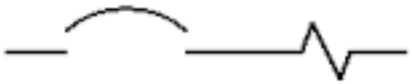

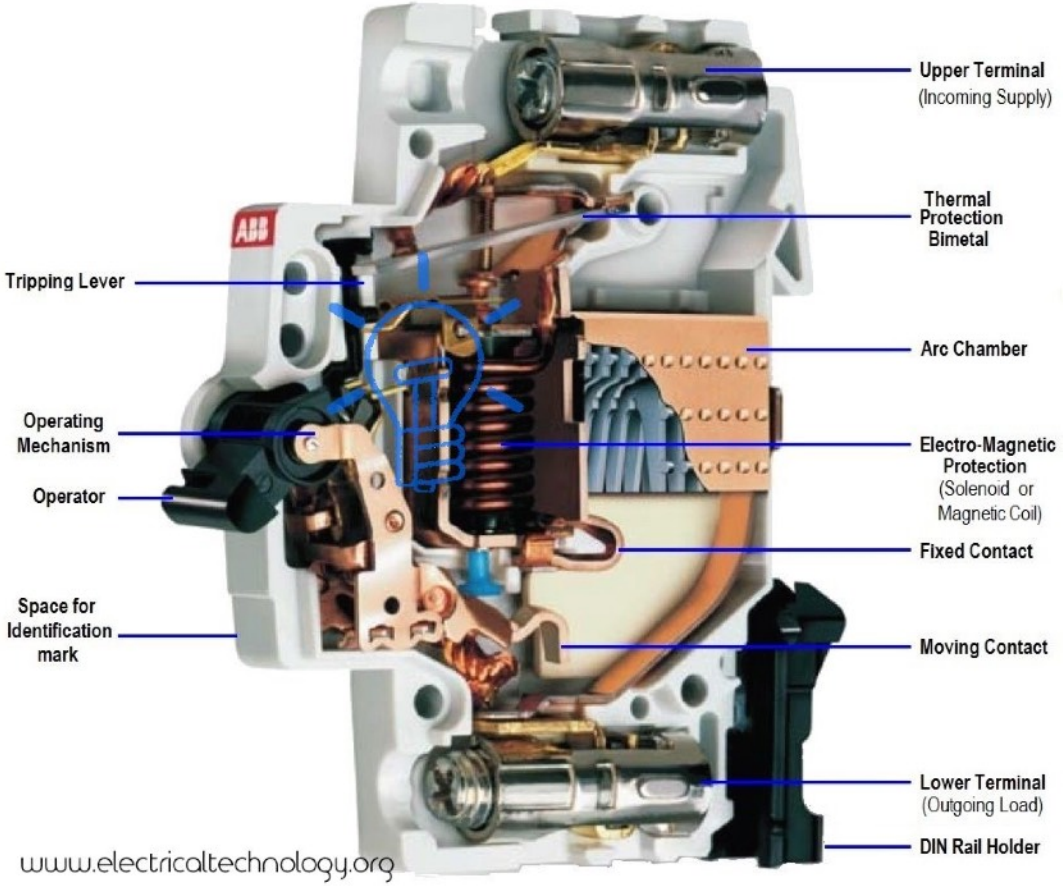

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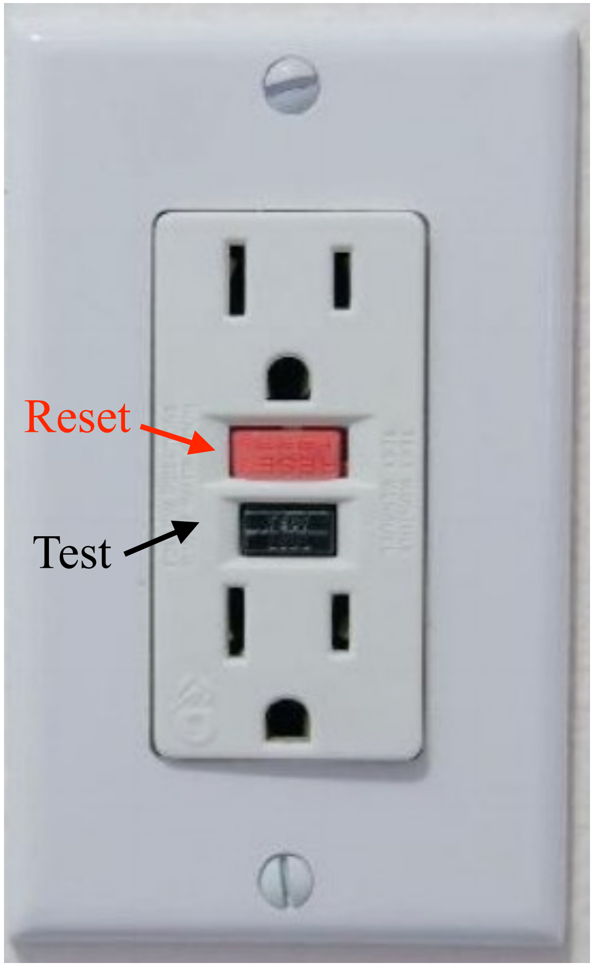
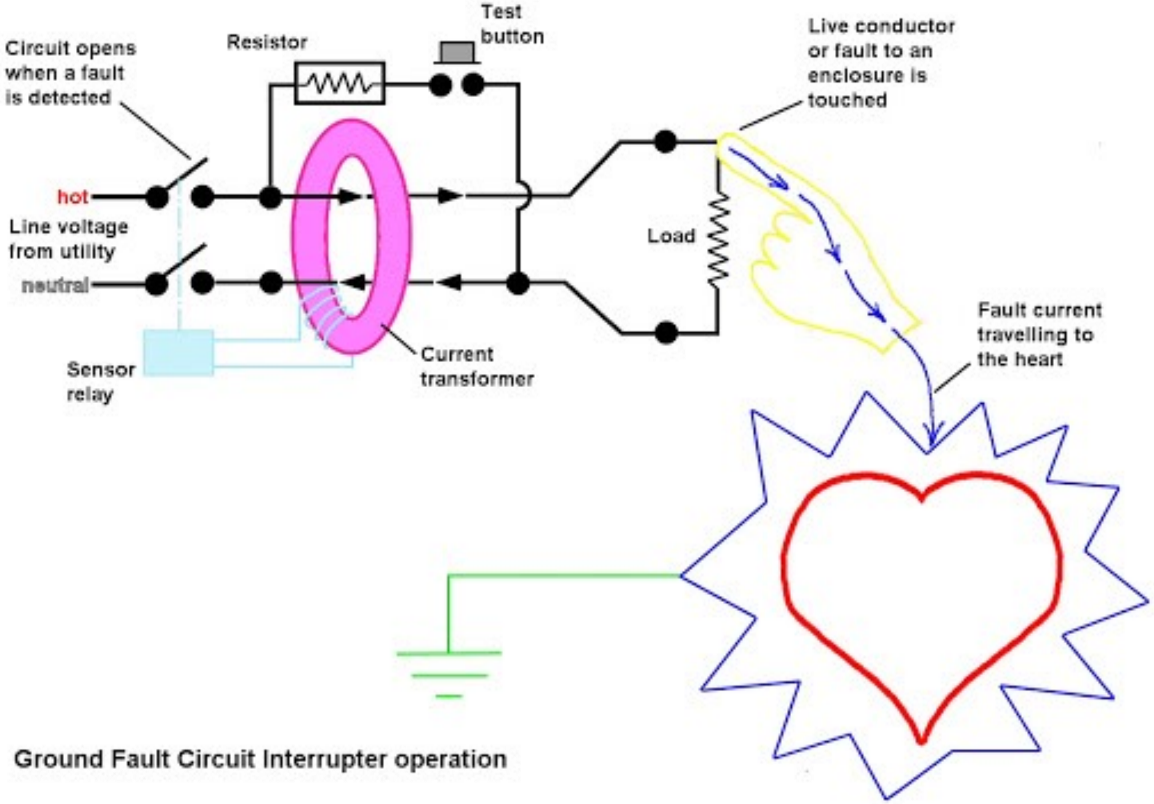
Digression on fuses — ground fault interrupter

For kitchens and bathrooms (where standing water is likely), power outlets must use a GFCI to avoid current shorting to ground through external paths.

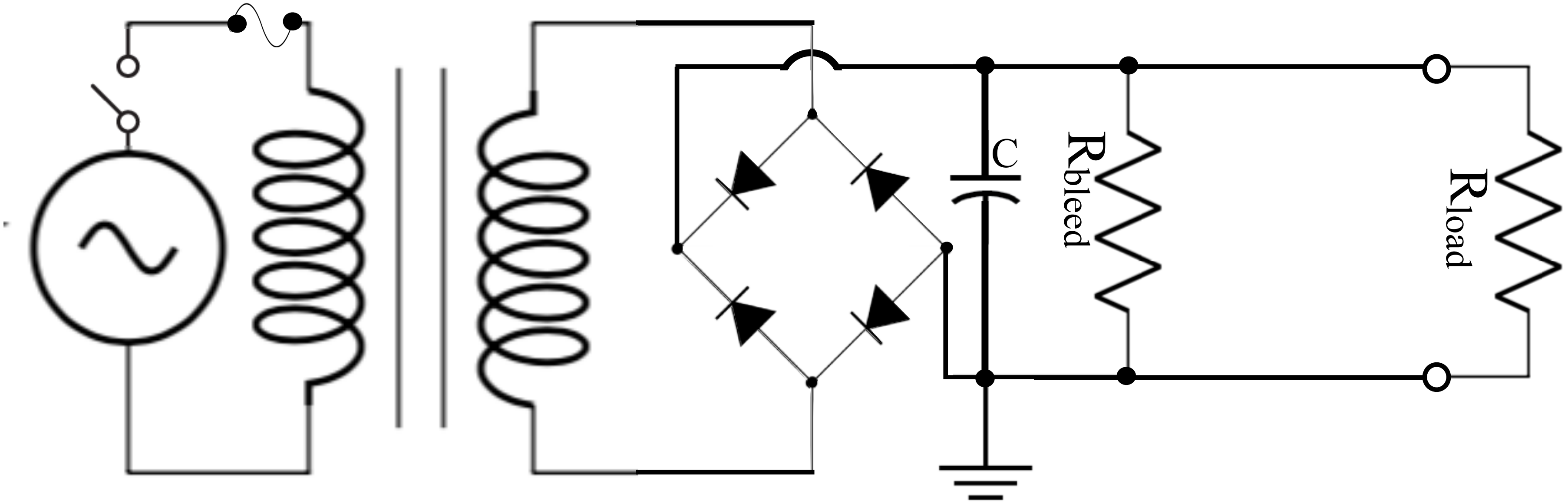


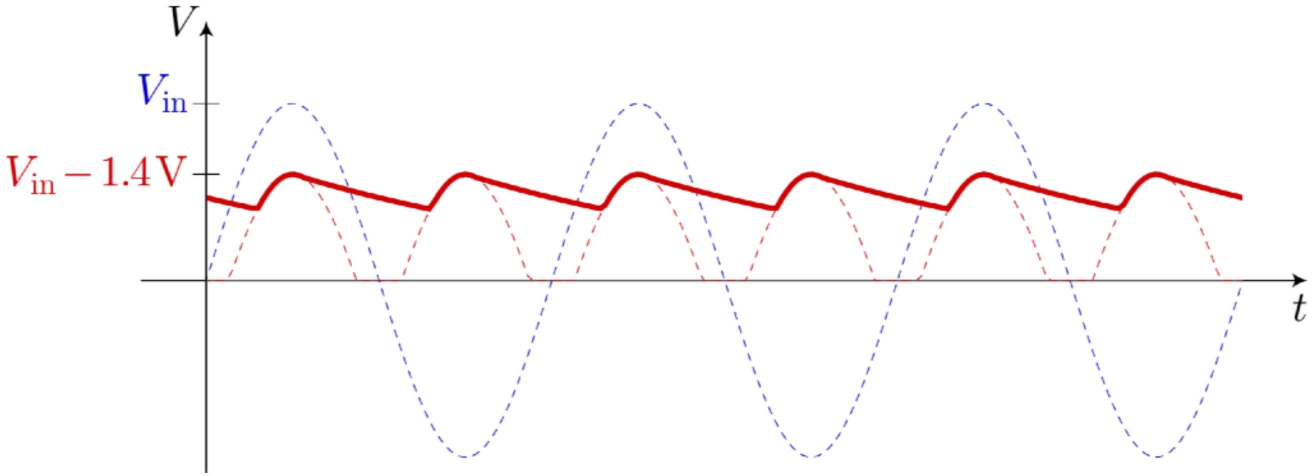


Ground Fault Circuit Interrupter operation

Diode power supply circuits

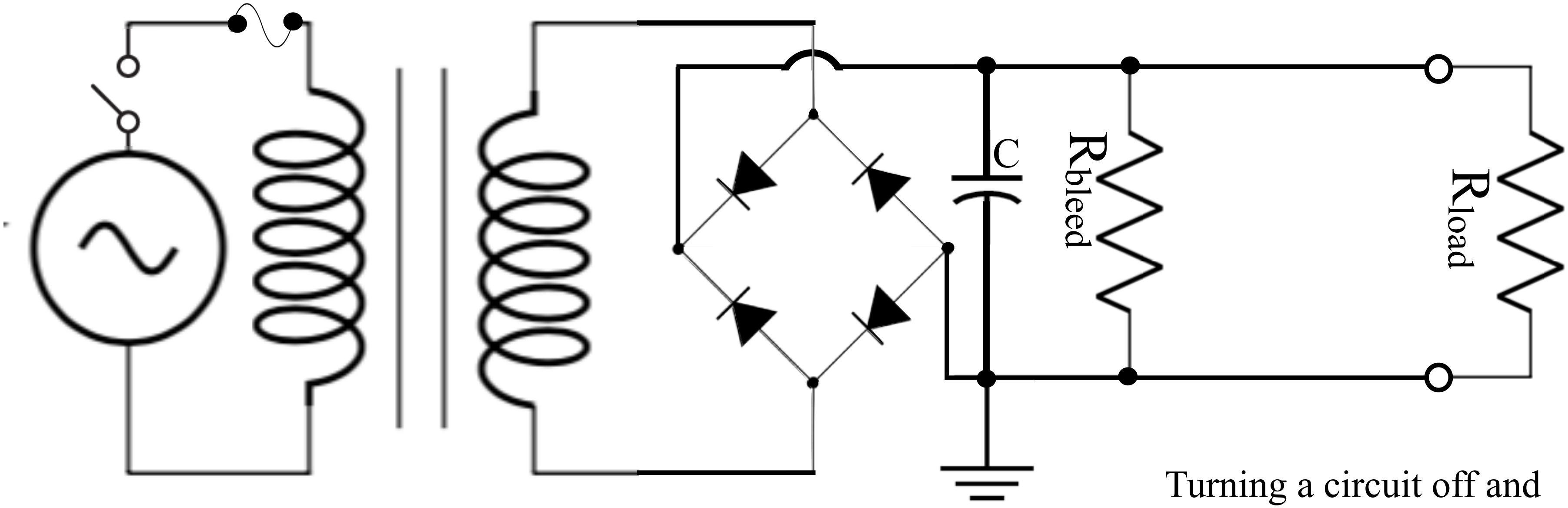
Full DC power supply circuit

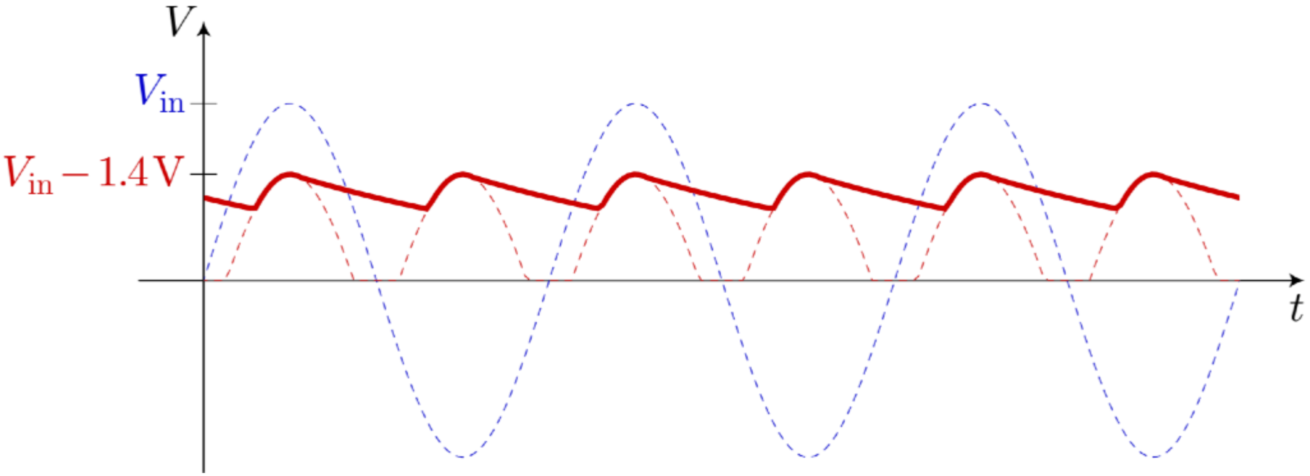




Diode power supply circuits

Full DC power supply circuit





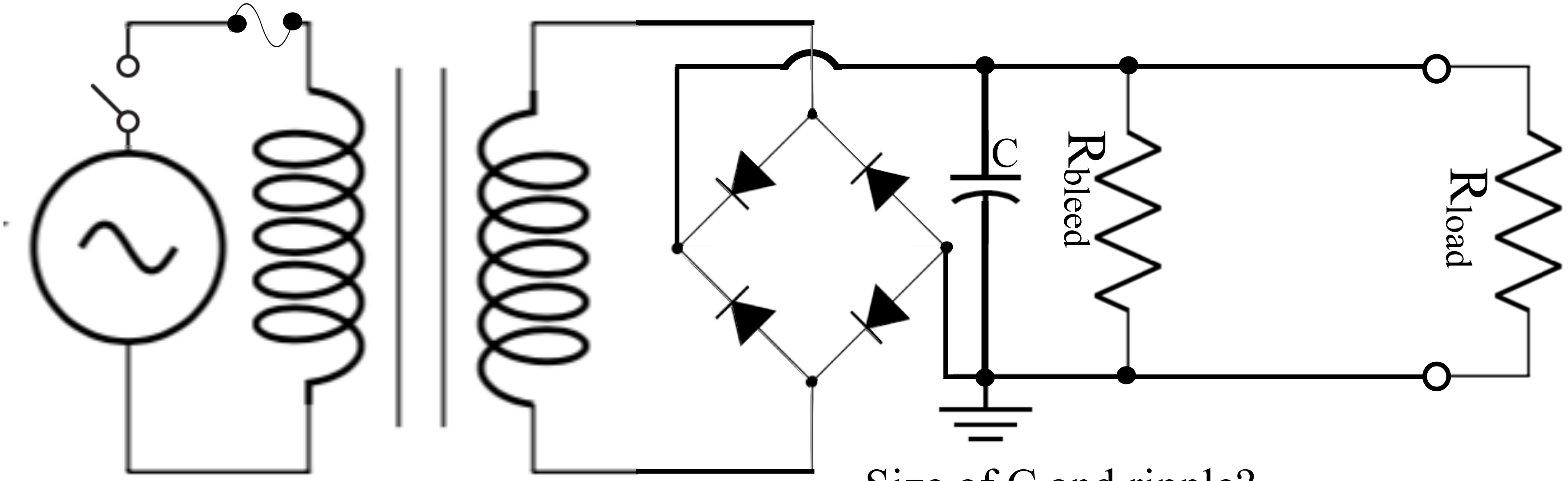
Turning a circuit off and waiting 15 seconds before turning it back on helps by:

Bleeding capacitor.

Resetting thermal fuses.

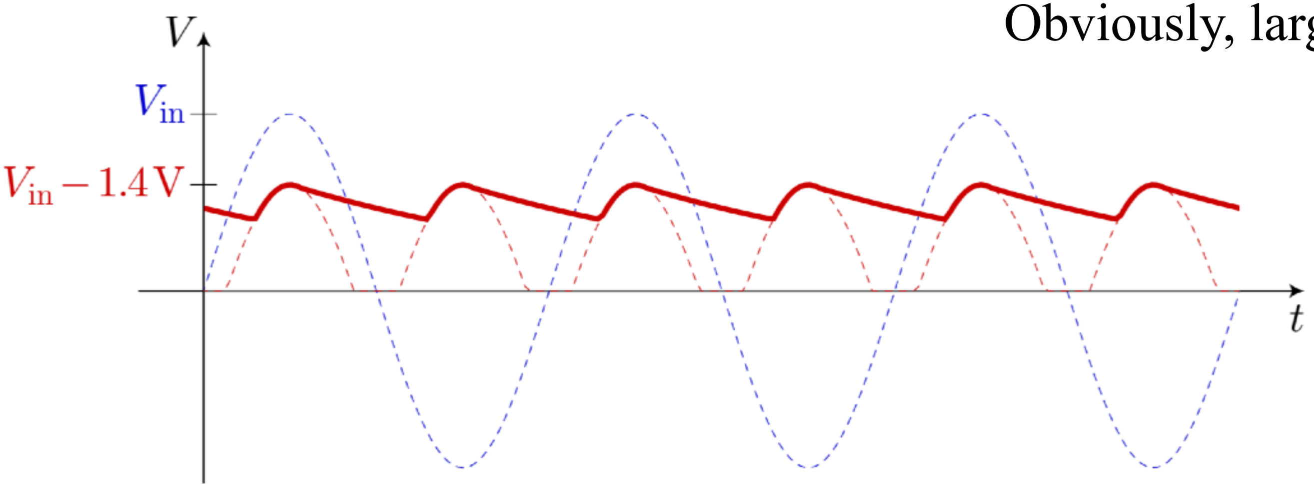
Diode power supply circuits

Full DC power supply circuit



Size of C and ripple?

Obviously, larger C reduces ripple.



RC >> 1/(2x60 Hz) = 8ms

Or, define ΔV and I_{max}.

E.g., ΔV = 1 V & I_{max} = 1 A

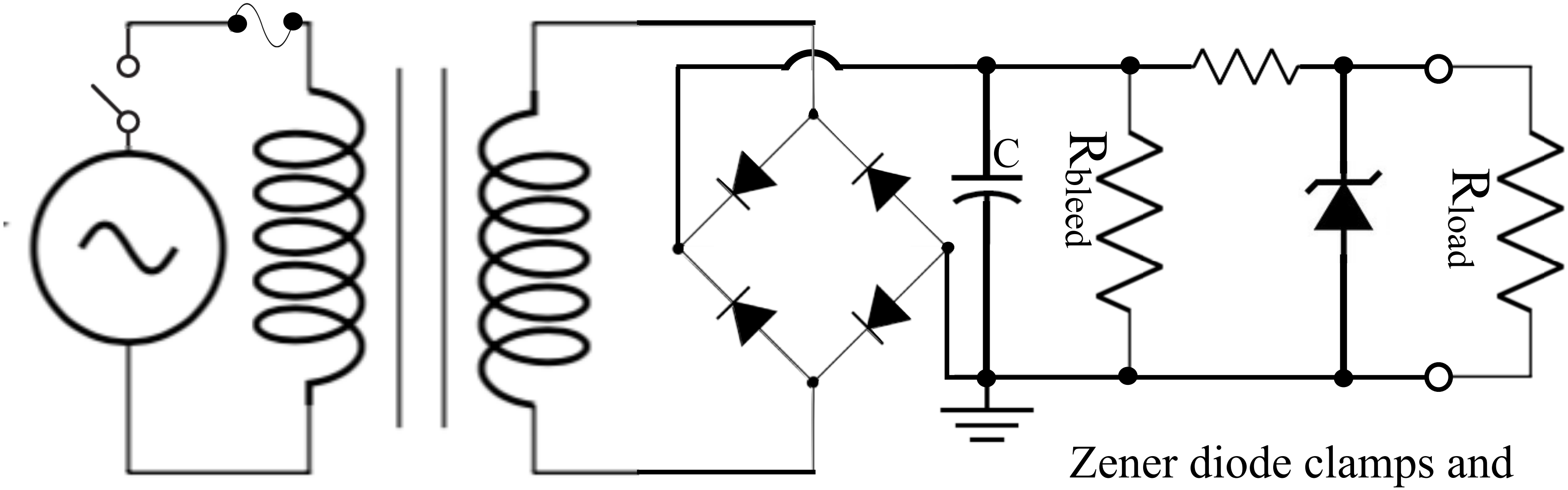
$q = CV$

$C = (dq/dt)/(\Delta V) = I\,(\Delta t)/(\Delta V)$

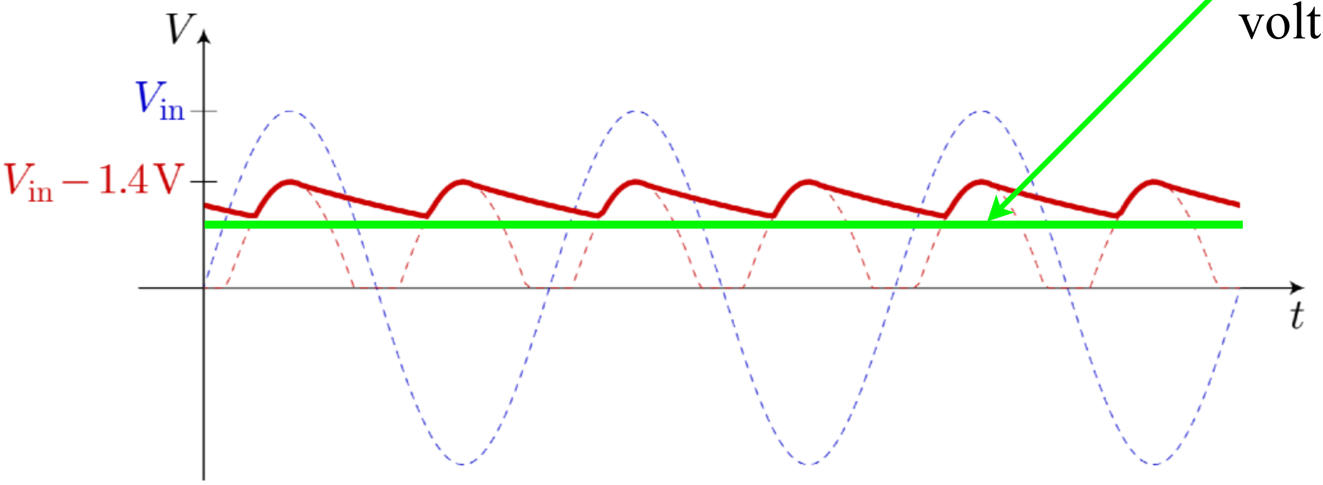
$C = 1\text{ A } 8\text{ ms} / 1 = 8000\ \mu\text{F}$

Final diode power supply circuits

Select a zener diode with a breakdown to match the desired clamping voltage.



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



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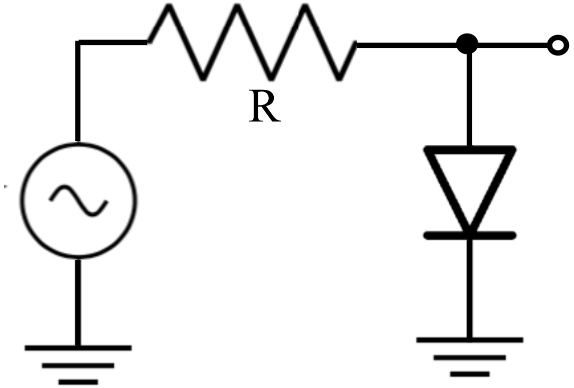
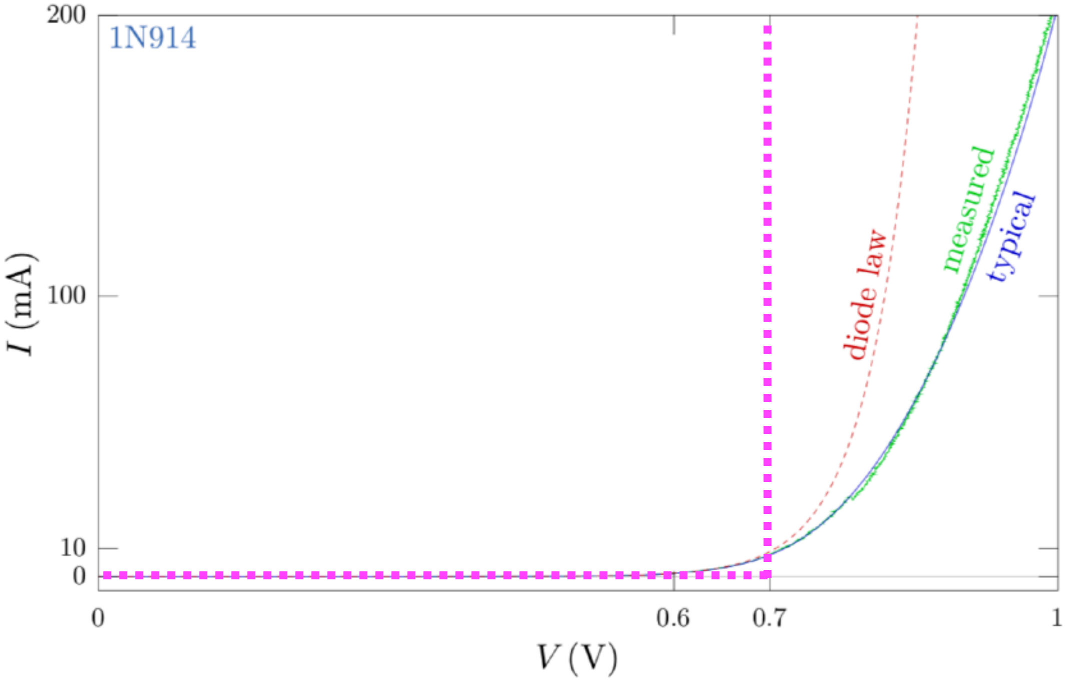
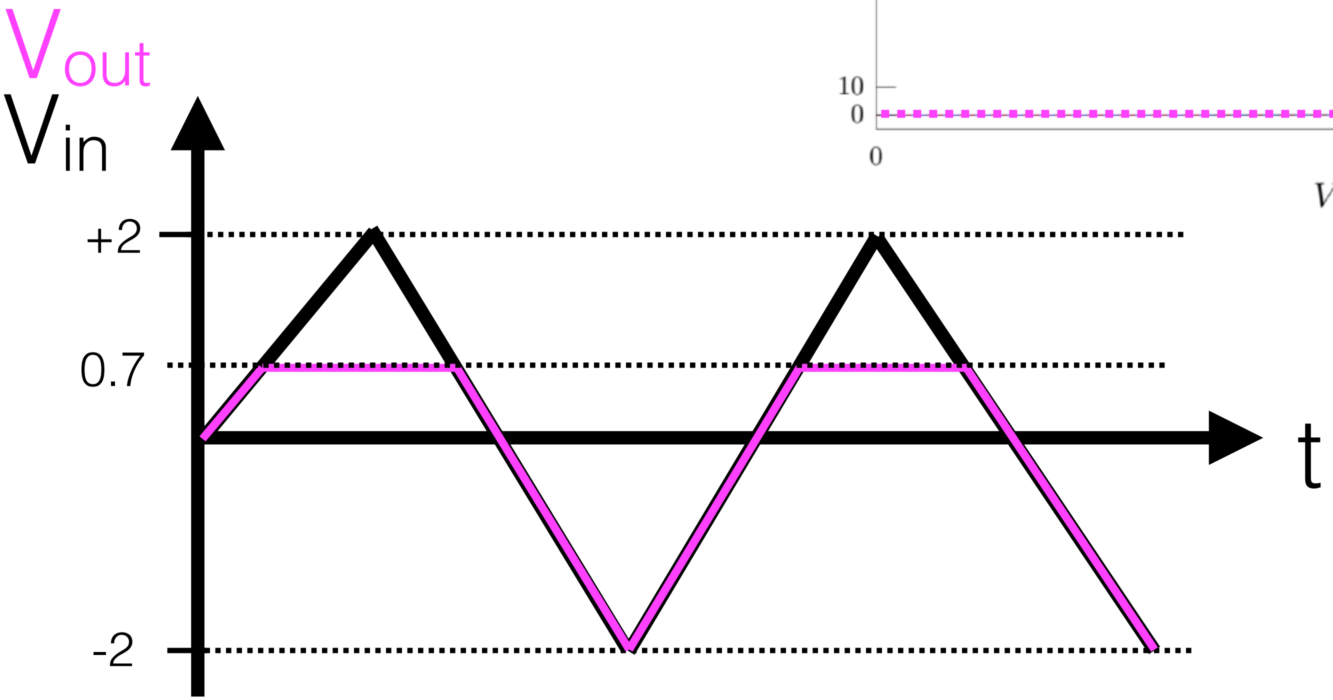
More realistic diode behavior

We initially approximated the diode IV as a short circuit above 0.7 V







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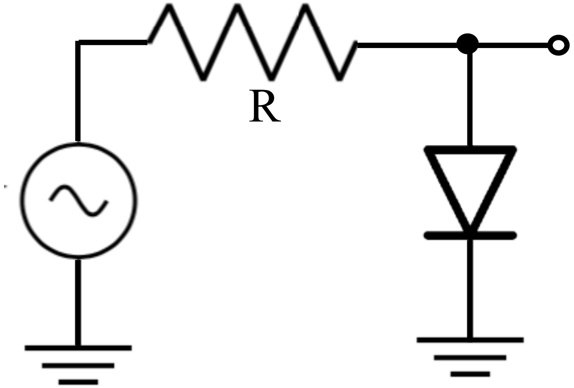
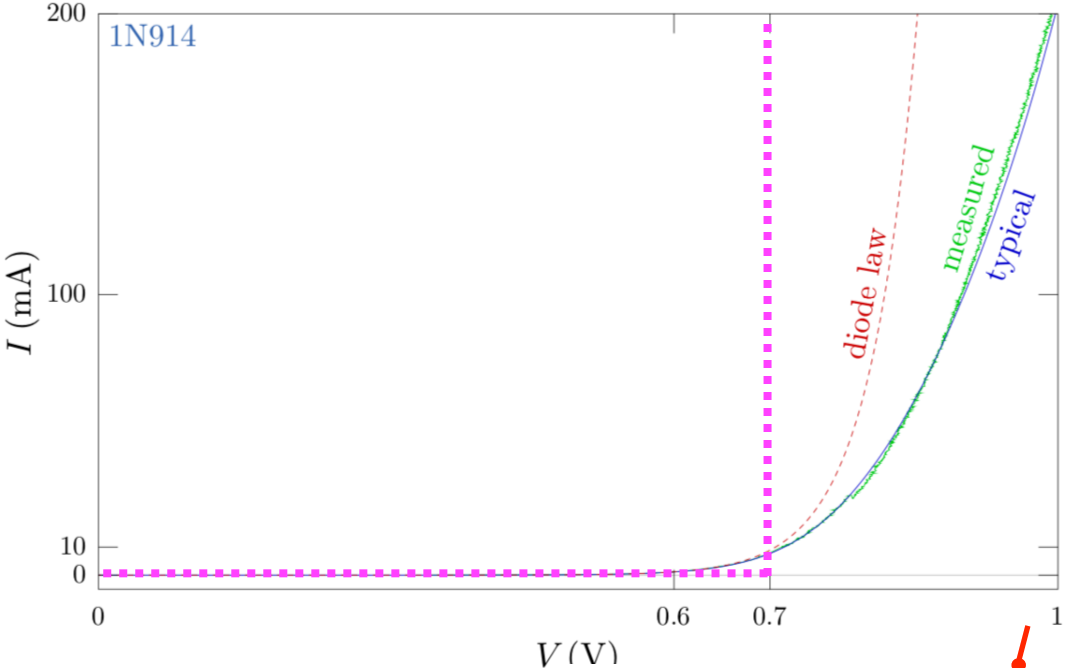
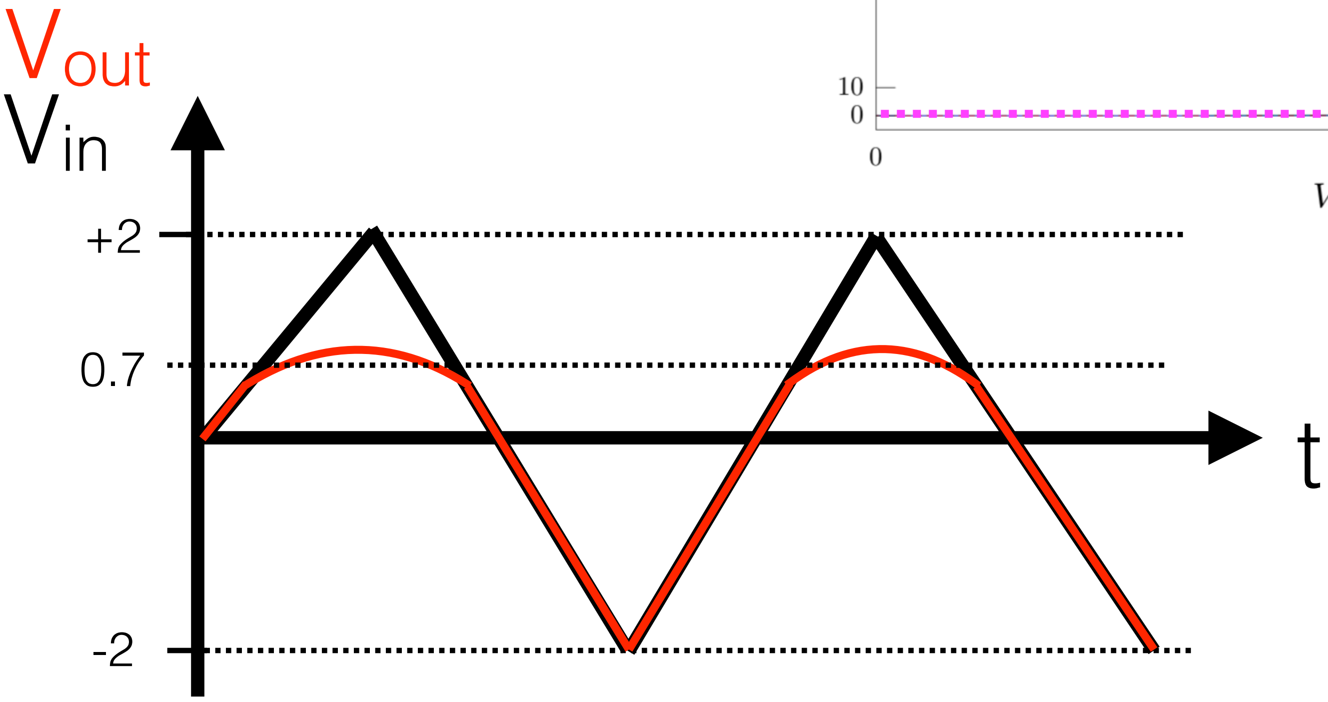
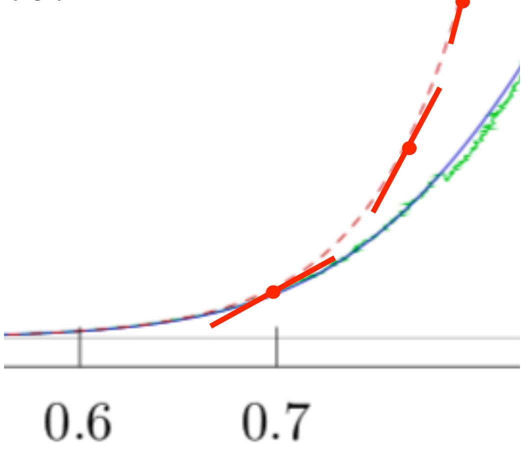
More realistic diode behavior

We initially approximated the diode IV as a short circuit above 0.7 V; but it actually starts earlier and is less steep.

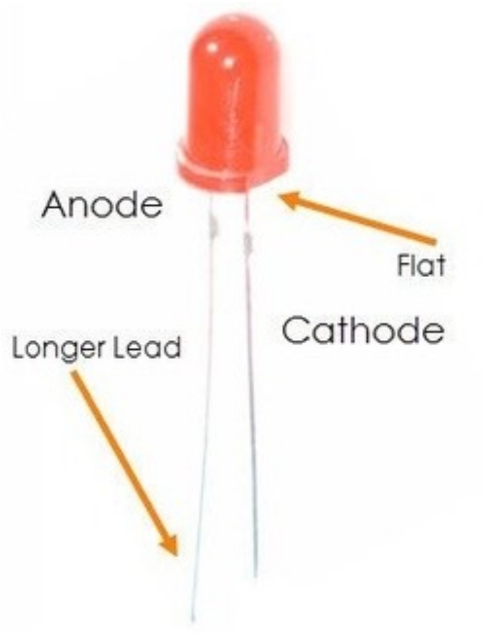


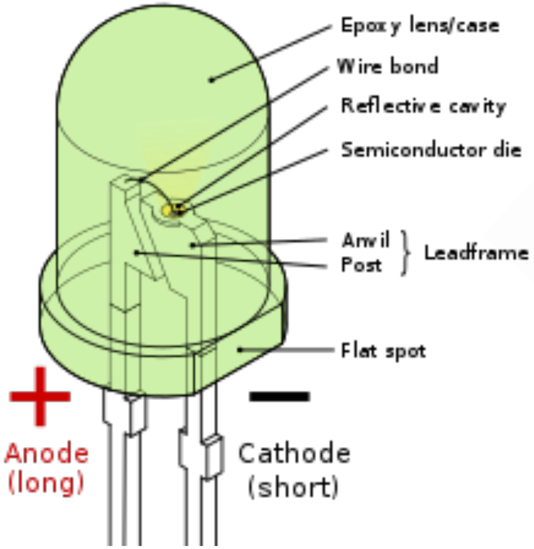






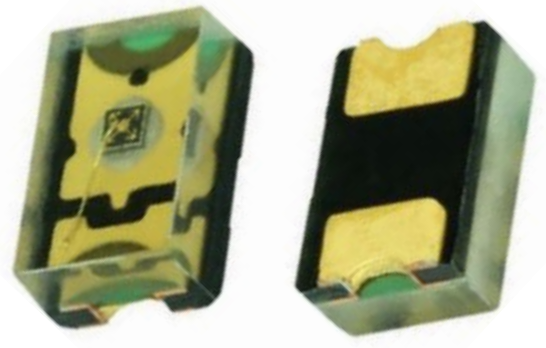
Light Emitting Diodes

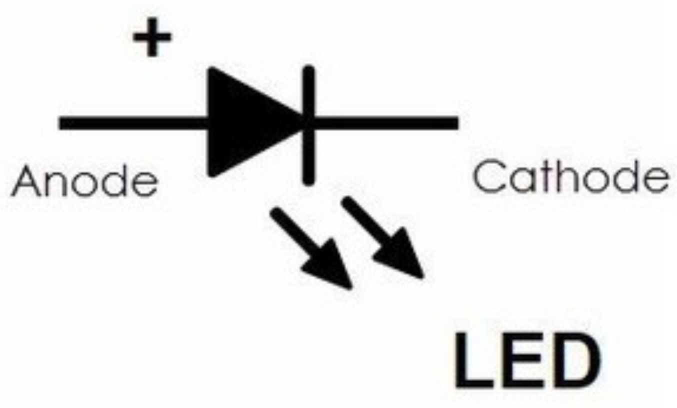


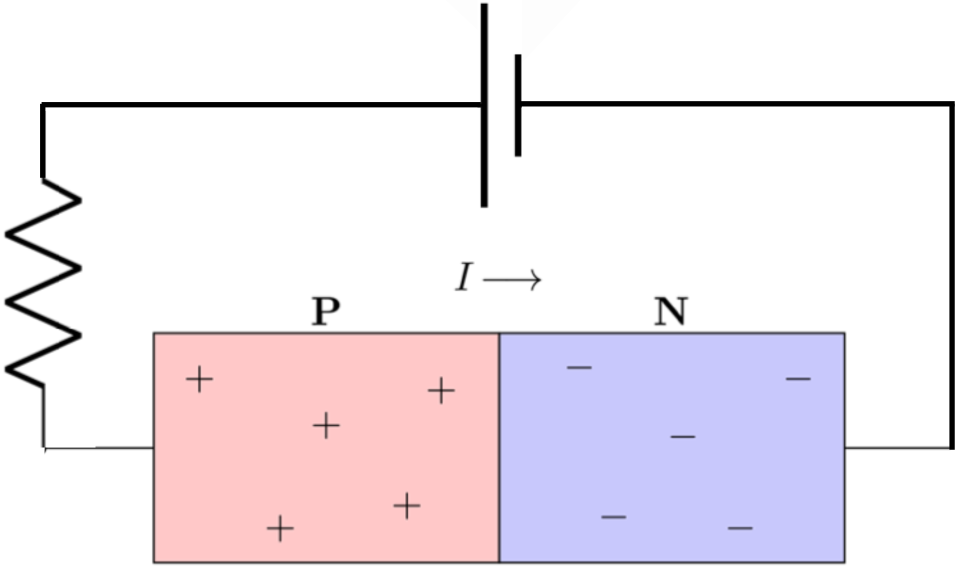


SMT LED

(Top) (Bottom)

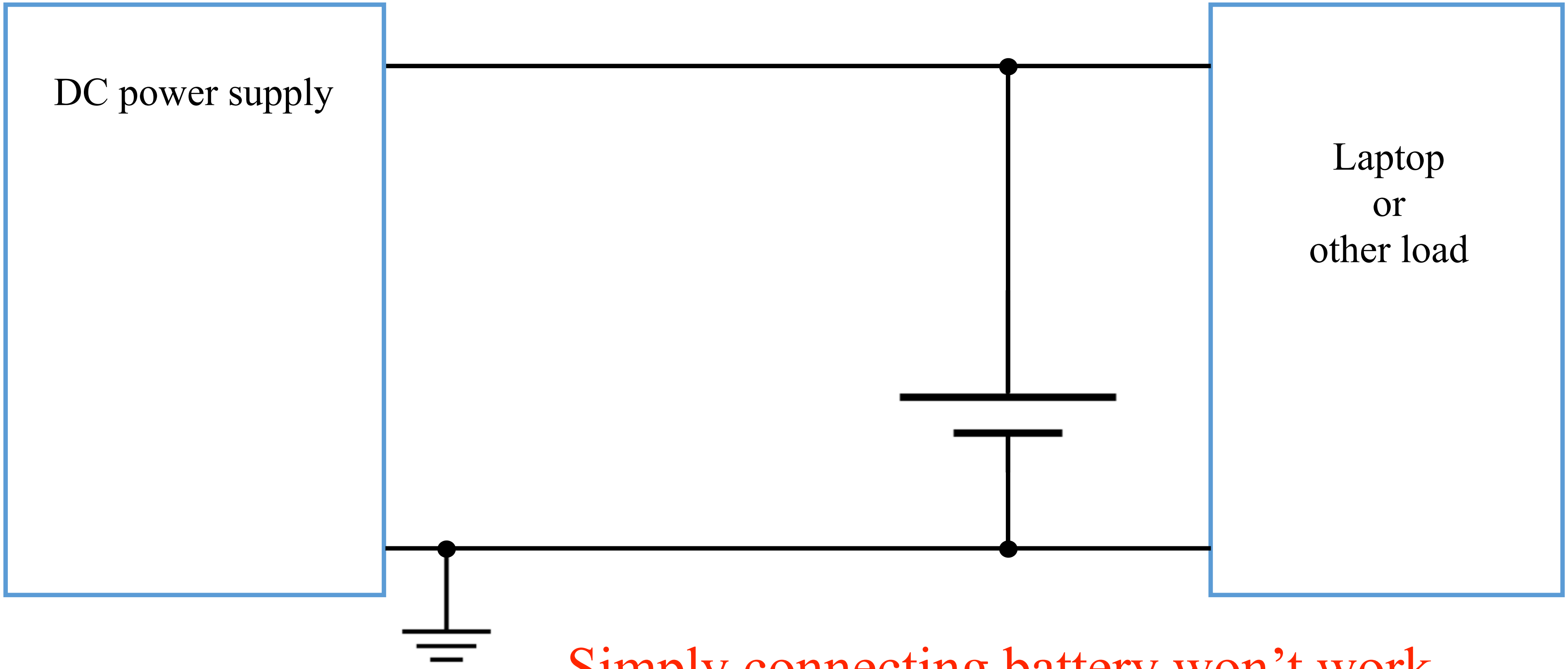






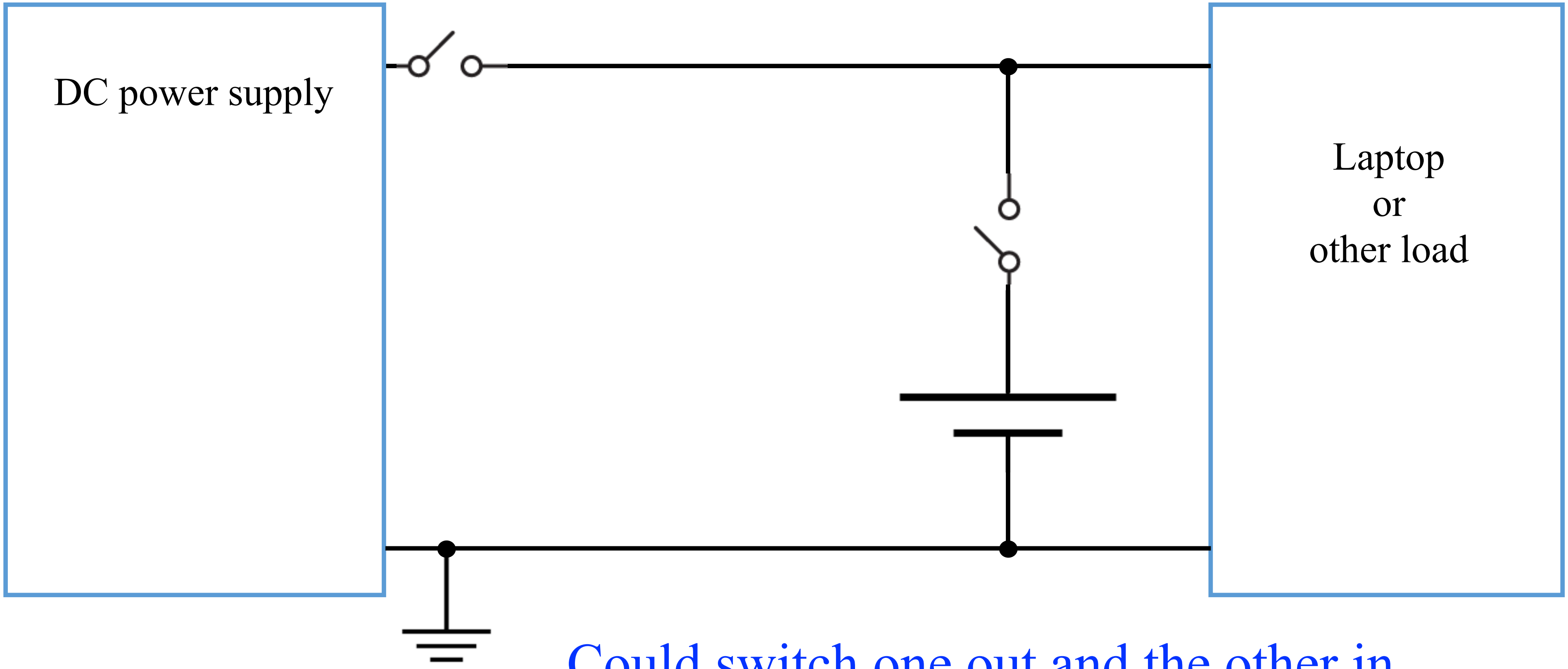
(no depletion zone)

Battery backup circuit with diodes



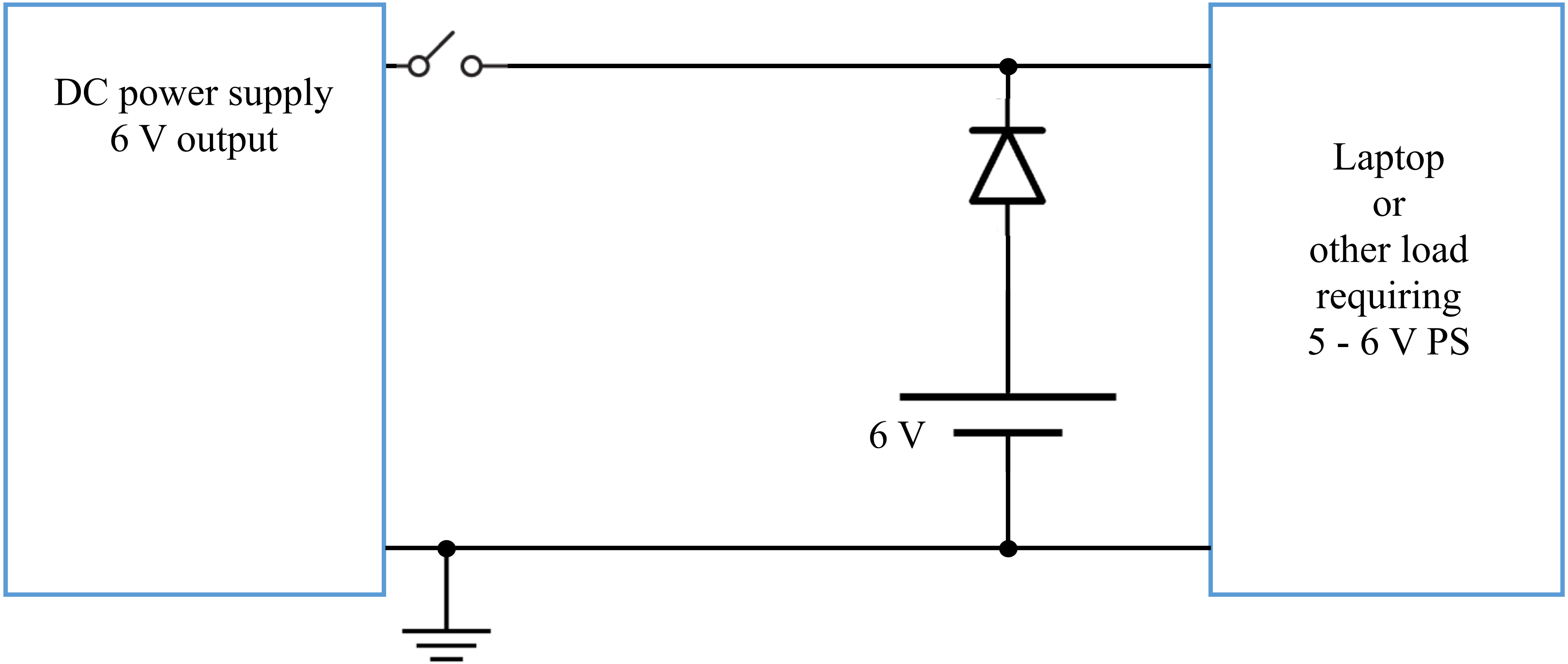
Simply connecting battery won’t work. Will overcharge battery and cause it to burn.

Battery backup circuit with diodes



Could switch one out and the other in

Battery backup circuit with diodes

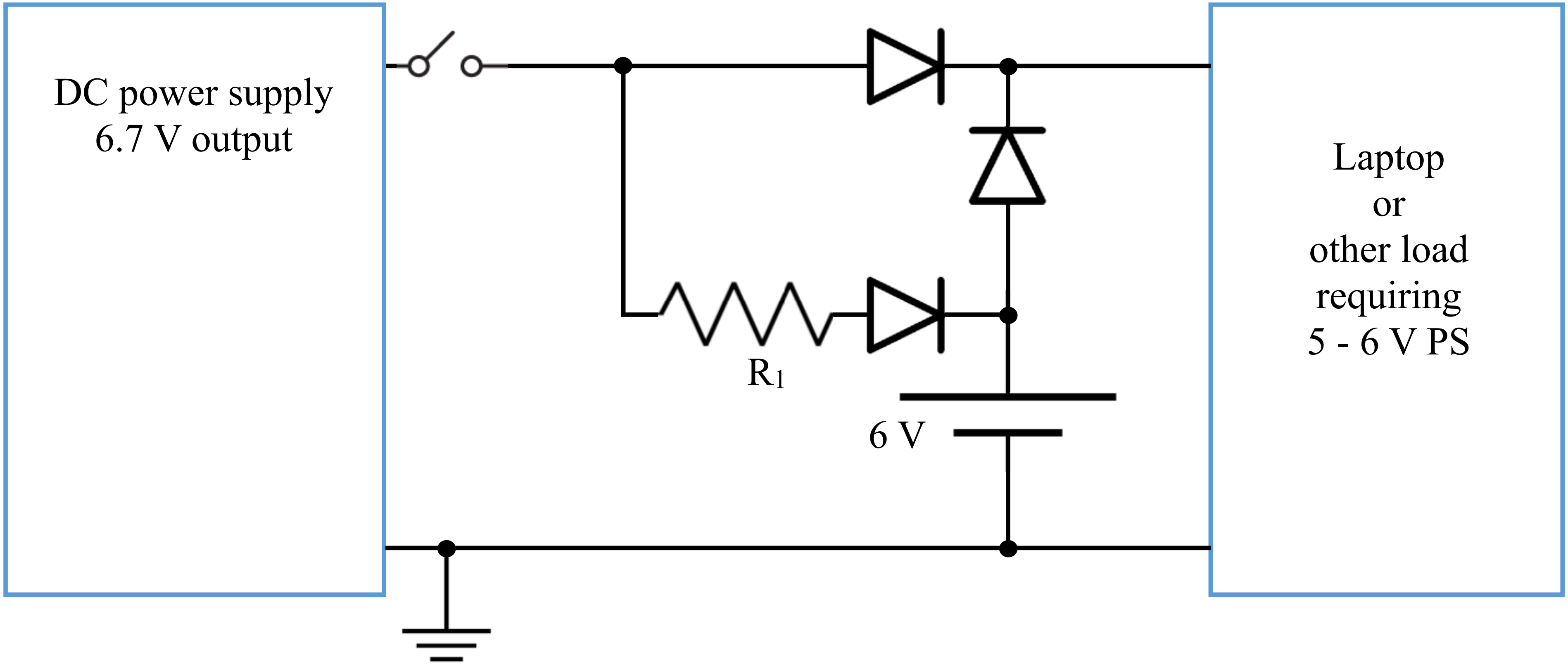


DC power supply
6 V output

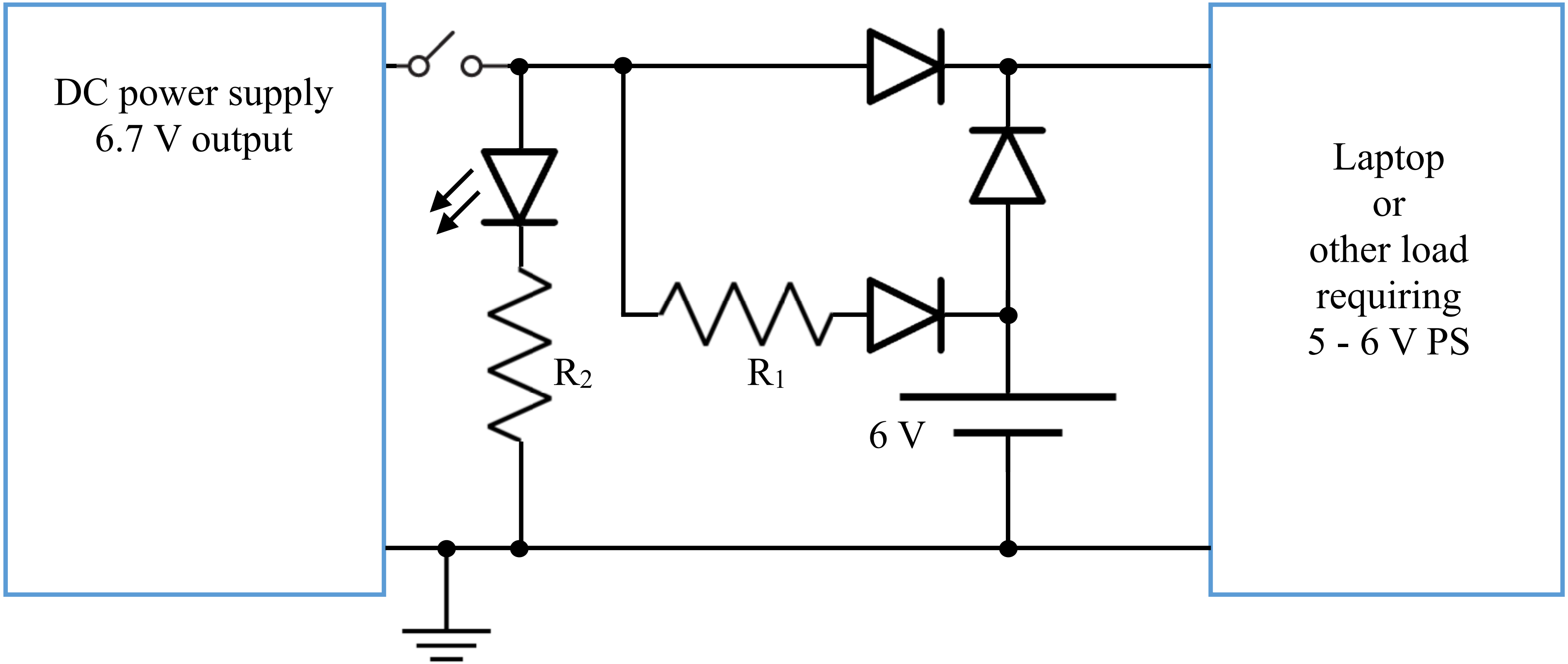
6 V

Laptop
or
other load
requiring
5 - 6 V PS

Battery backup circuit with diodes



Battery backup circuit with diodes



LED lights when DC power supply is active.

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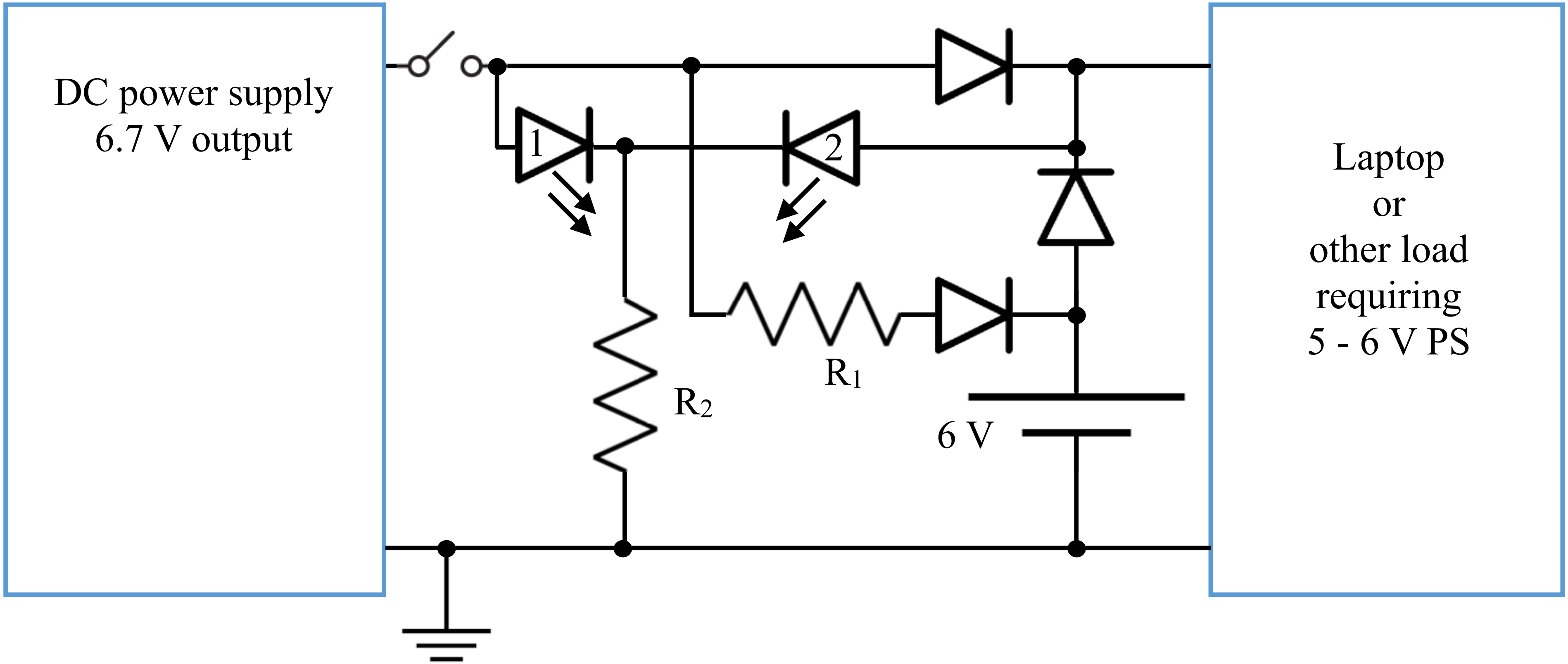
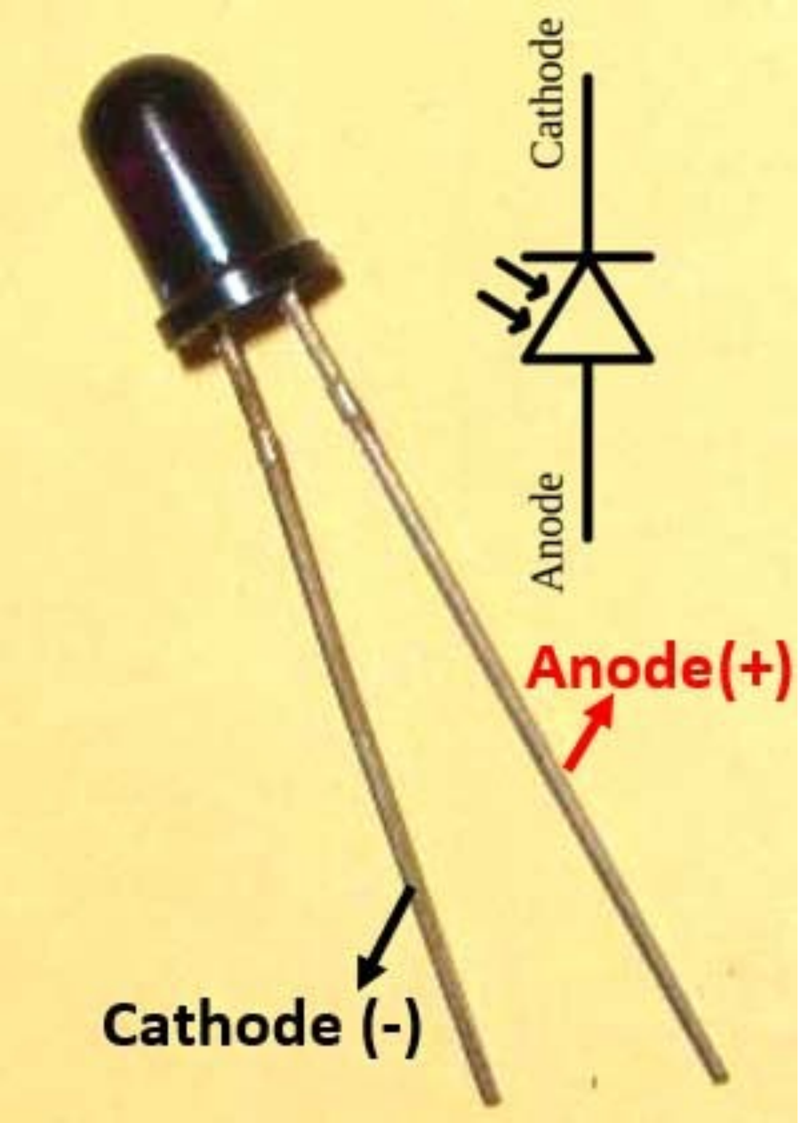
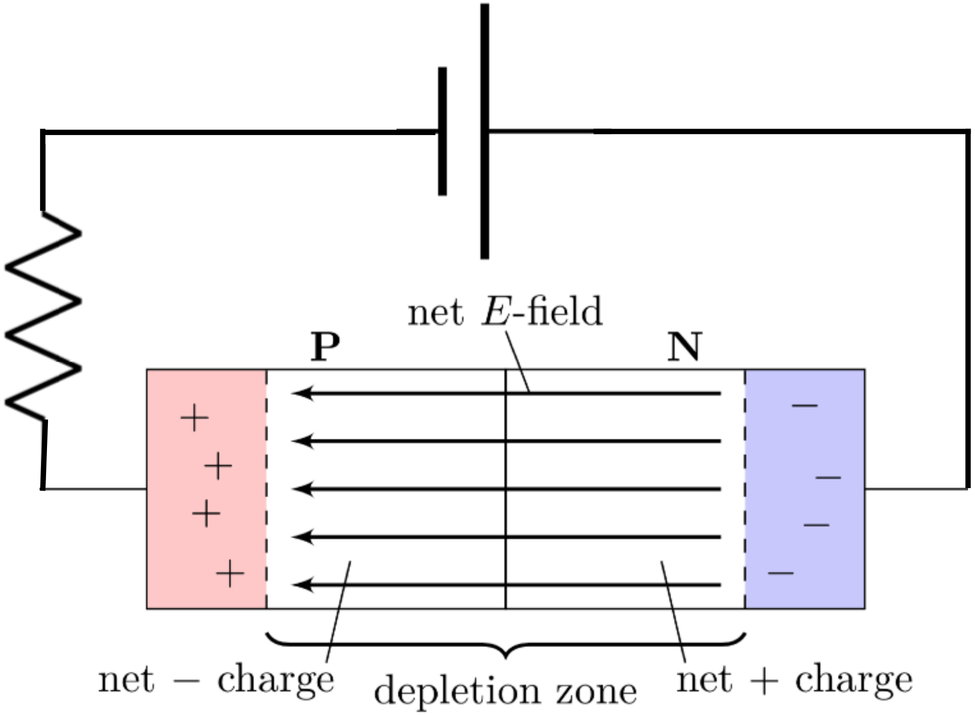
Battery backup circuit with diodes

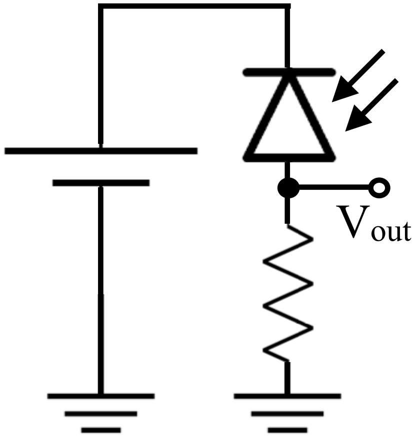


LED1 lights when DC power supply is active.
LED2 lights when battery is active.

Photo Diodes







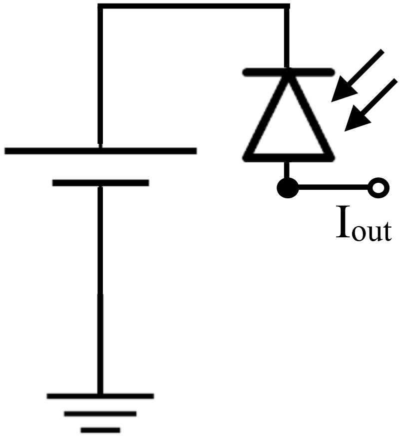
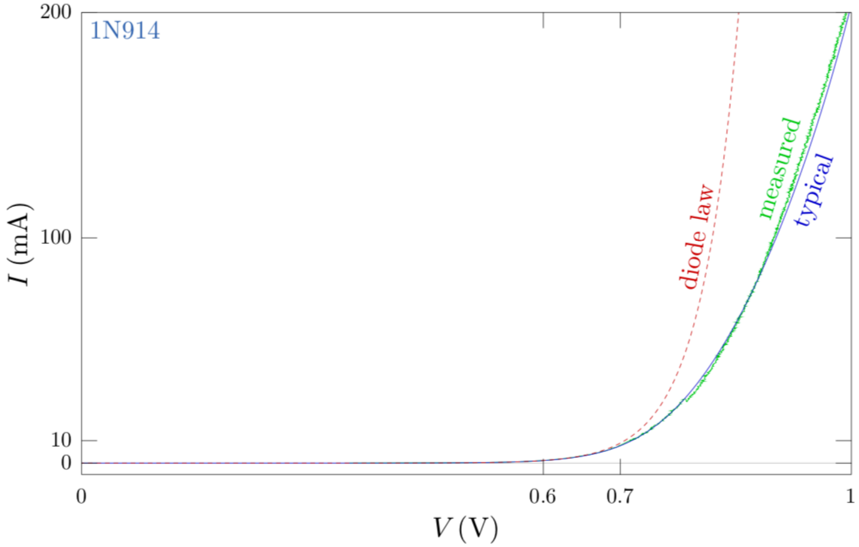
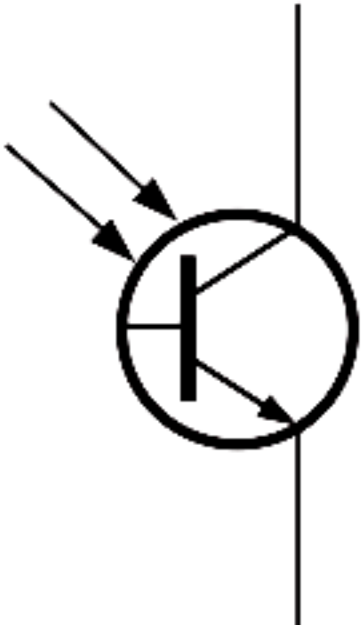


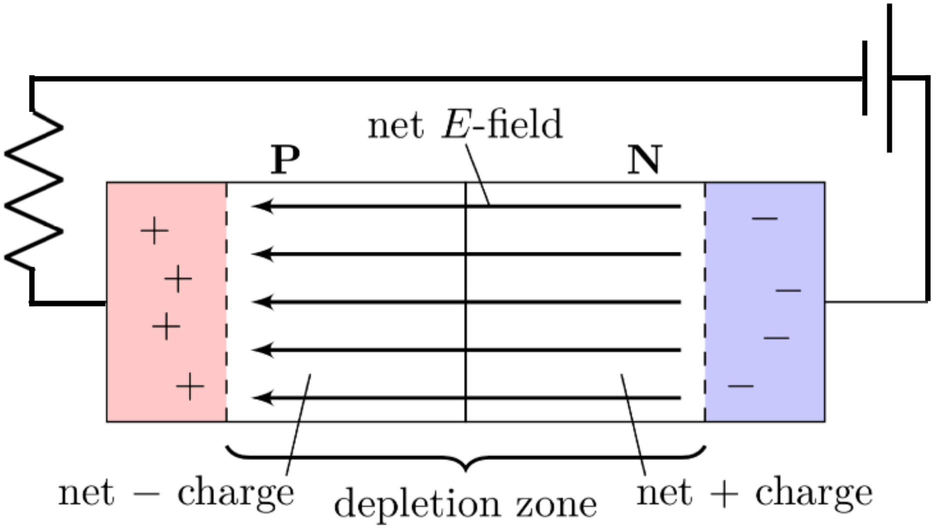
Photo Transistors

For detecting light, we often use phototransistors rather than photodiodes. They amplify the $I(N_\gamma)$ response.



We get a hint of how by seeing that diode current increases with voltage across it.
Current flow frees more carriers.
Photocurrent controls larger current.

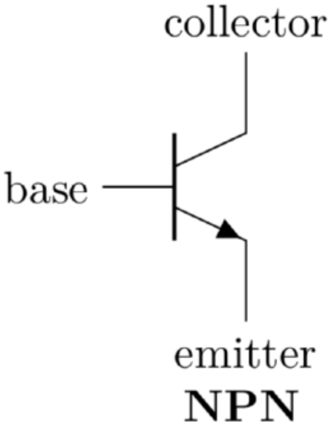


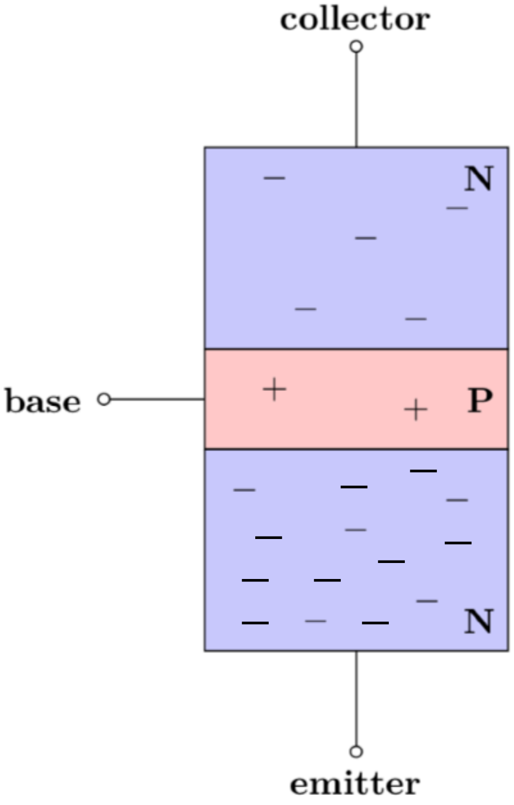


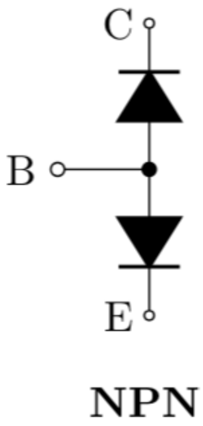
Transistors

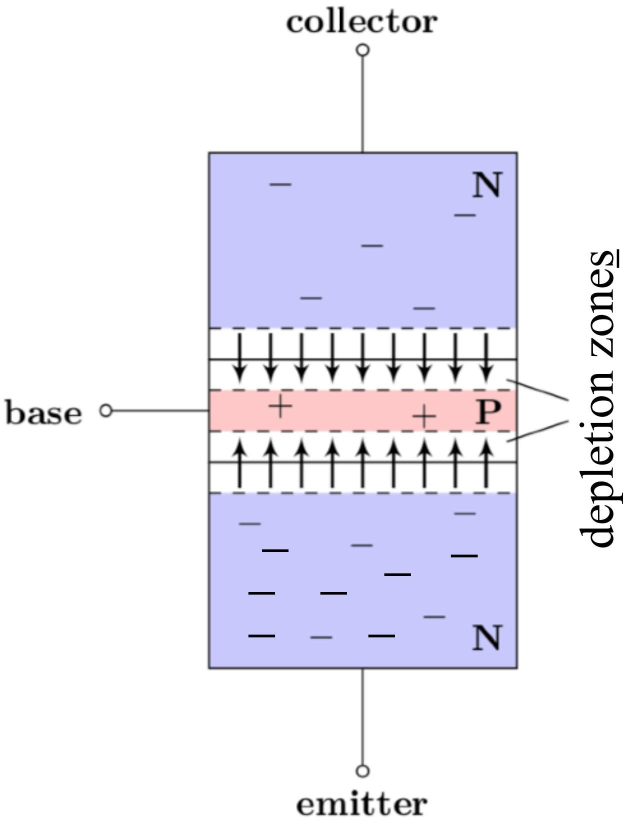
A transistor operates by amplifying current.
It is *active*, meaning more power out than in.
Previous components were *passive*.

Made by sandwiching a thin, lightly-doped p-type layer between n-type regions.



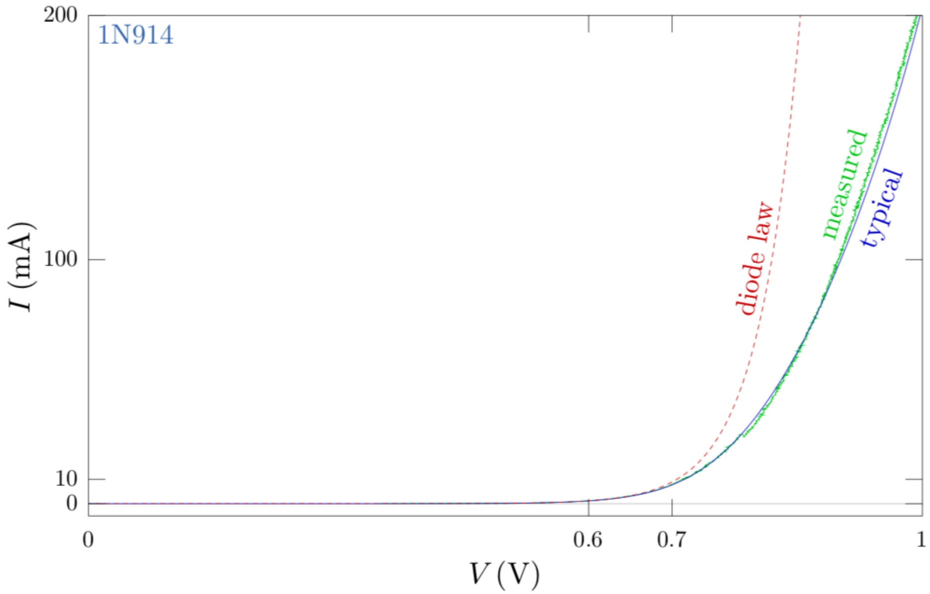


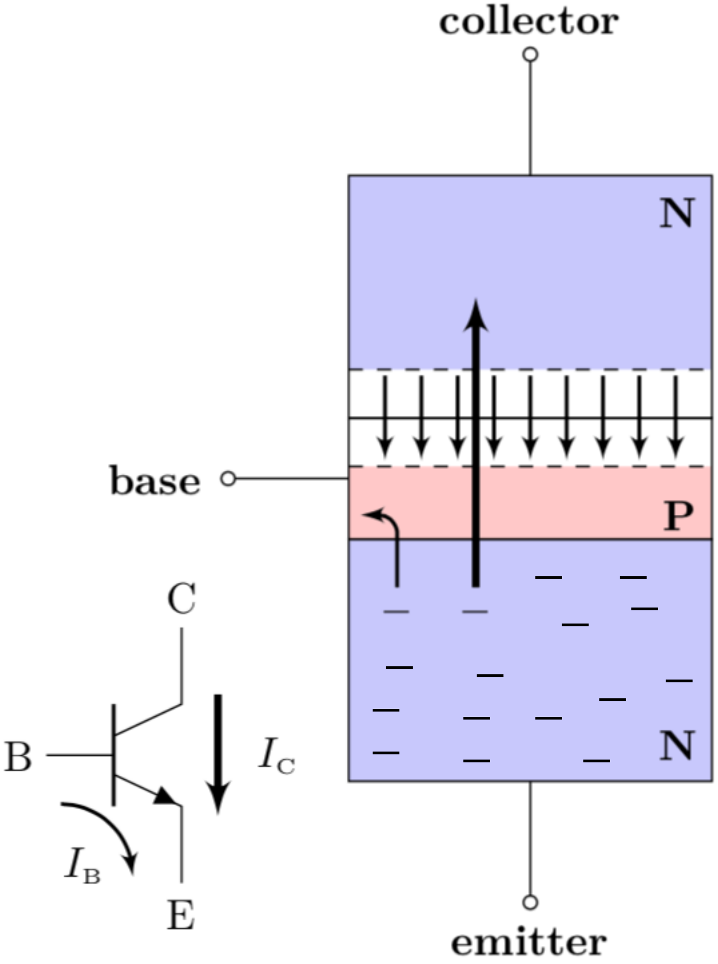




Transistors

If we have a voltage across the base-emitter junction > 0.6 V it becomes forward biased.
Negative charge carries move from the emitter to the base, but they can also move across the field region to the collector.

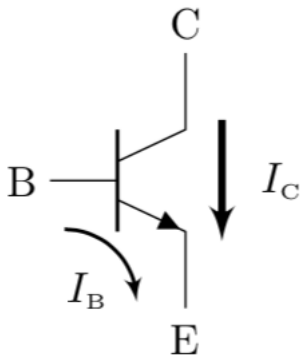




This corresponds to a small current into the base and a larger current into the collector.

I_B controls I_C and amplifies it by a factor $\beta \cong 100$.

Transistor rules of operation



1). $V_{BE} = 0.6$ V or the transistor is off
I.e., $V_B = V_E + 0.6$ V
Once the transistor is on, $\Delta V_B = \Delta V_E$.

2). $I_C = \beta\, I_B$.
And by charge conservation $I_E = I_B + I_C$ so $I_E \cong I_C$

3). $V_{CE} > 0.2$ V

With these simple rules we can analyze most transistor circuits.
We'll add some nuance later.

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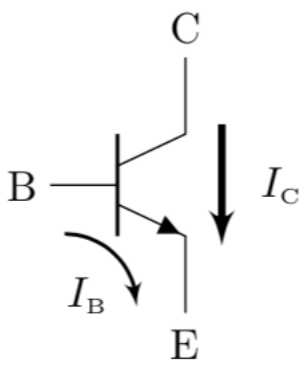

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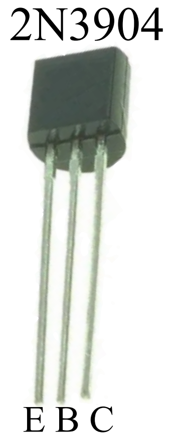
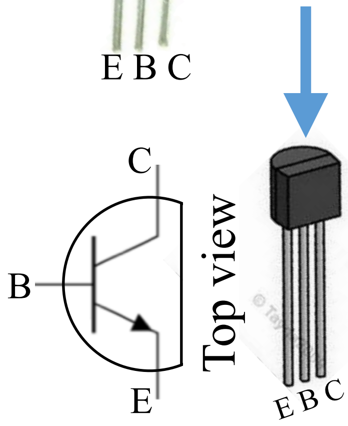
The 2N3904 is an NPN transistor.
You also have others we will discuss later.





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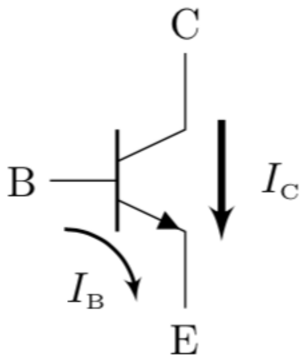

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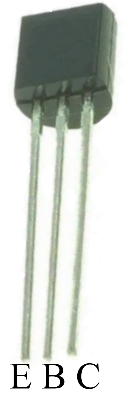
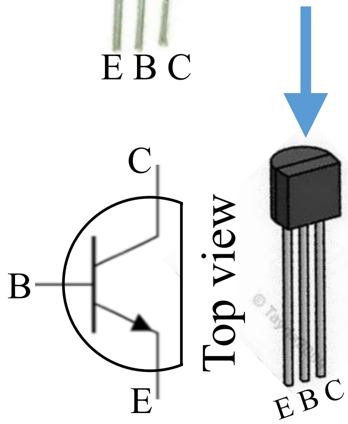
2N3904

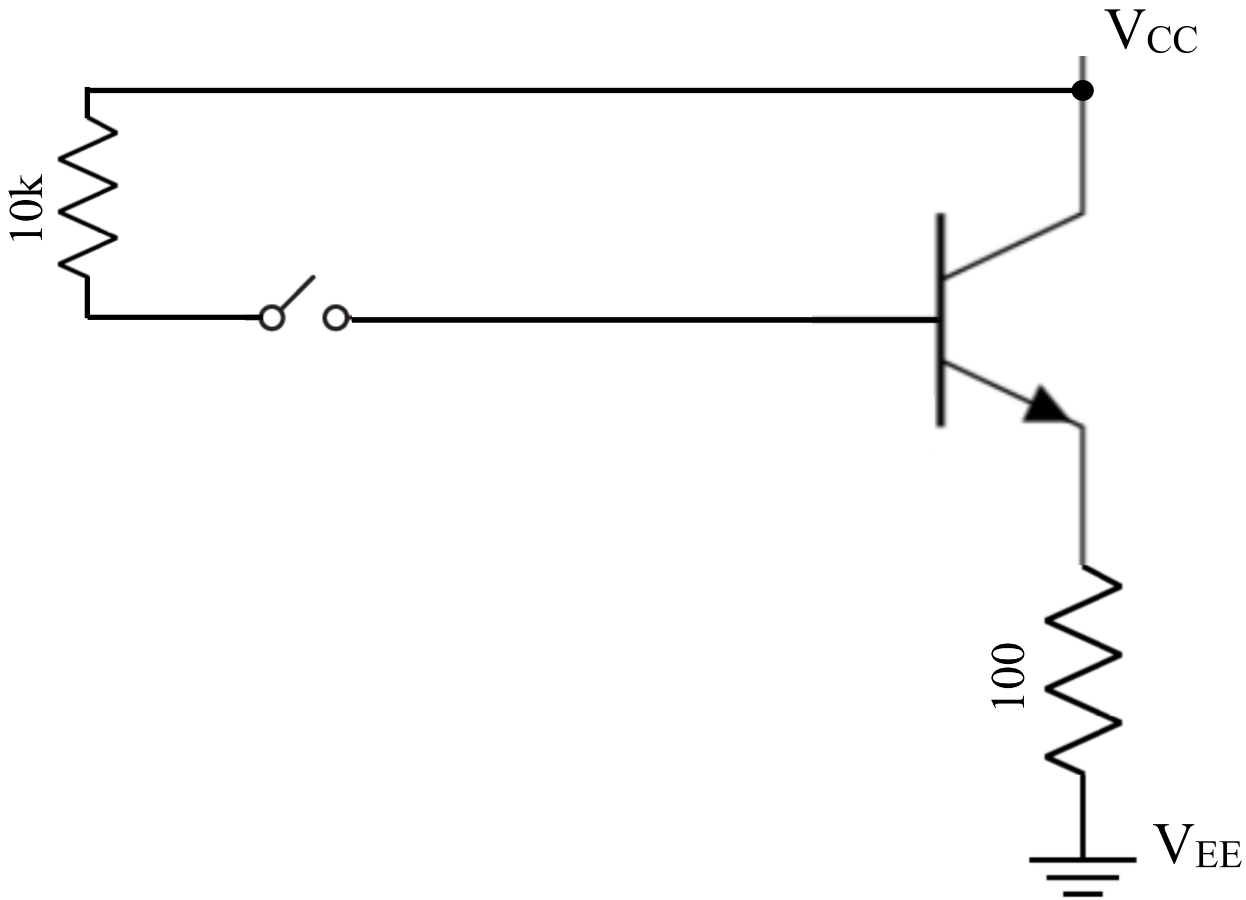


Some terminology:
The power supply connected to the collector is called V_{CC}.
The power supply connected to the emitter is called V_{EE}.



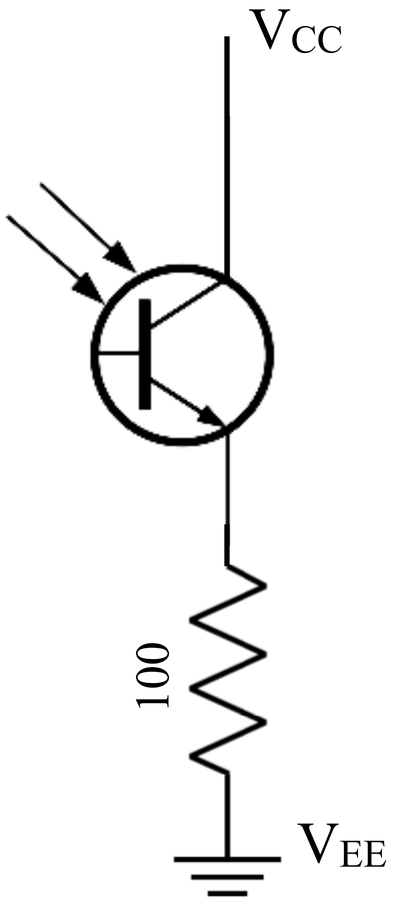
Simplest transistor circuit

Can switch a large current with a small current.



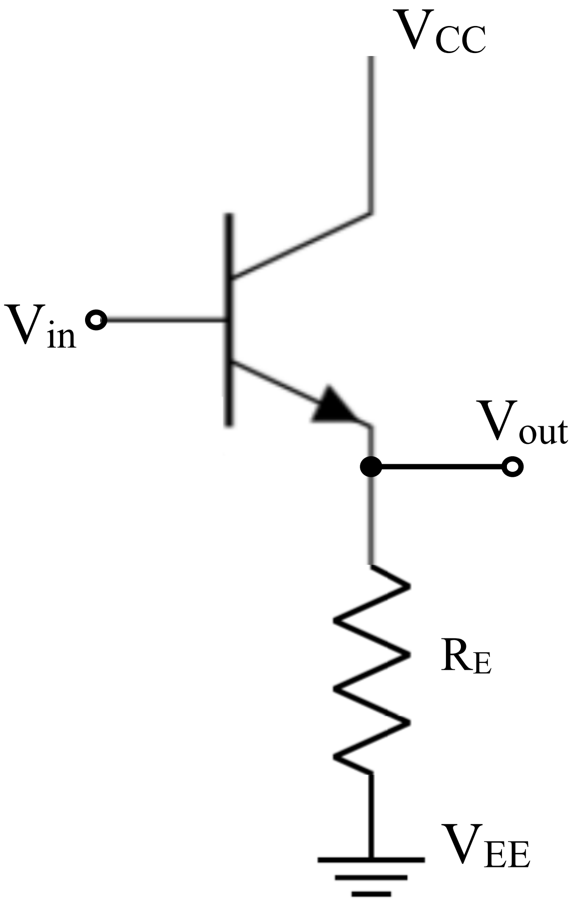
Simplest transistor circuit

Can switch a large current with a few photons.



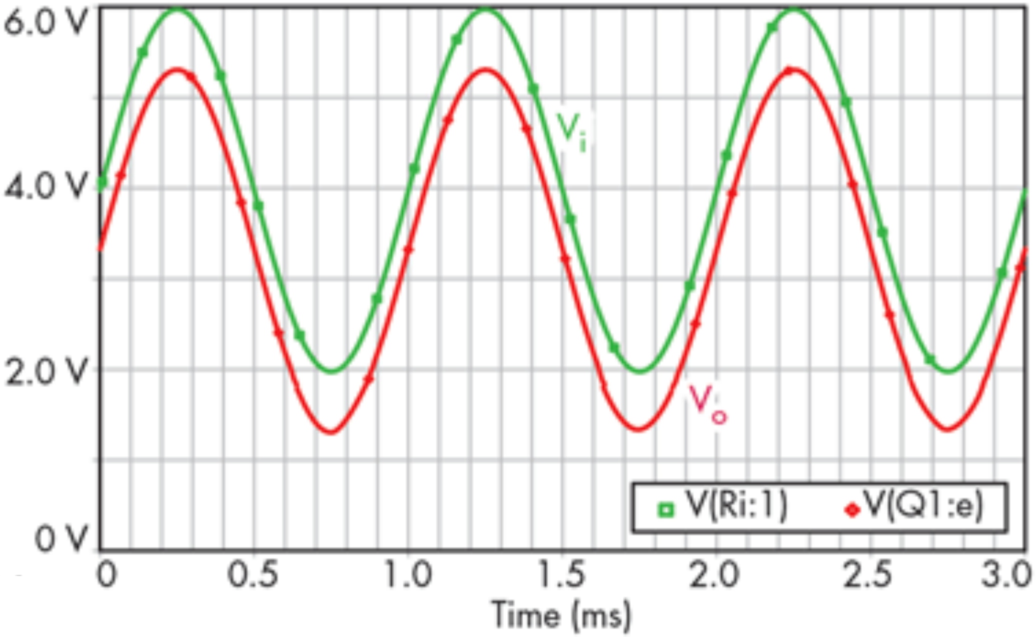
Emitter follower

This transistor circuit has the output “follow” the input, with a 0.6 V drop.



$V_{in} = 4 + 2 \sin \omega t$

$V_{out} = 3.4 + 2 \sin \omega t$



DavidStuart@UCSB.edu

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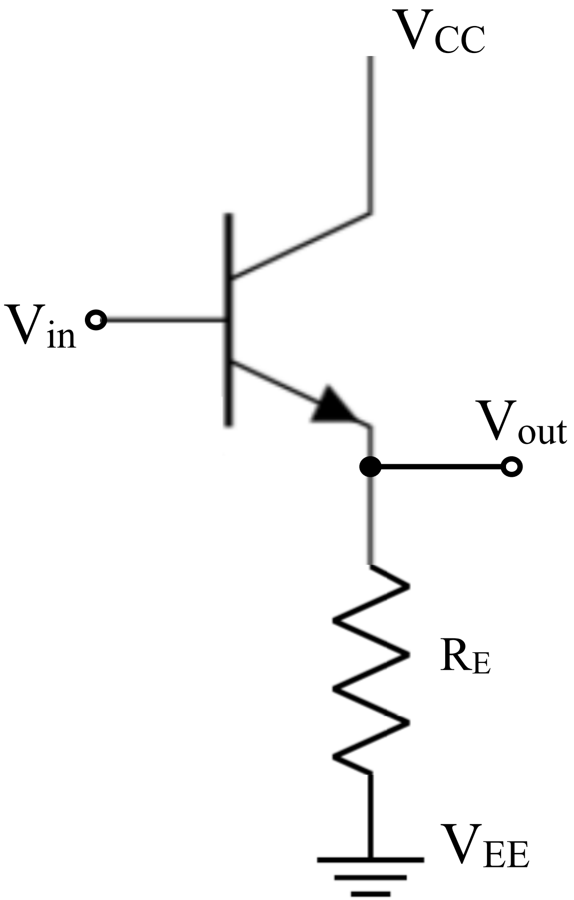
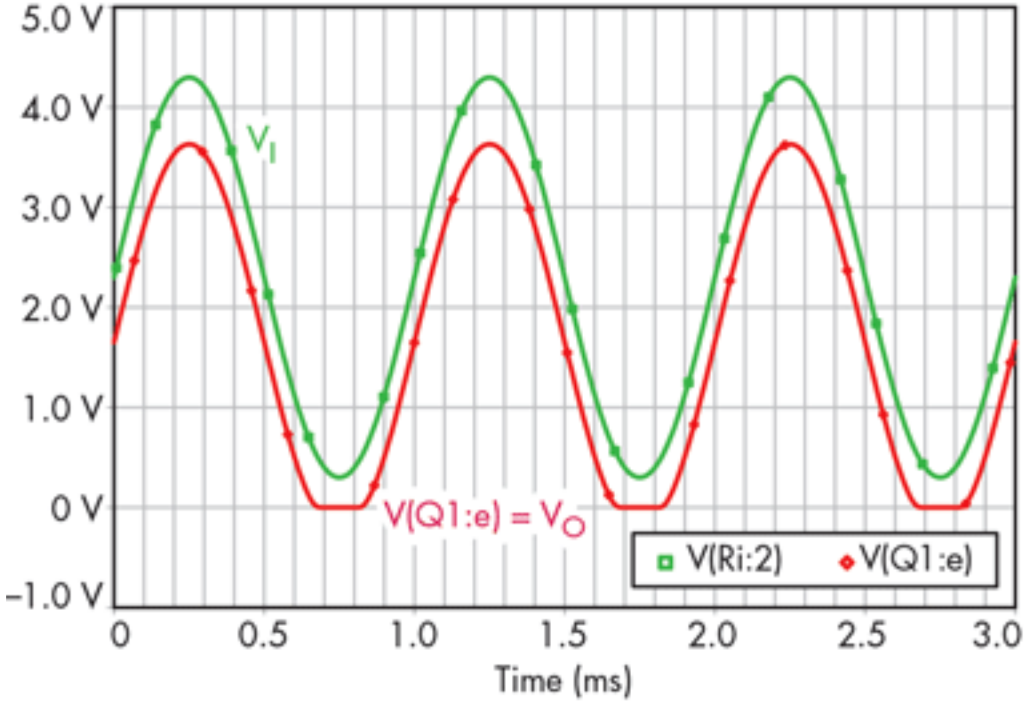


$V_{in} = 2.2 + 2 \sin \omega t$

$V_{out} = 1.6 + 2 \sin \omega t$ but output clips at 0 V



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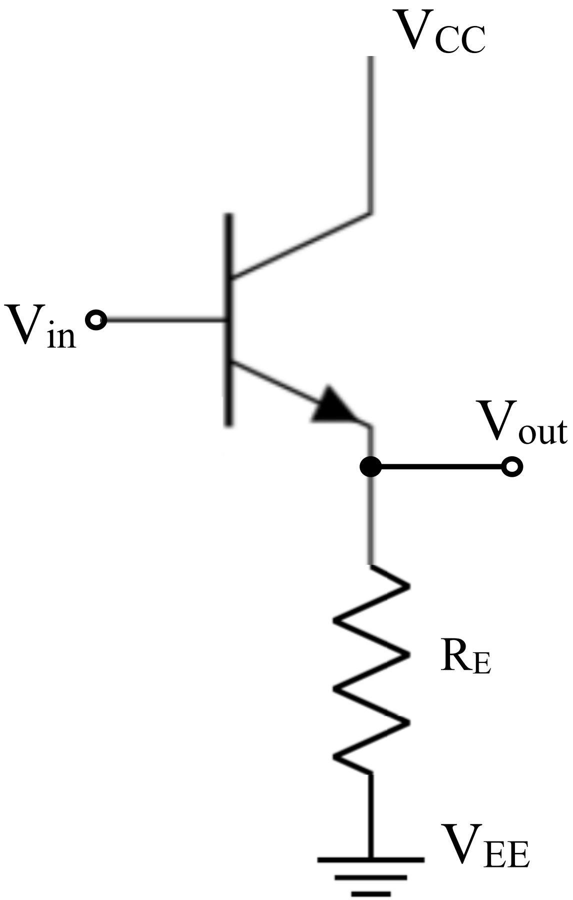

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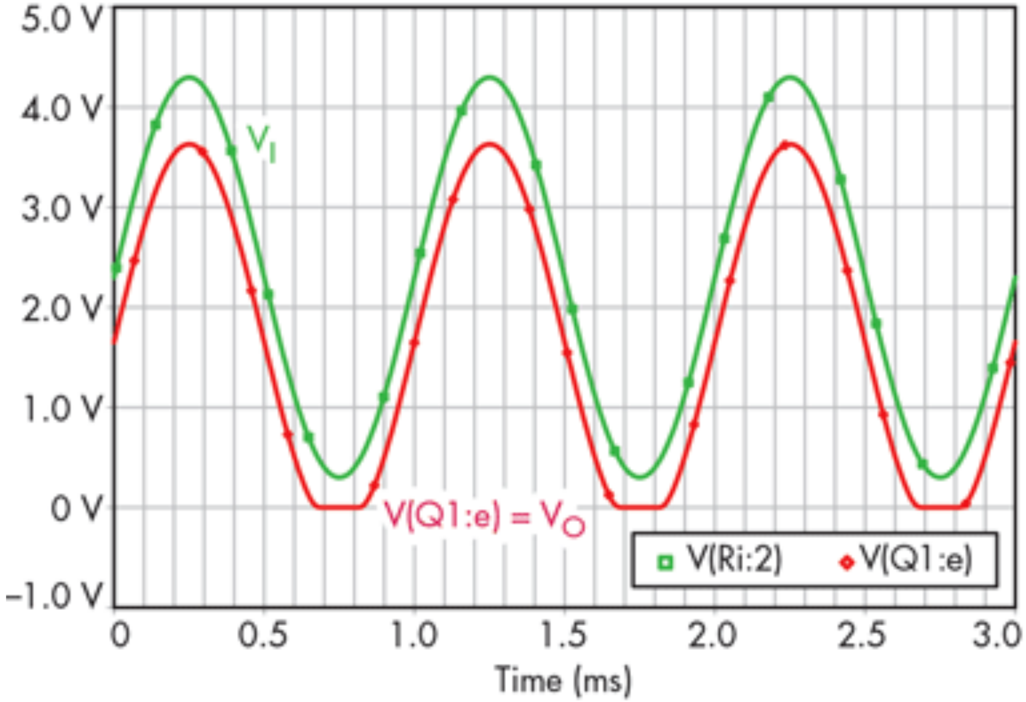
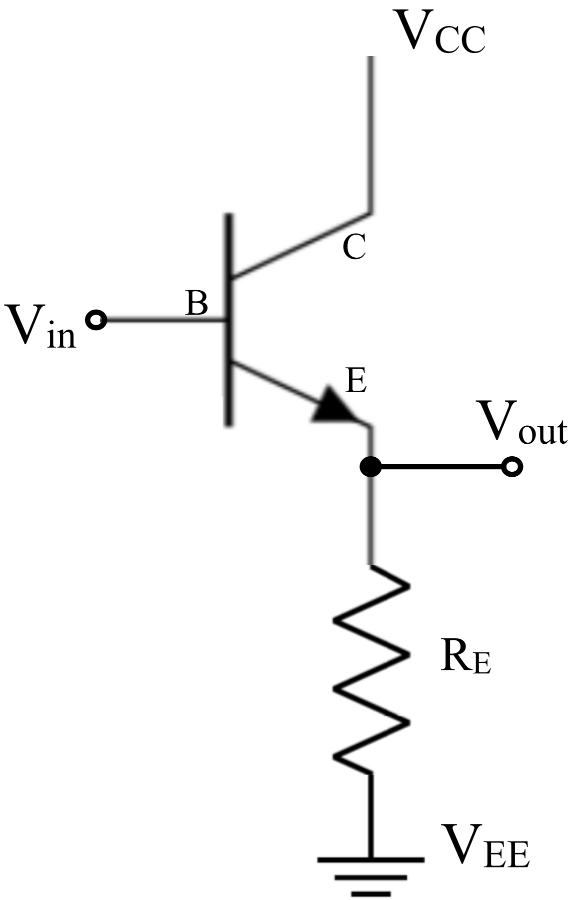
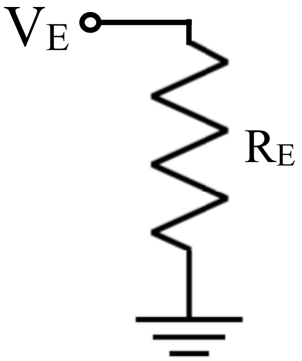


Emitter follower

The benefit here is increased input impedance. Recall that impedance is $R = \Delta V/\Delta I$





Without the transistor we need to flow
$\Delta I = \Delta V / R_E$ to change V_{in} by ΔV

With the transistor, we can calculate R_{in} from

$$R_{in} = \Delta V_{in} / \Delta I_{in} = \Delta V_B / \Delta I_B$$

The base current is $1/\beta$ of the emitter current, since $I_E \cong I_C = \beta\, I_B$. So,

$$R_{in} = \Delta V_{in} / \Delta I_{in} = \Delta V_B / (\Delta I_E/\beta) = \beta \Delta V_B / \Delta I_E$$

We also had $\Delta V_B = \Delta V_E$ from the transistor rules, so

$$R_{in} = \beta \Delta V_B / \Delta I_E = \beta \Delta V_E / \Delta I_E = \beta R_E$$

The input impedance is β times larger than R_E.
<u>The transistor amplifies the impedance by $\beta \cong 100$.</u>

DavidStuart@UCSB.edu

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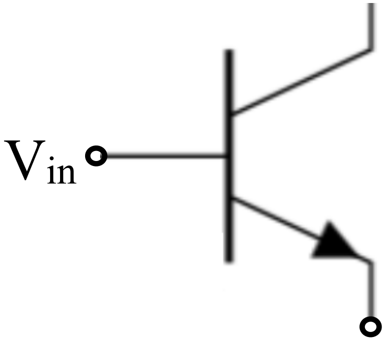

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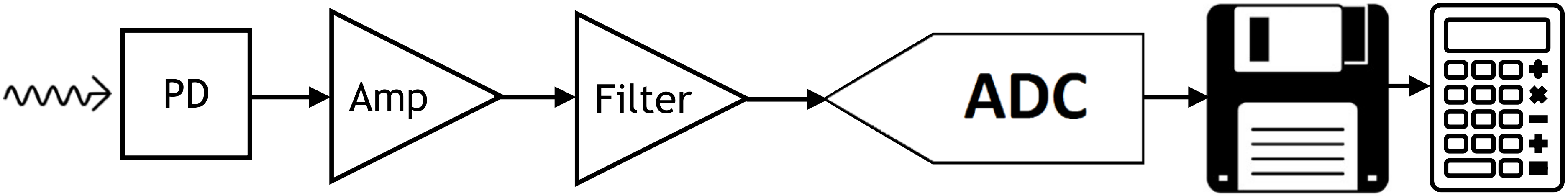
This is the way to make each stage have large input impedance; put a transistor at its input.

The emitter will follow the variations in the input.
The DC shift of 0.6 V is not a problem because
the variation of V_{in} *is the signal.*

The additional power needed is supplied by V_{CC}.



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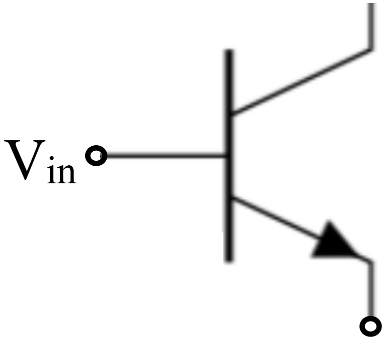

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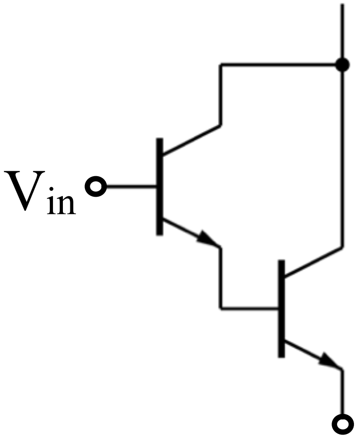

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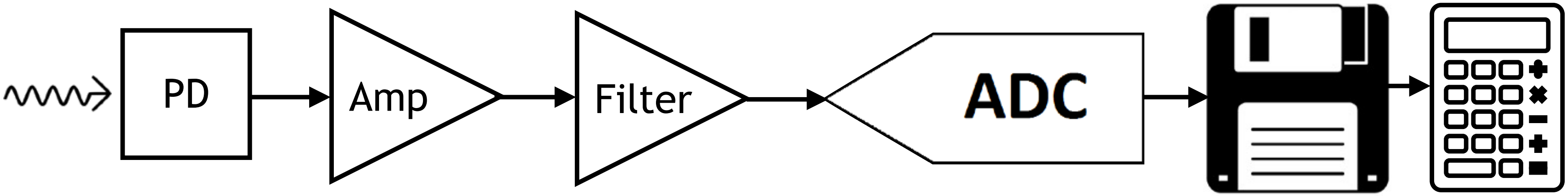
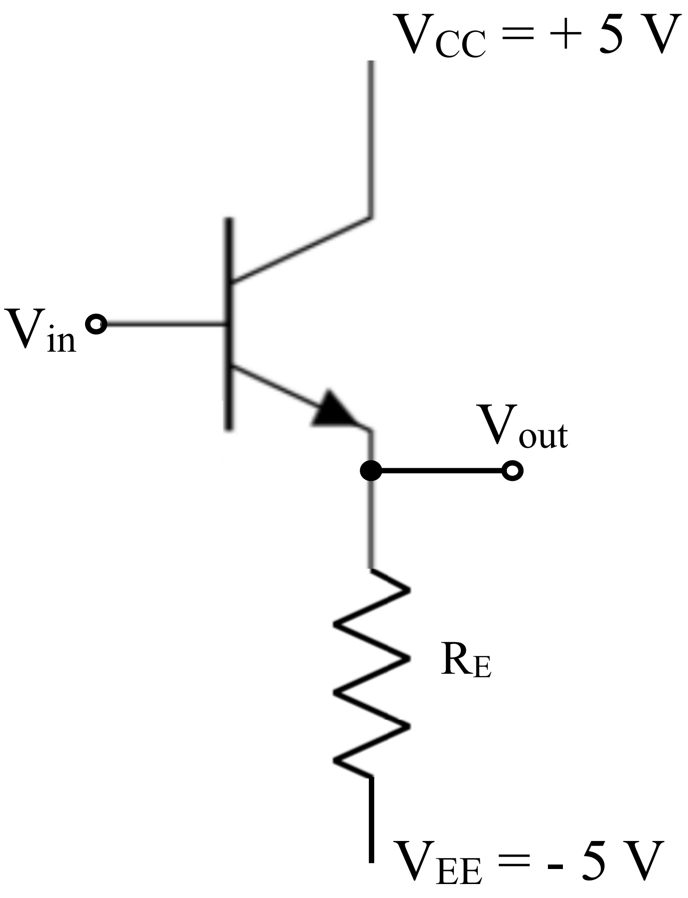
Can get a factor of β^2 with two followers. (Darlington configuration.)
However, that costs two diode drops.



DavidStuart@UCSB.edu

Emitter follower

We can remove the clipping at 0 V by setting V_{EE} to a negative supply.



$V_{CC} = +5\text{ V}$

V_{in}

V_{out}

R_E

$V_{EE} = -5\text{ V}$

$V_{in} = 2.2 + 2 \sin \omega t$

$V_{out} = 1.6 + 2 \sin \omega t$ but output clips at 0 V

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