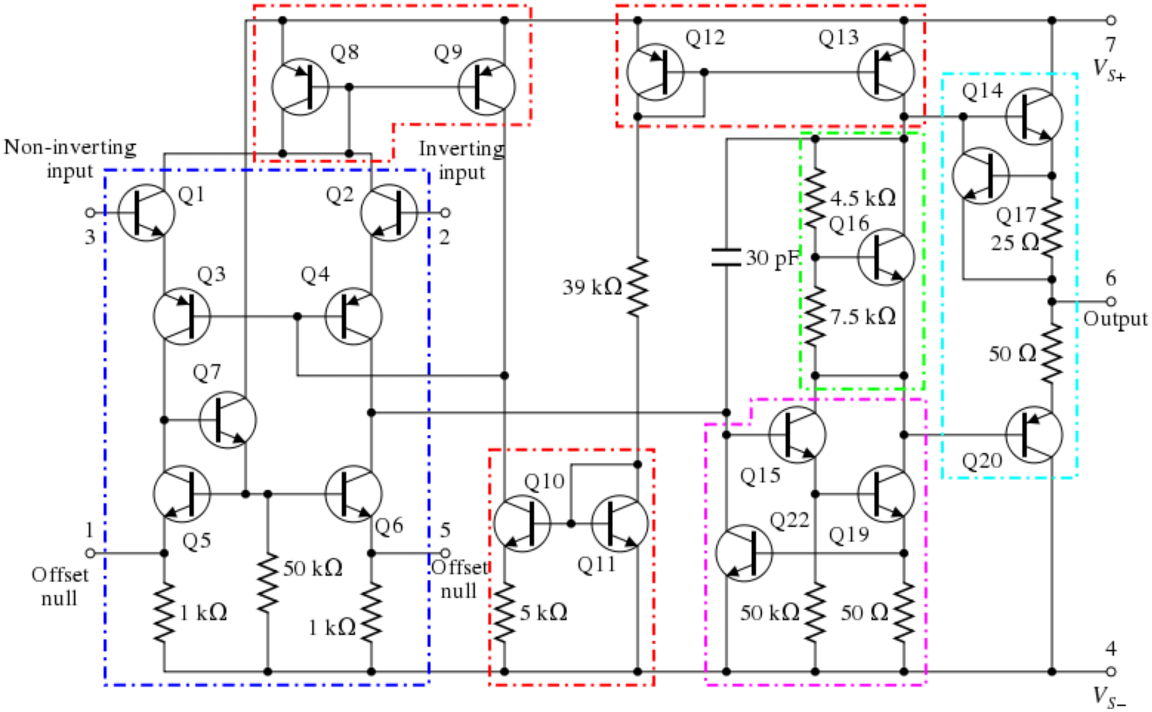
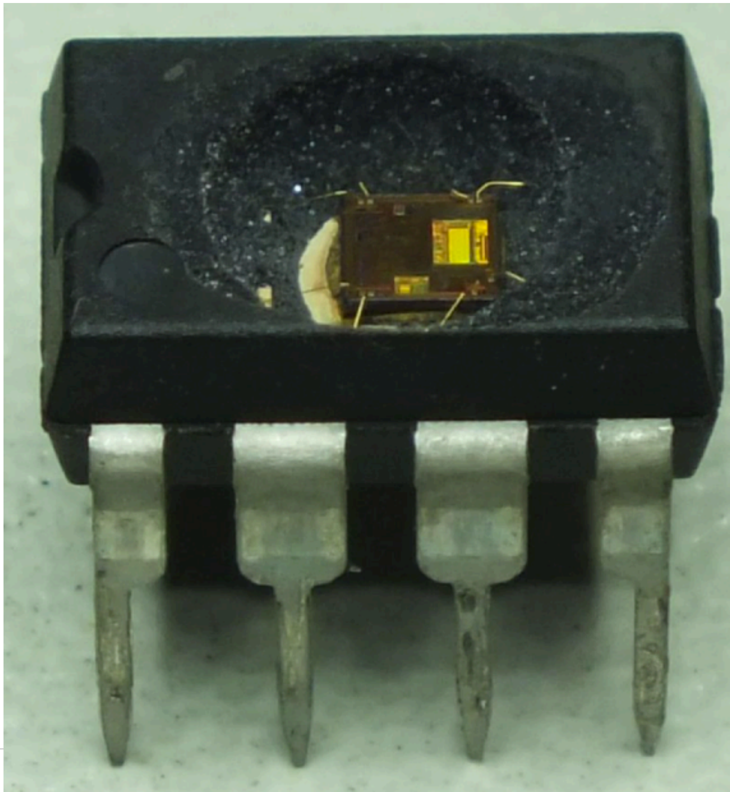
PHYS127AL Lecture 11

David Stuart, UC Santa Barbara

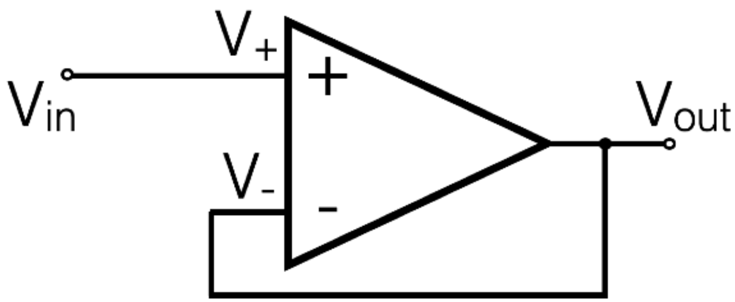
Operational Amplifiers continued





Op-amp review: negative feedback; golden rules

The "golden rules" for op-amp operation encode this idea in two simple rules that are sufficient to analyze the behavior of most op-amp circuits:



Golden rules:

1). No current flows into the inputs, i.e.,

$$I_+ = 0 \quad \& \quad I_- = 0$$

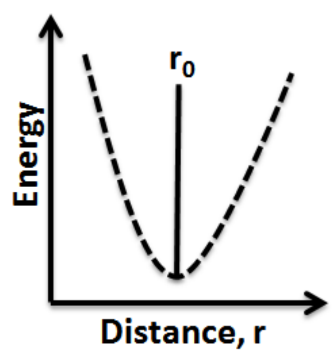
This follows from the FET inputs.

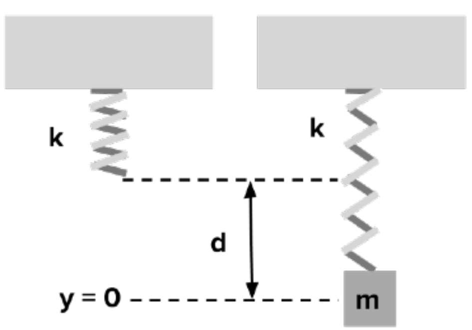
2). The op-amp output will do whatever it can to force the inputs to be equal, i.e.,

$$V_+ = V_-$$

Rule 2 can only work when there is some sort of feedback from V_{out} to V_-. Otherwise, V_{out} is "*at a rail*" if $V_+ \neq V_-$.

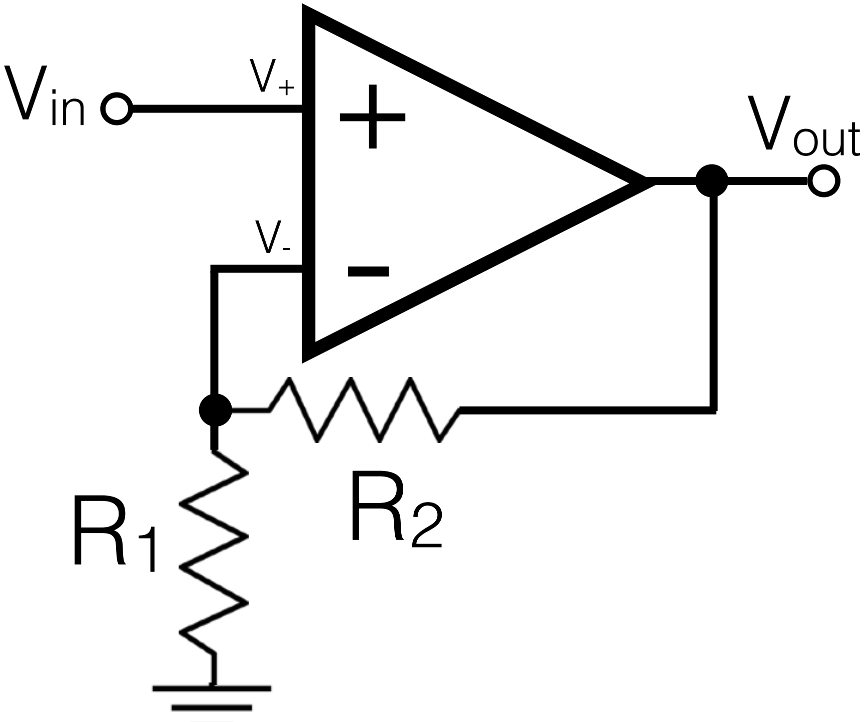
Relies on enormous gain to apply "force back to equilibrium position", through negative feedback.





Op-amp review: non-inverting amplifier

Using the golden rules we can analyze the circuit for a non-inverting amplifier



Rule 1 means high impedance.
Rule 2 means that V_{out} relates to $V_{in}=V_+=V_-$ through a simple voltage divider relationship.

$$V_- = V_{out} R_1/(R_1+R_2) = V_{in}$$

Solving for V_{out} in terms of V_{in} gives

$$V_{out} = V_{in}(R_1+R_2)/R_1$$

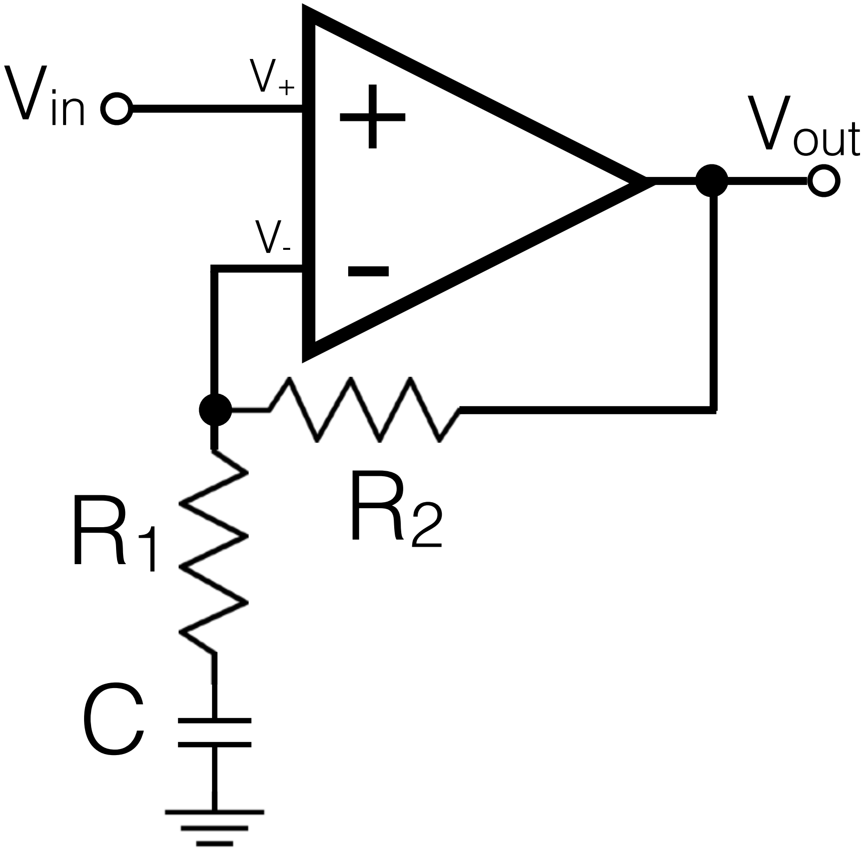
$$V_{out} = V_{in}(1+R_2/R_1)$$

$$G = 1+R_2/R_1$$

Limits on R_1 and R_2.

Non-inverting amplifier

What would we get if we added a capacitor in the non-inverting amplifier?



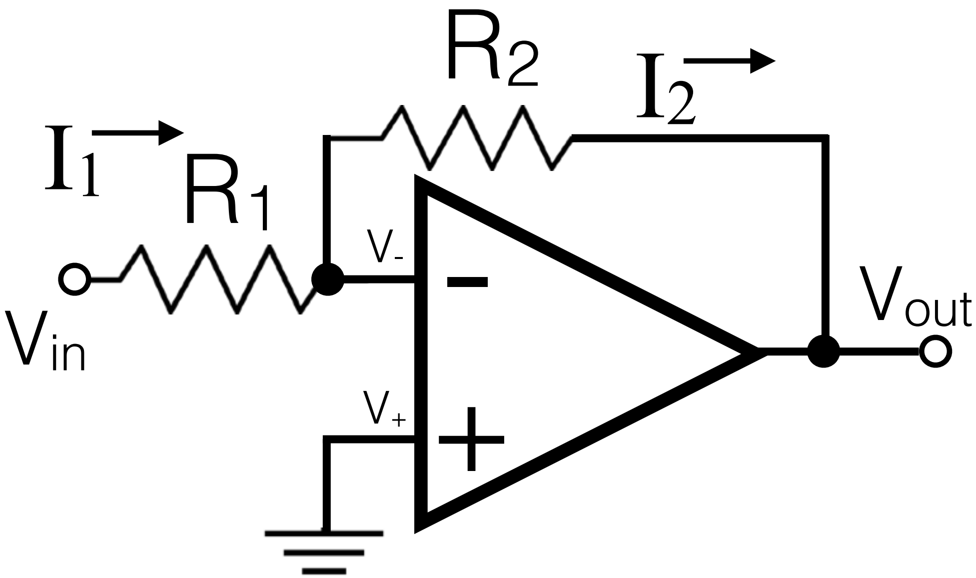
$G = 1+R_2/R_1$

becomes

$G = 1+R_2/(R_1+X_C) = 1+R_2/(R_1+1/\omega C)$

Op-amp review: inverting amplifier

Using the golden rules we can analyze the circuit for an inverting amplifier



Rule 2 means V_- = ground. Called a "virtual ground".

Rule 1 means that no current flows into inverting input. So, $I_1 = I_2$

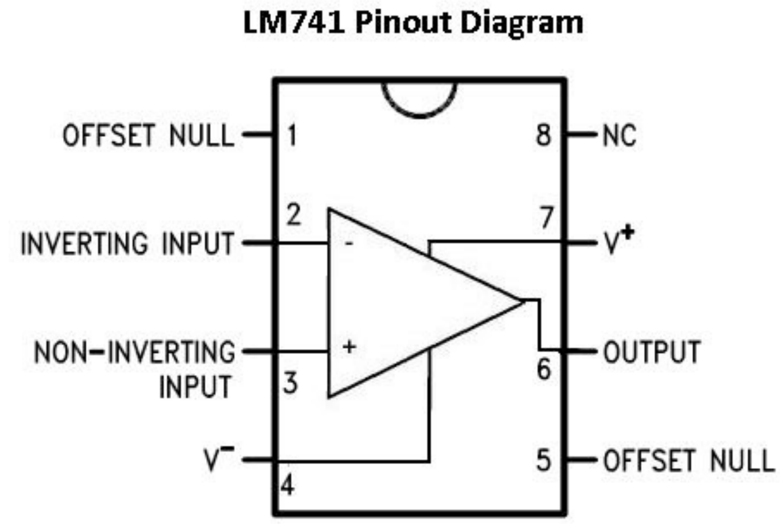
$V_{in} = I_1R_1$

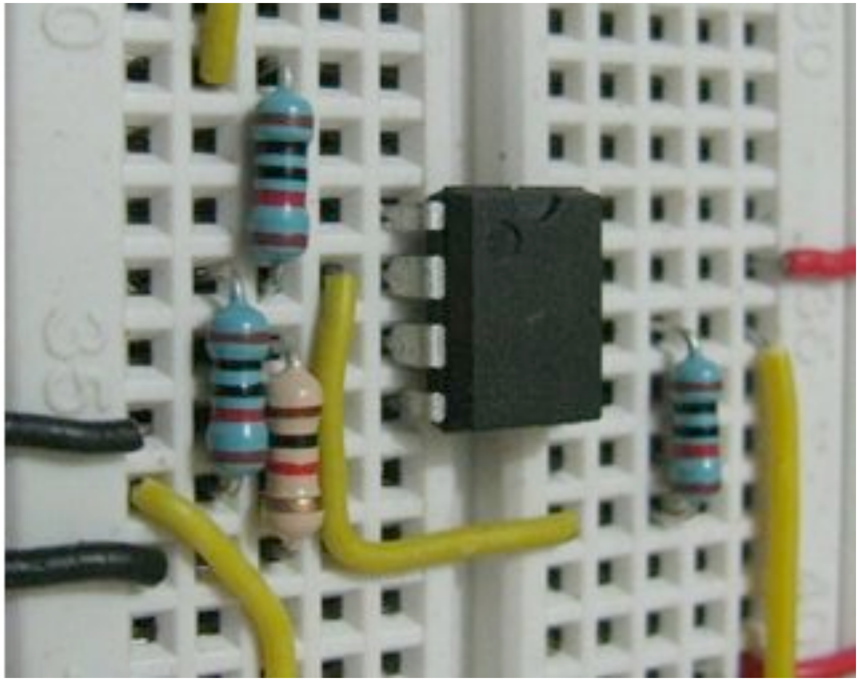
$V_{out} = -I_2R_2 = -I_1R_2 = -V_{in}R_2/R_1$

$G = -R_2/R_1$

Package

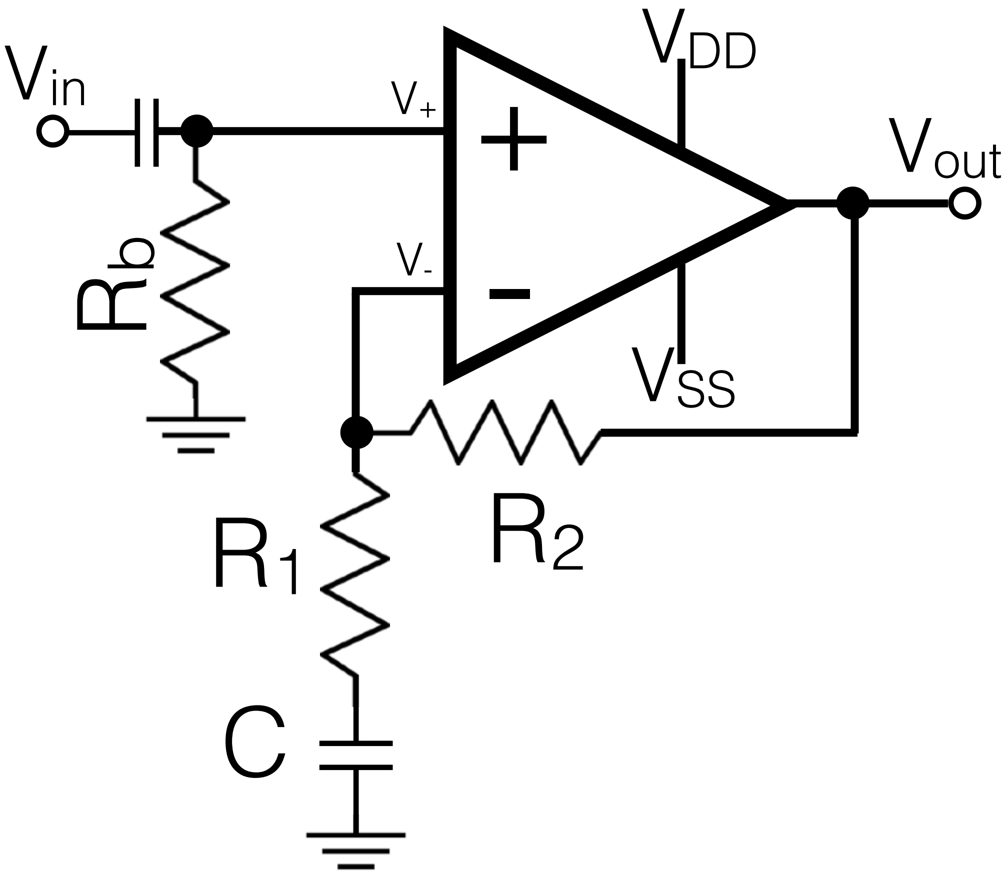
You will use an LM741 in an 8-pin DIP





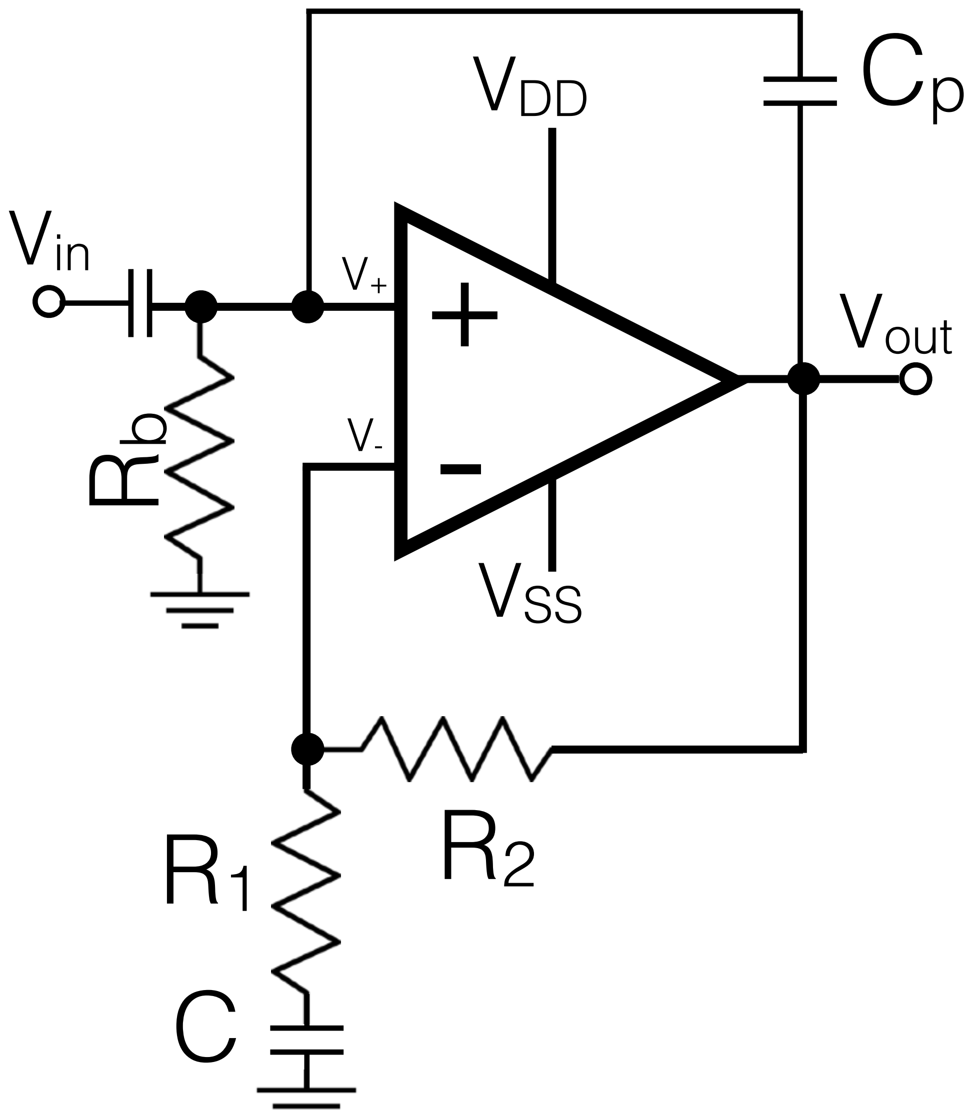
Input biasing

We need to bias the input because AC coupling gives no ground reference.



Power supply by-passing

What would we get if we added a capacitor to the positive feed-back loop?



This would feed the signal back to the input, with a small delay.

That would be amplified, and that would feedback further causing a growing oscillation.

Parasitic capacitance and inductance can cause oscillation even when there is not input.

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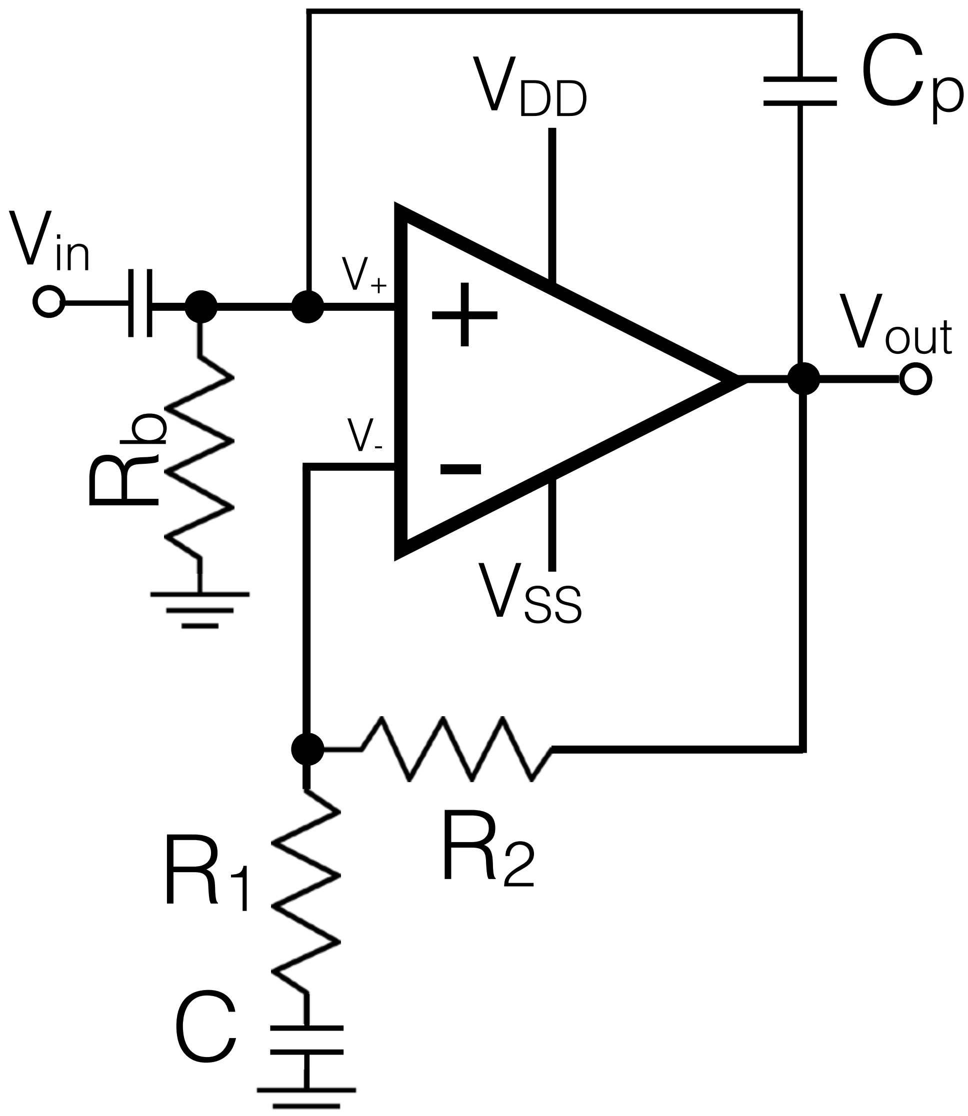

We can also get "ground bounce" or power supply sag from current surges when the output signal changes.

The power supplies can't provide that current fast enough through long (inductive) wires.

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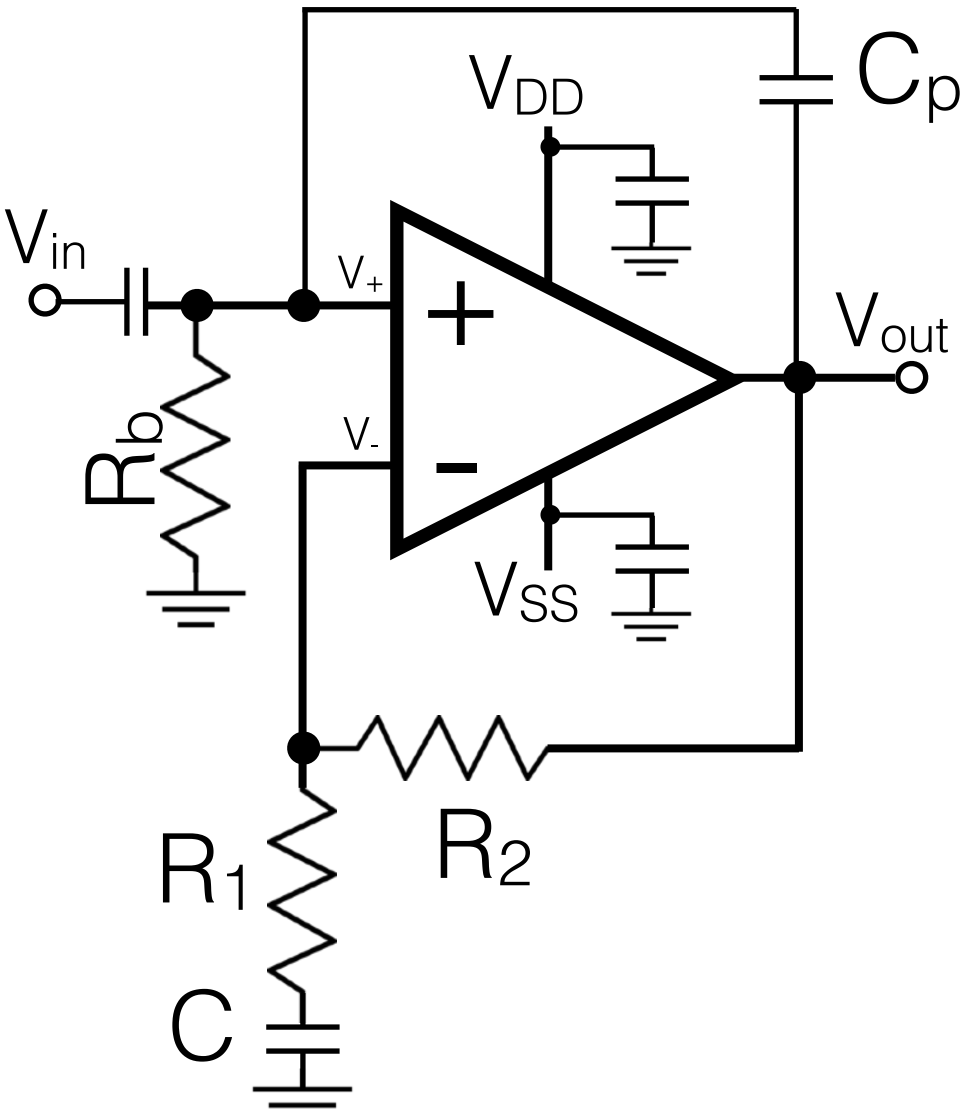

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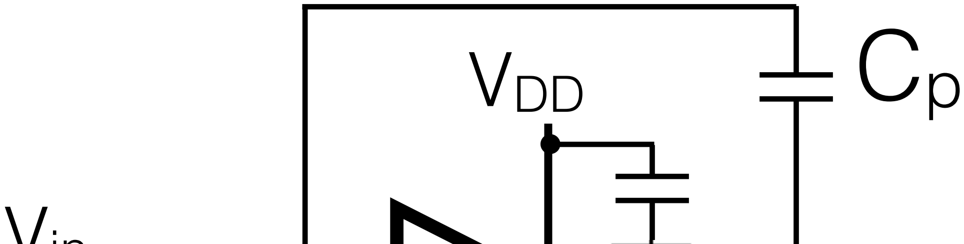

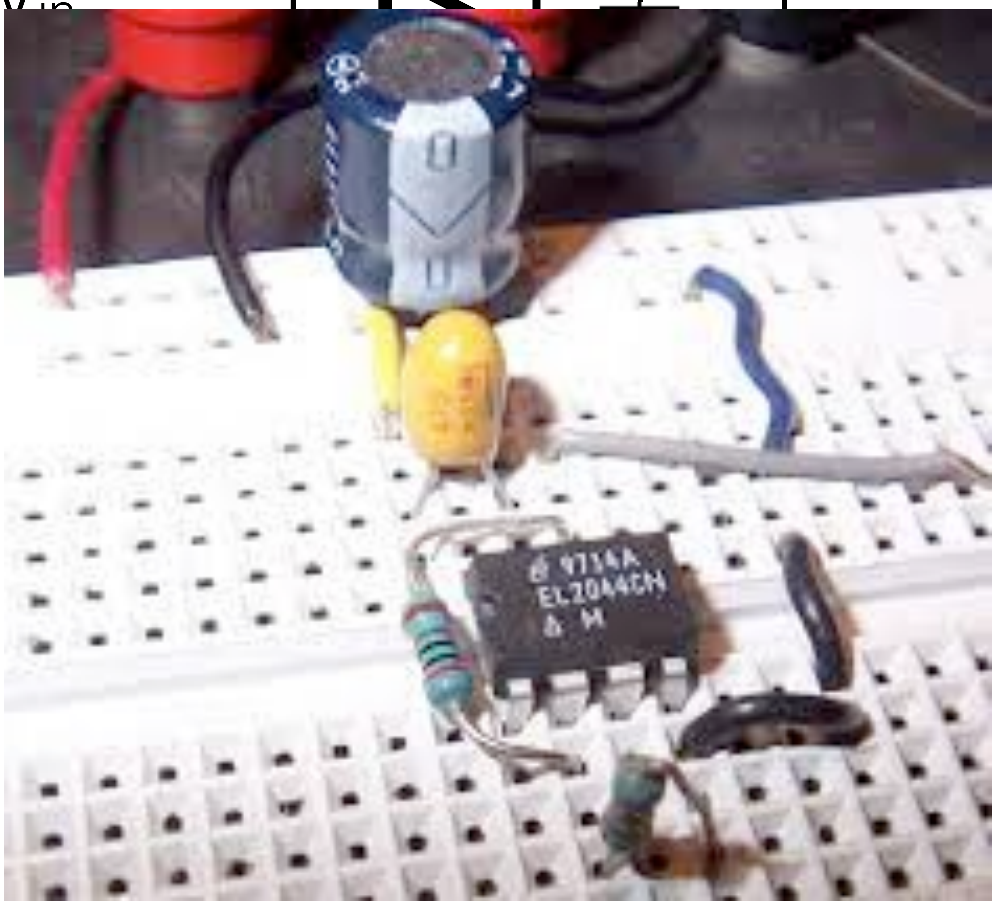

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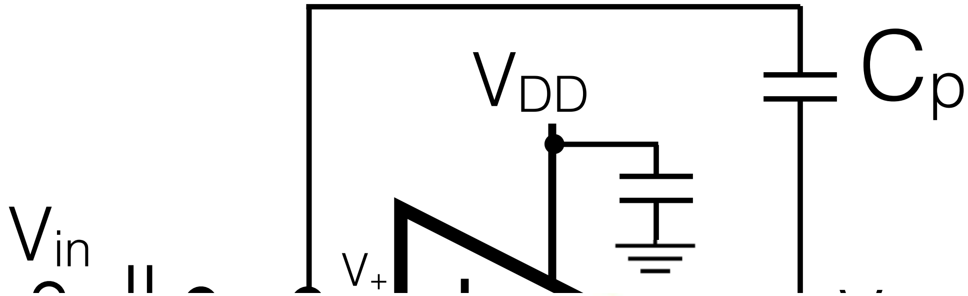

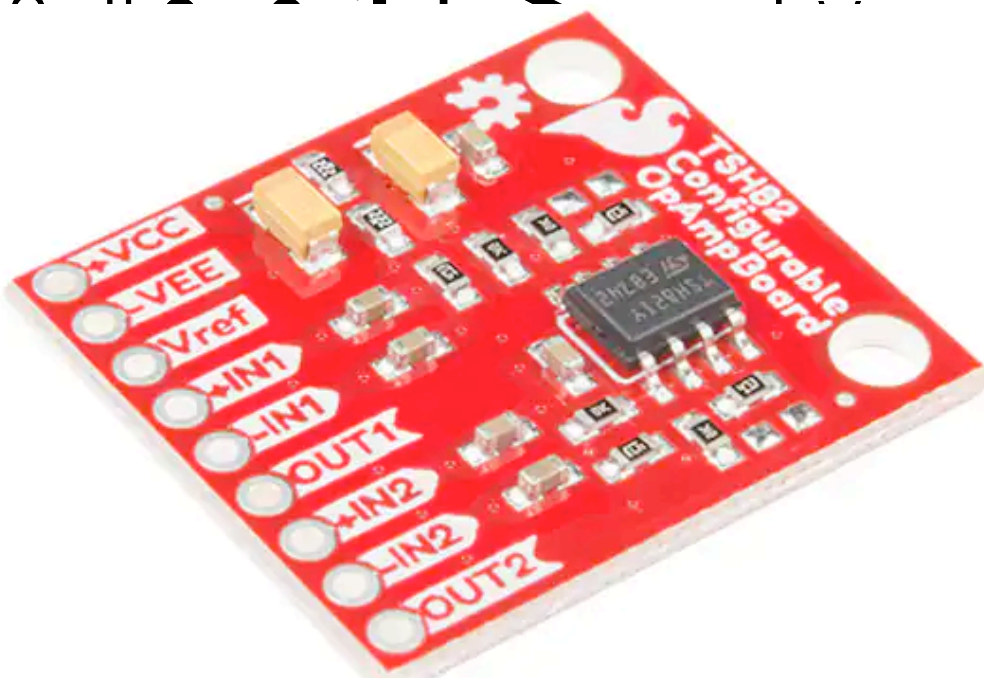

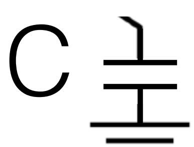

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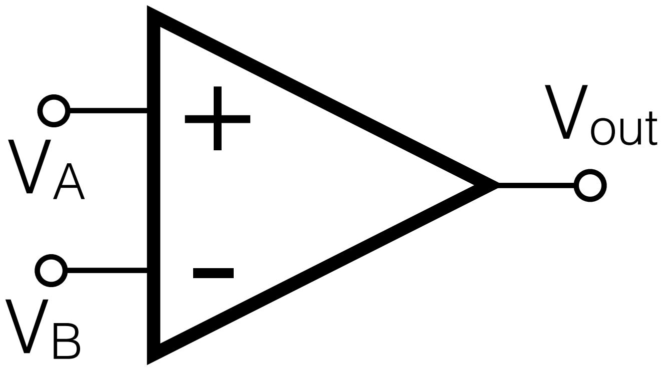
Comparator

If $V_A > V_B$ then $V_{out} = V_{CC}$, otherwise $V_{out} = V_{EE}$.
Can use this to "trigger" at a threshold, similar to your scope.



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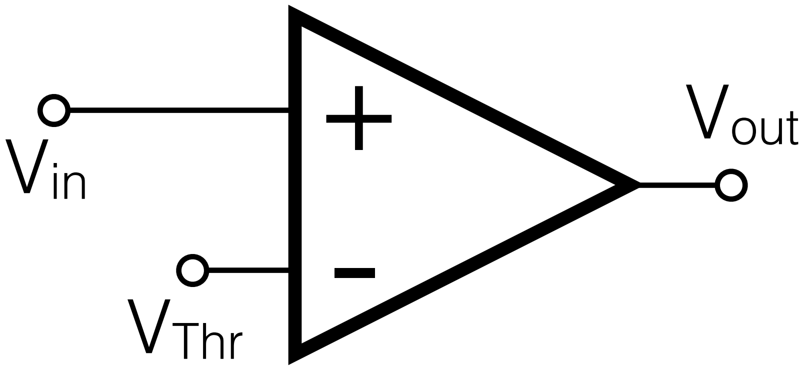

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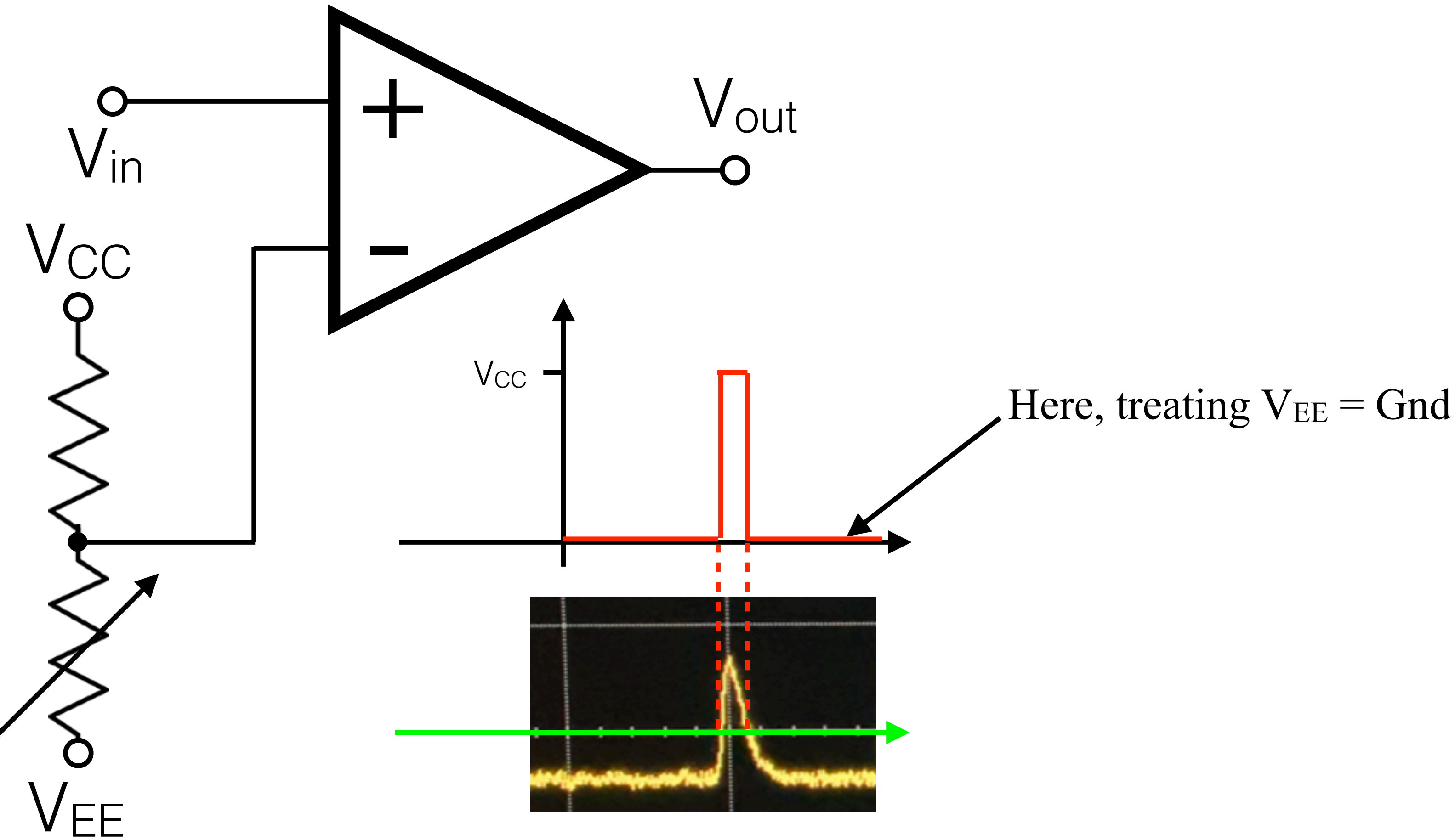

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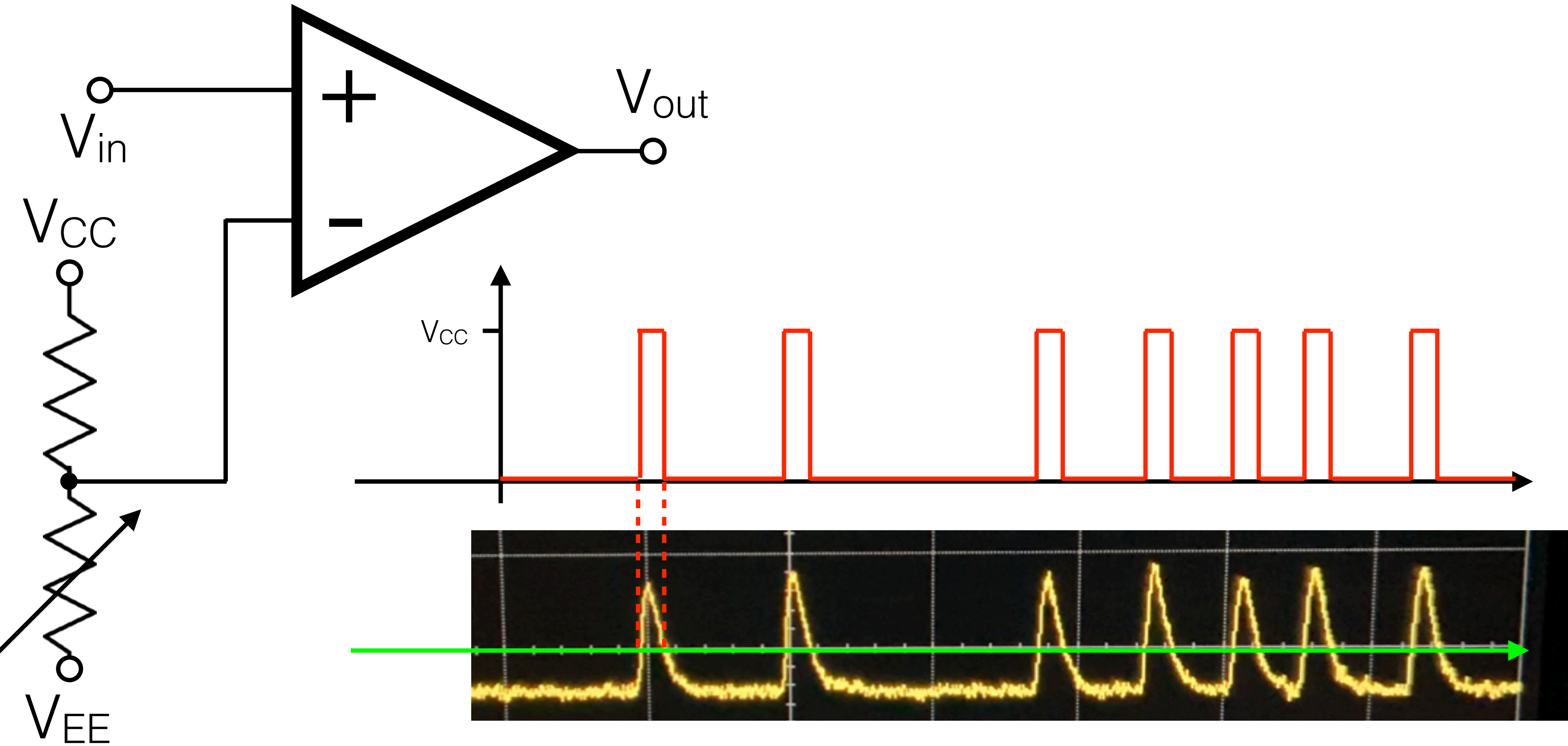
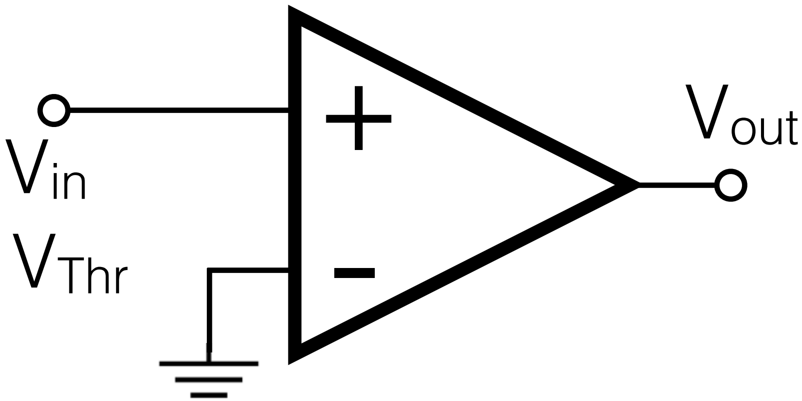
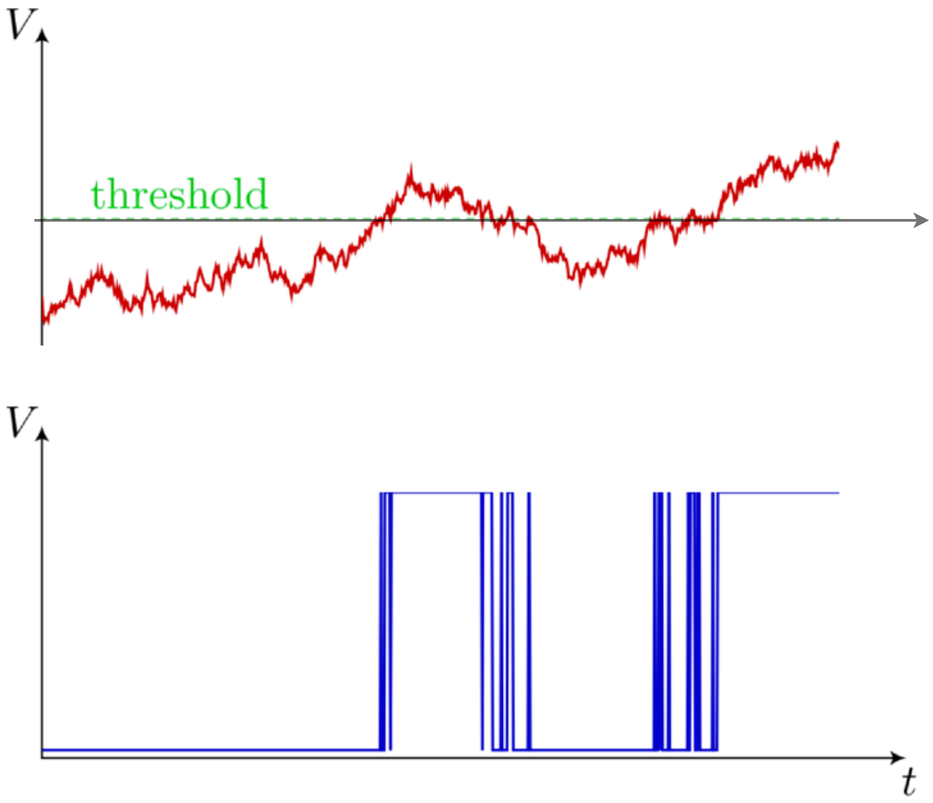


Comparator problem from noise

A fast comparator can fire on noise.





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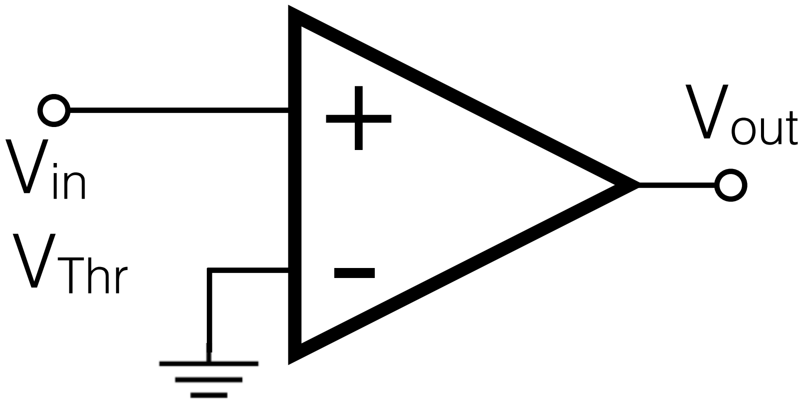
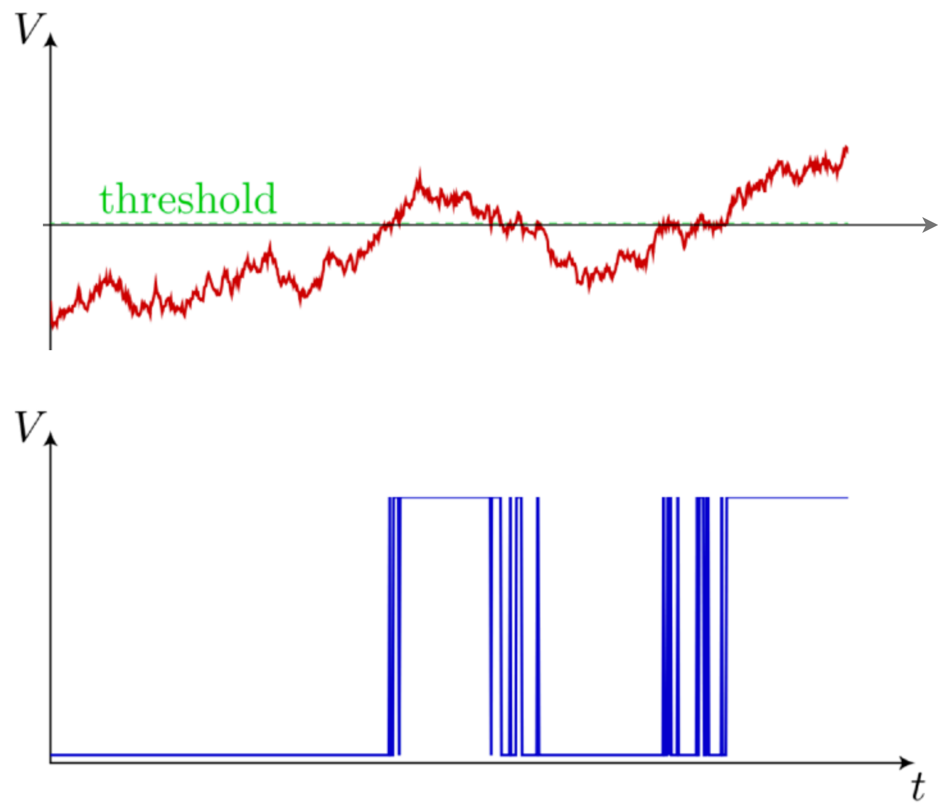
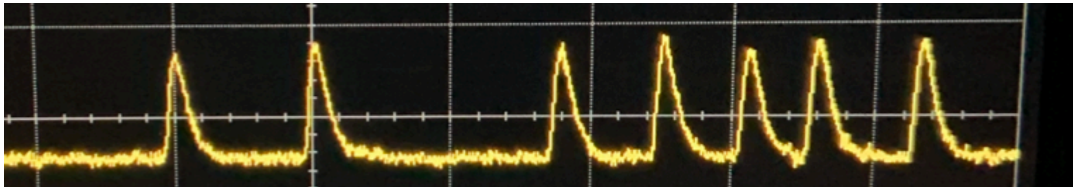




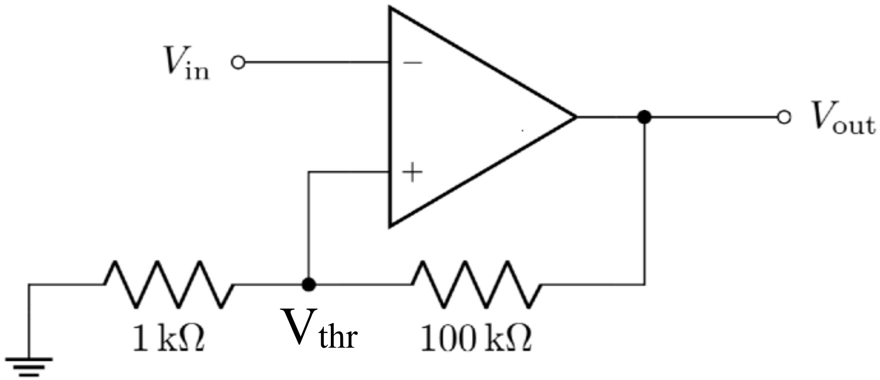
If we are counting pulses going over threshold, this will over count.

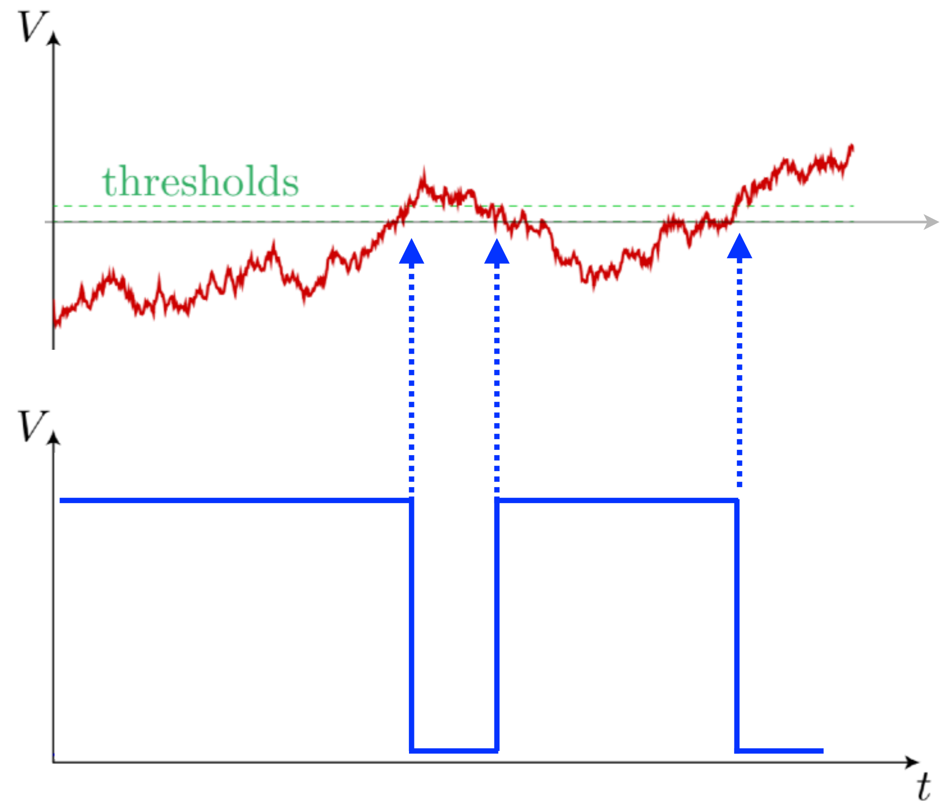


We can fix this…

Schmitt trigger to fix comparator noise problem

We can fix this by *changing the threshold* for rising and falling transitions





Note the <u>opposite polarity</u> of inputs!

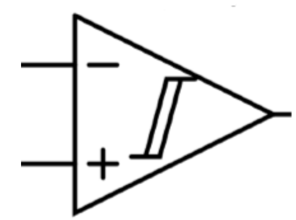
V_{out} is low when $V_{in} > V_{thr}$

V_{out} is high when $V_{in} < V_{thr}$

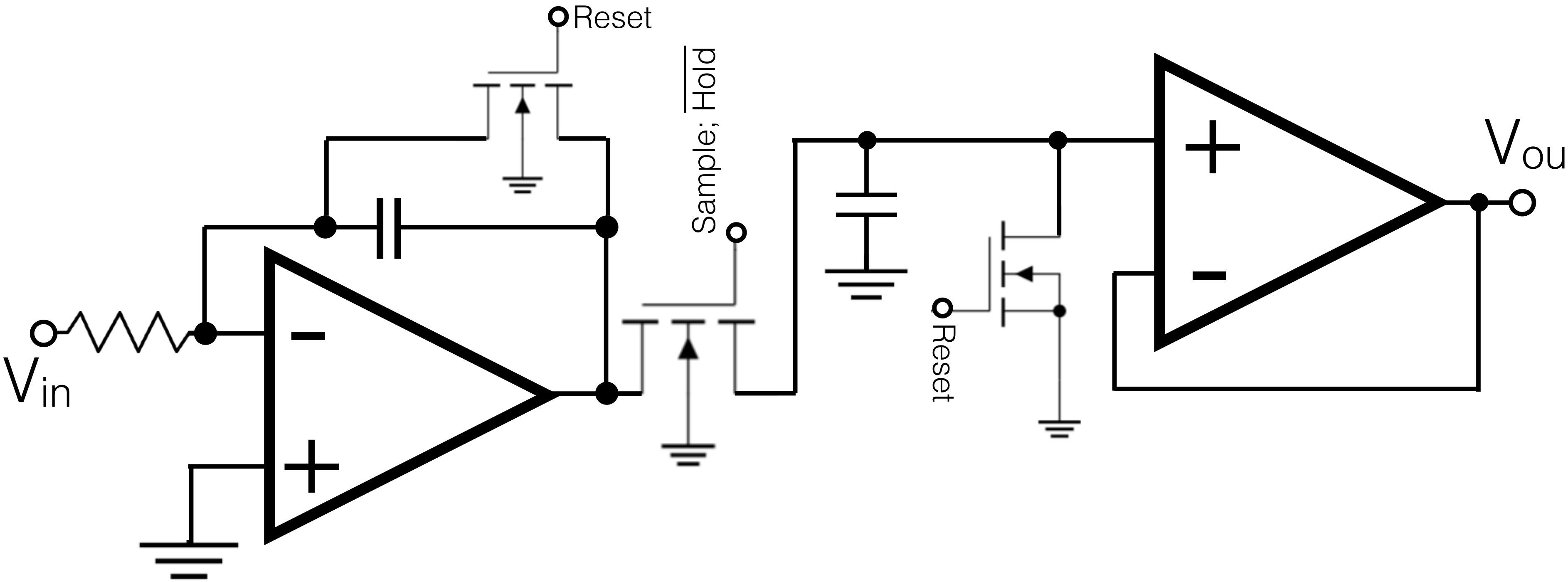
When V_{out} is low the threshold is 0 V.
When V_{out} is high, the threshold is higher;
here $V_{Thr} = 5 * 1k/(101k) = 50$ mV.

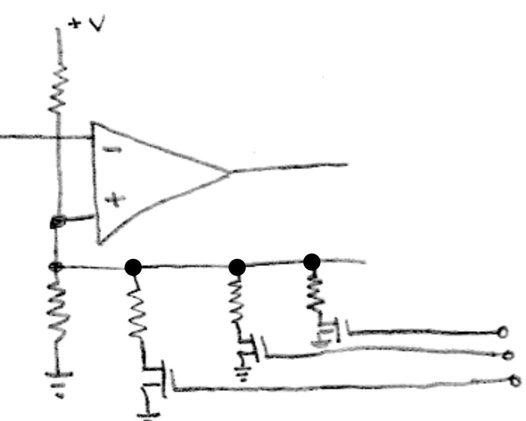
V_{out} stays high until V_{in} goes above 50 mV.
V_{out} stays low until V_{in} goes below 0 V.

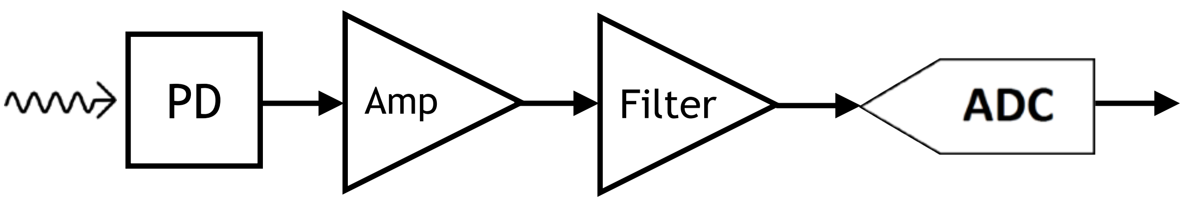
This adds hysteresis, hence the symbol for this "Schmitt trigger".



Integrate, sample, hold, and compare

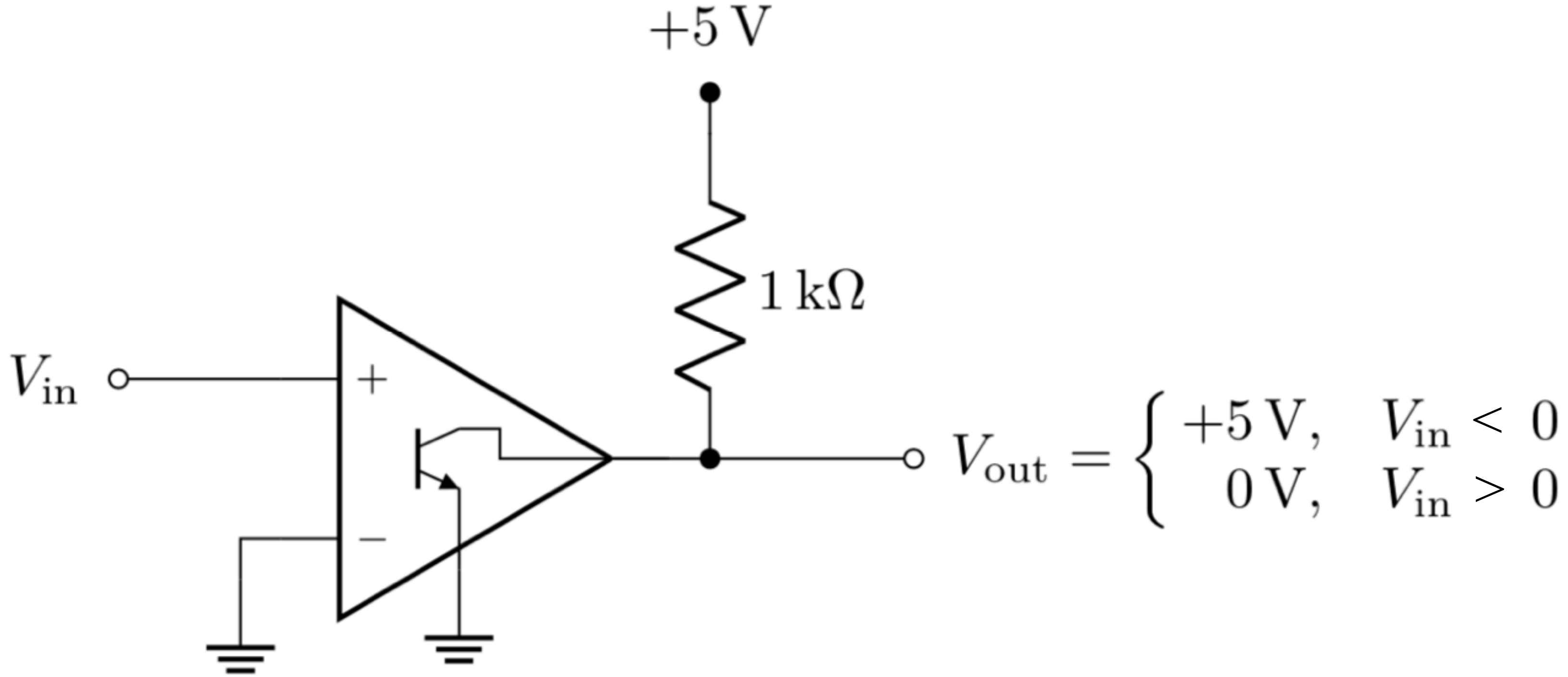






Comparator with "open-collector" output

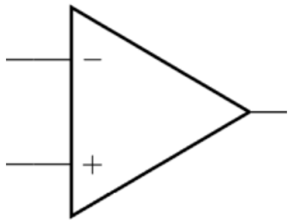
Often comparator chips differ from standard op-amps in that they have a special output stage with the output connected to a transistor's collector. This allows optimization for speed, and external control of logic levels.



This requires a pull-up resistor.
Note the opposite polarity of the comparator response.
Without a pull-up, it goes high impedance, aka tri-state.

Differential amplifier

The op-amp is a huge gain differential amplifier. We can get controlled differential amplification with negative feedback using…



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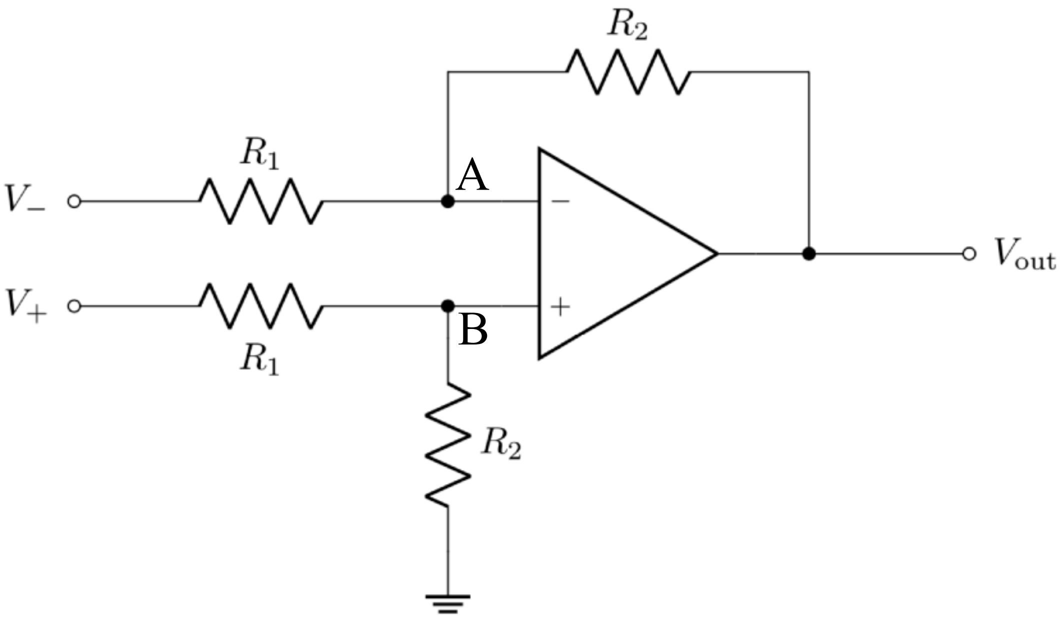

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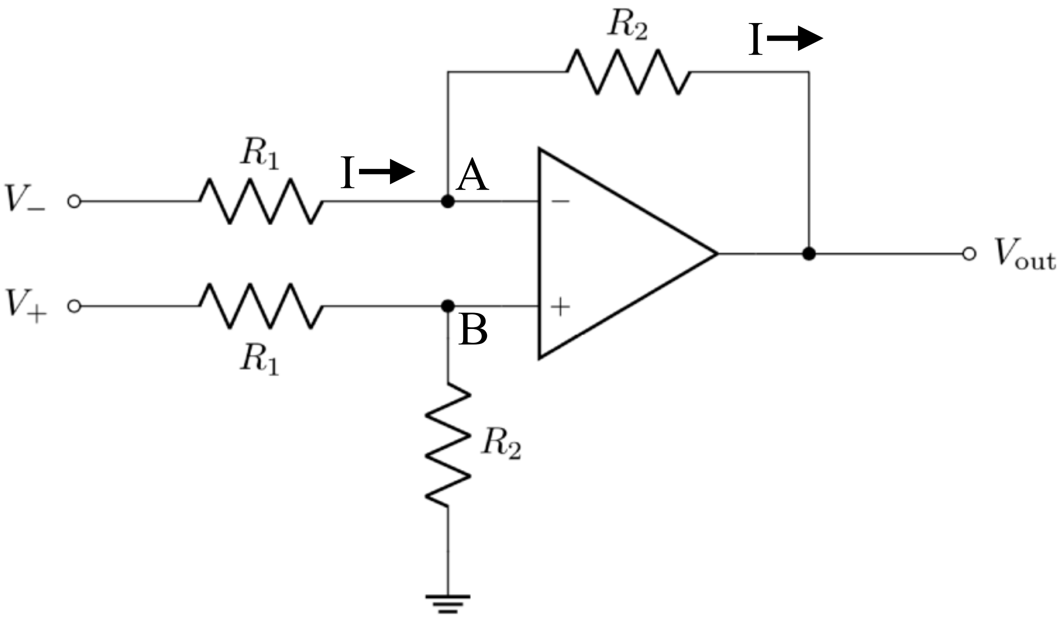

$V_B = V_+ R_2/(R_1+R_2) = V_A$

$I = (V_- - V_A)/R_1$

$V_{out} = V_A - I\,R_2$

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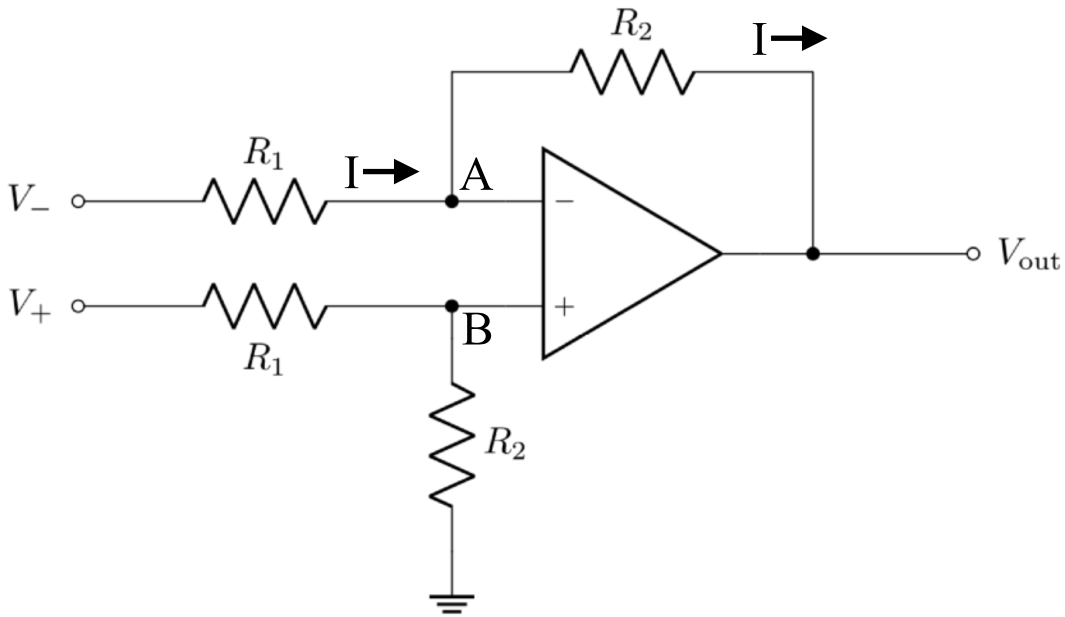

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$$
\begin{aligned}
V_{out} &= V_+ R_2/(R_1+R_2) - (V_- - V_A)R_2/R_1 \\
&= R_2 [V_+ /(R_1+R_2) - V_- /R_1 + V_+ R_2/R_1(R_1+R_2)] \\
&= R_2 [V_+(1+R_2/R_1)/(R_1+R_2) - V_- /R_1] \\
&= R_2 [V_+(R_1/R_1+R_2/R_1)/(R_1+R_2) - V_- /R_1] \\
&= R_2 [V_+/R_1 - V_- /R_1] \\
&= (V_+ - V_-)R_2/R_1
\end{aligned}
$$

Design of a smoke alarm

We have enough tools to start *designing* things.

Learning the electronics design process is part of our goal here.

As we design, we might need to learn some new tools.

So, let's go through the design of a smoke alarm.
In lab next week you will make a "burglar alarm".

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In lab next week you will make a "burglar alarm".

Start with an overview of the required stages:

Sense smoke → Process information → Generate alarm

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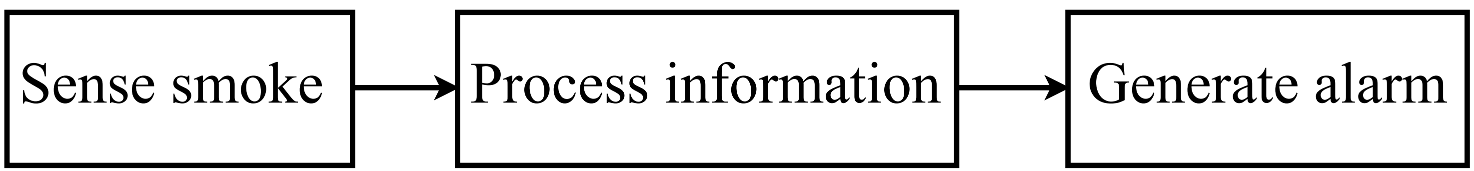

Sense

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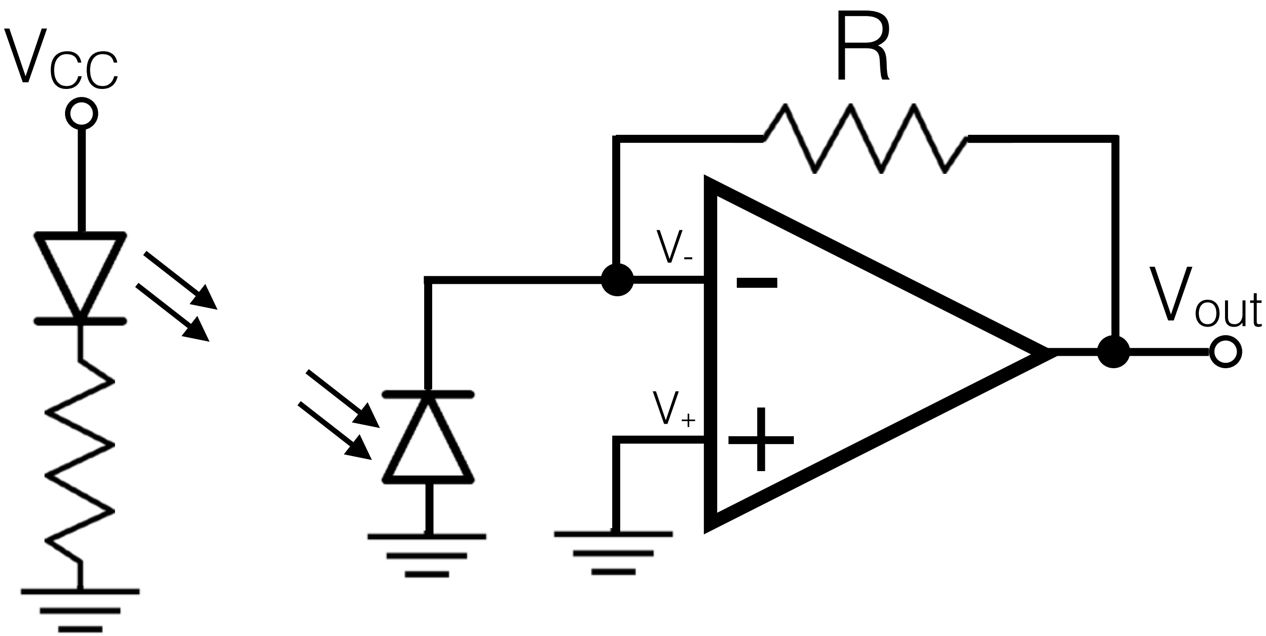

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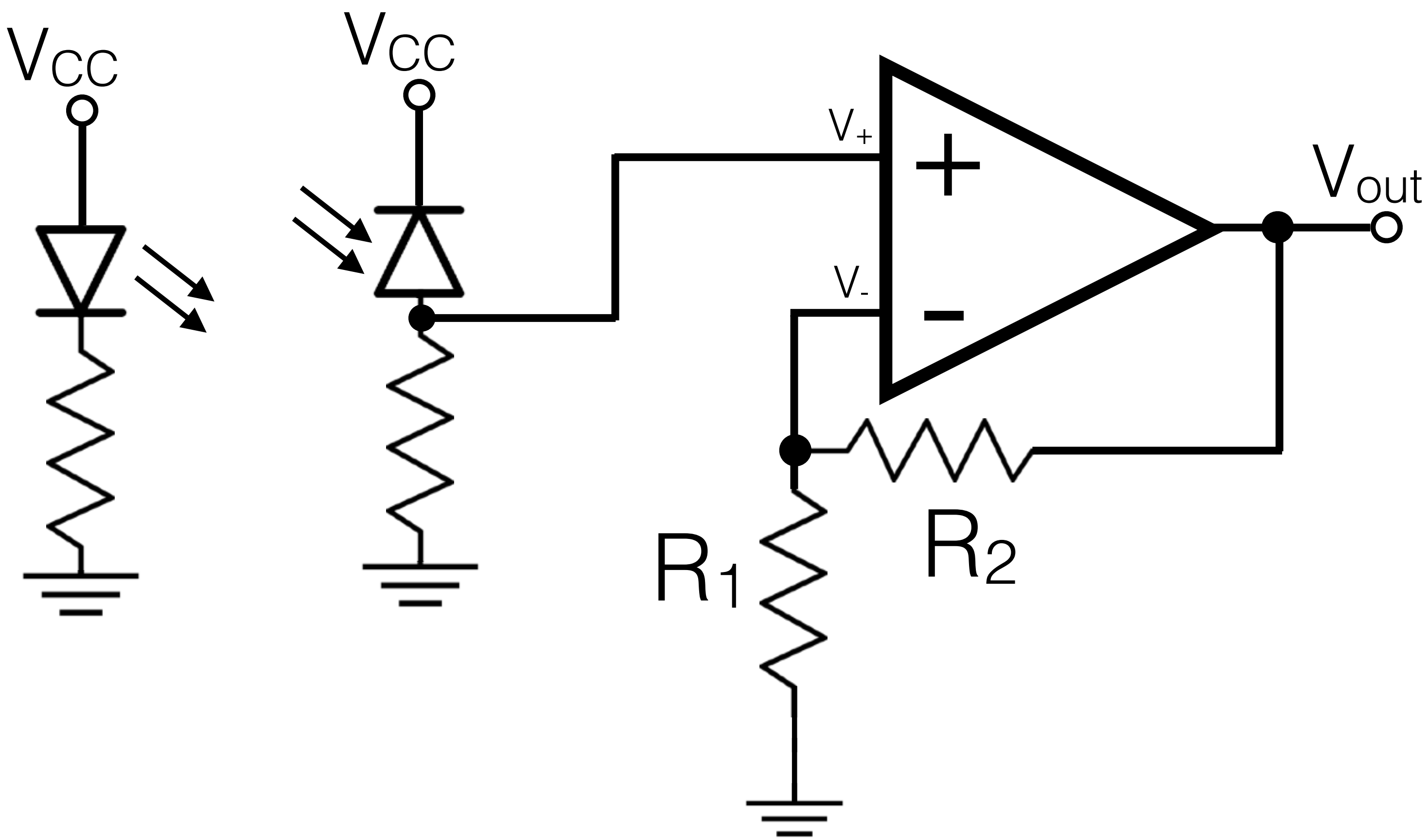

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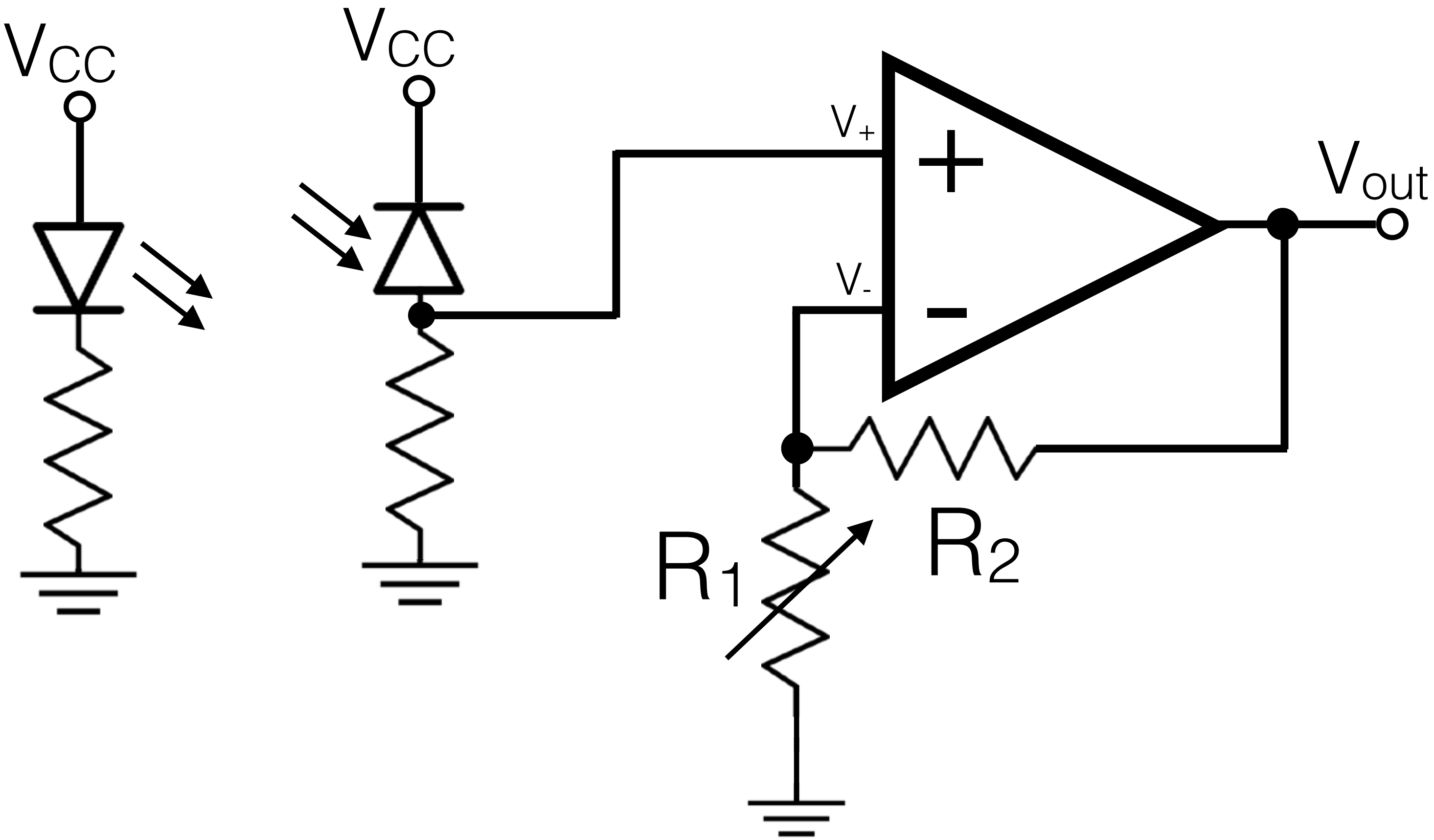
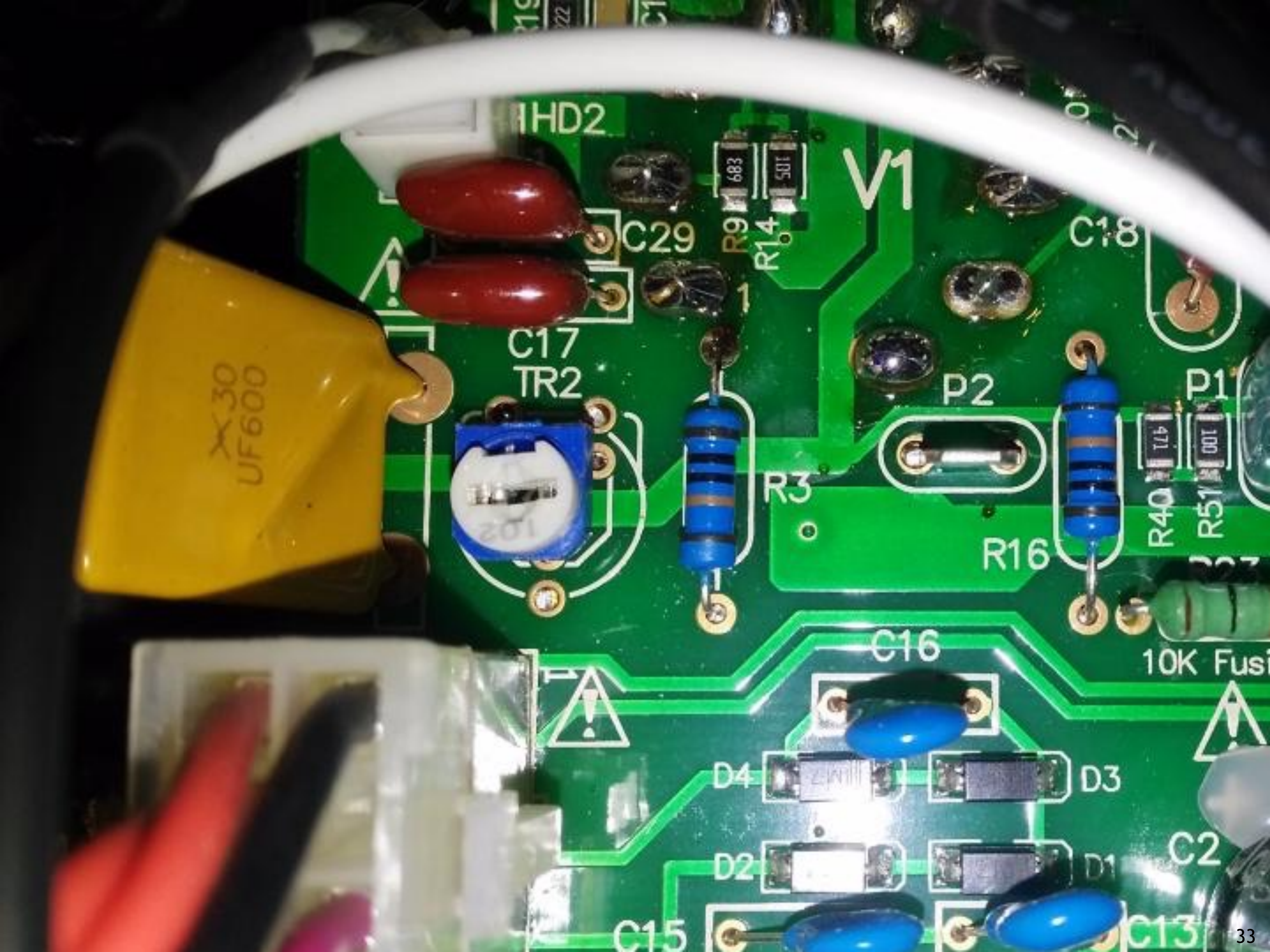
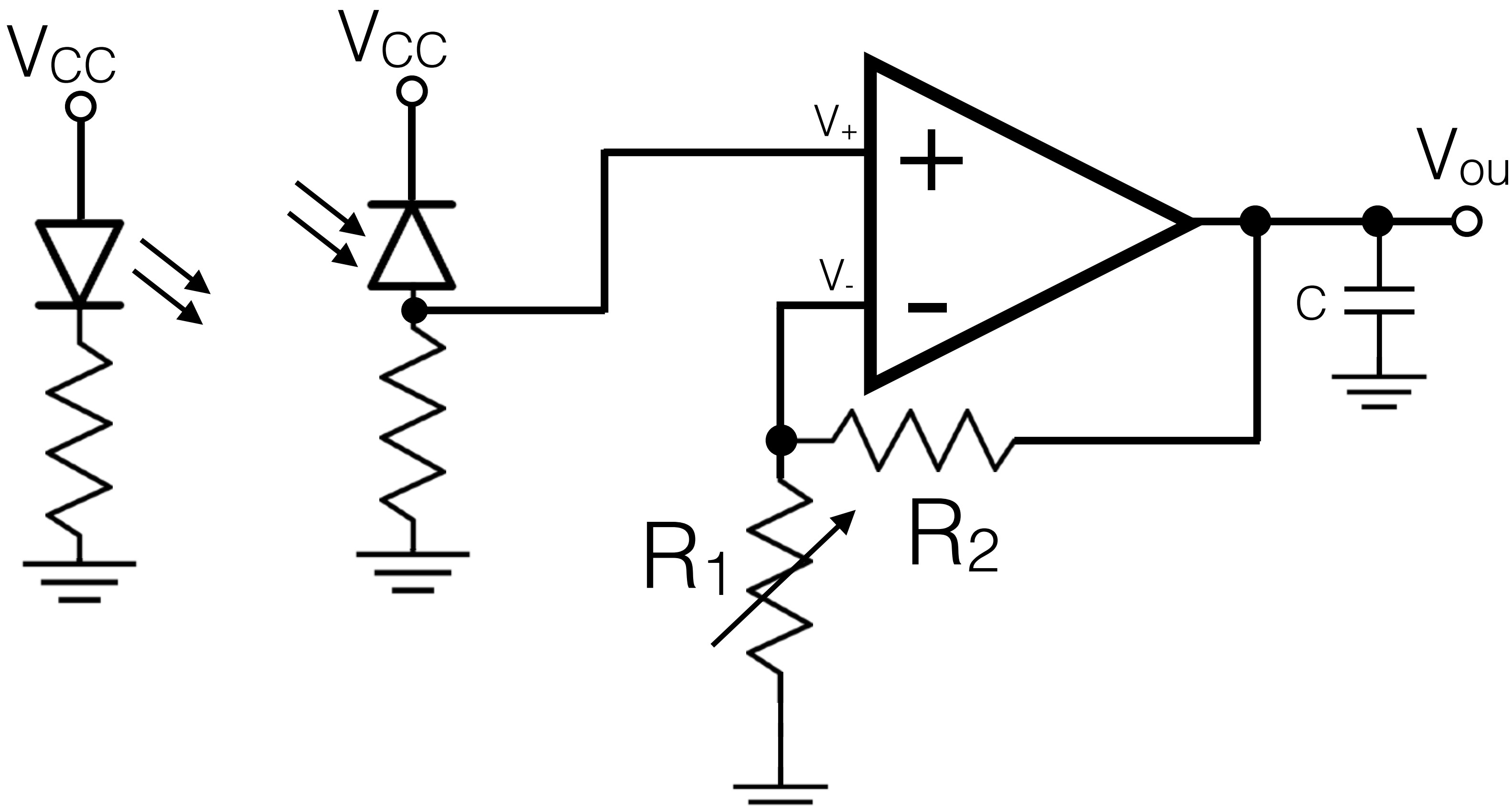


Adjust R_1 until V_{out} is in the desired range for smoke vs no-smoke


HD2
683
105
V1
C29
R9
R14
C18
C17
TR2
X30
UF600
201
P2
P1
471
100
R3
R16
R40
R51
C16
D4
D3
D2
D1
C2
C15
C13

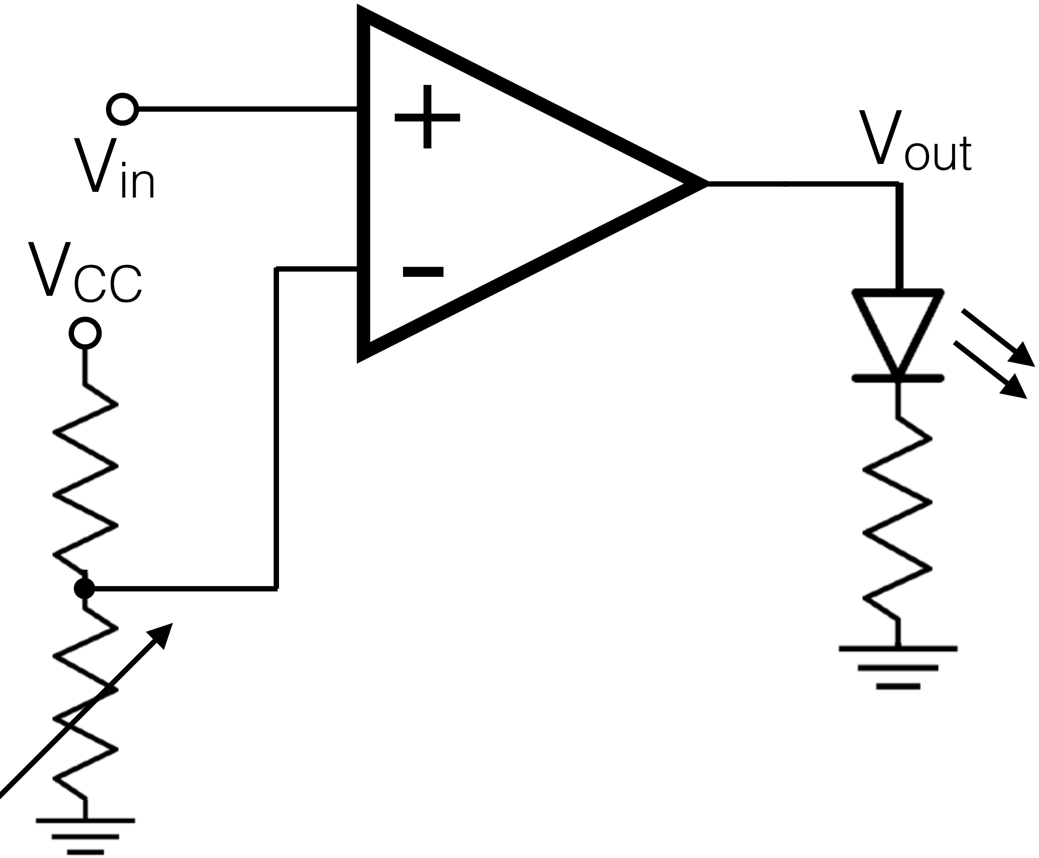
Process

We might want to add another amplifier, and a low pass filter, but this amp does most of what we need.



Alarm

We need to alarm if the voltage gets below some threshold



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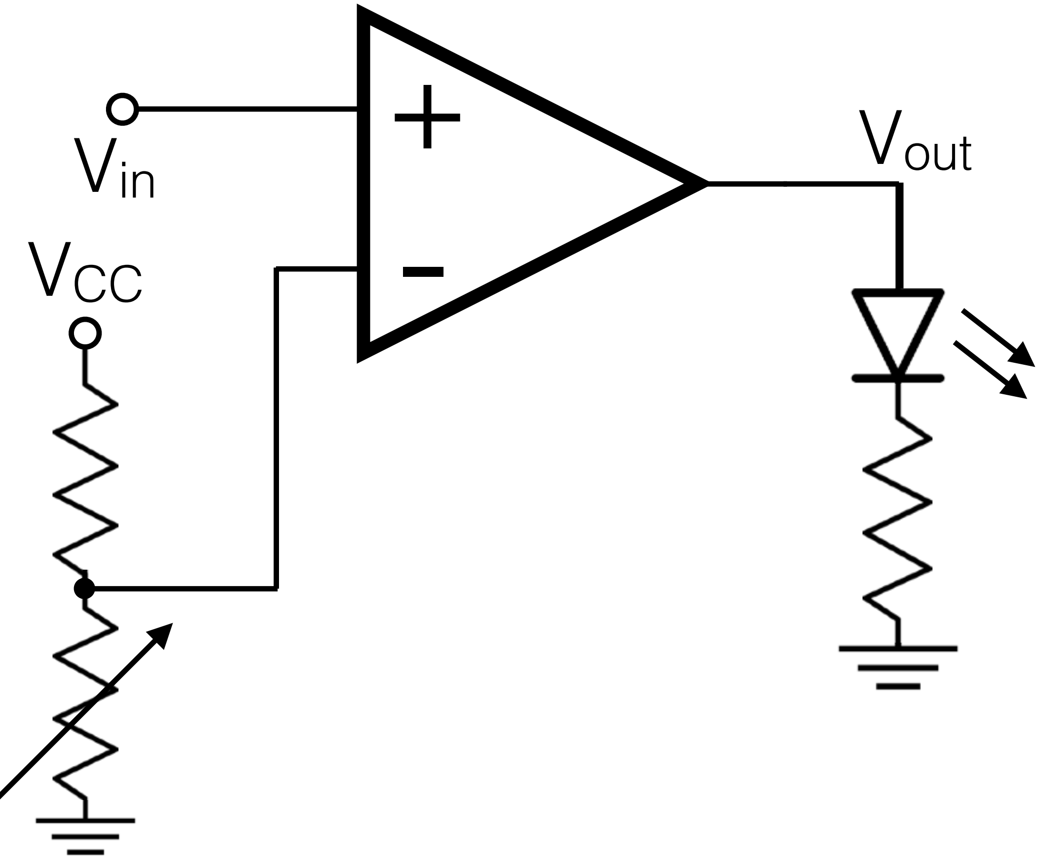

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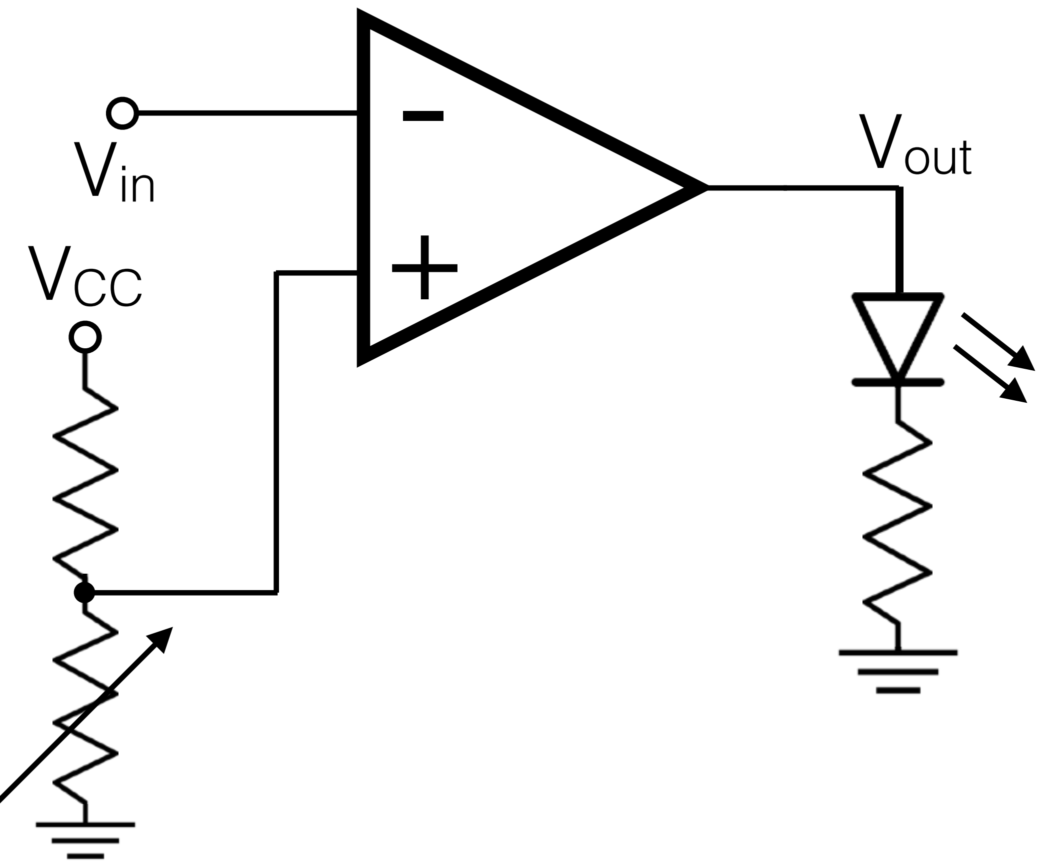

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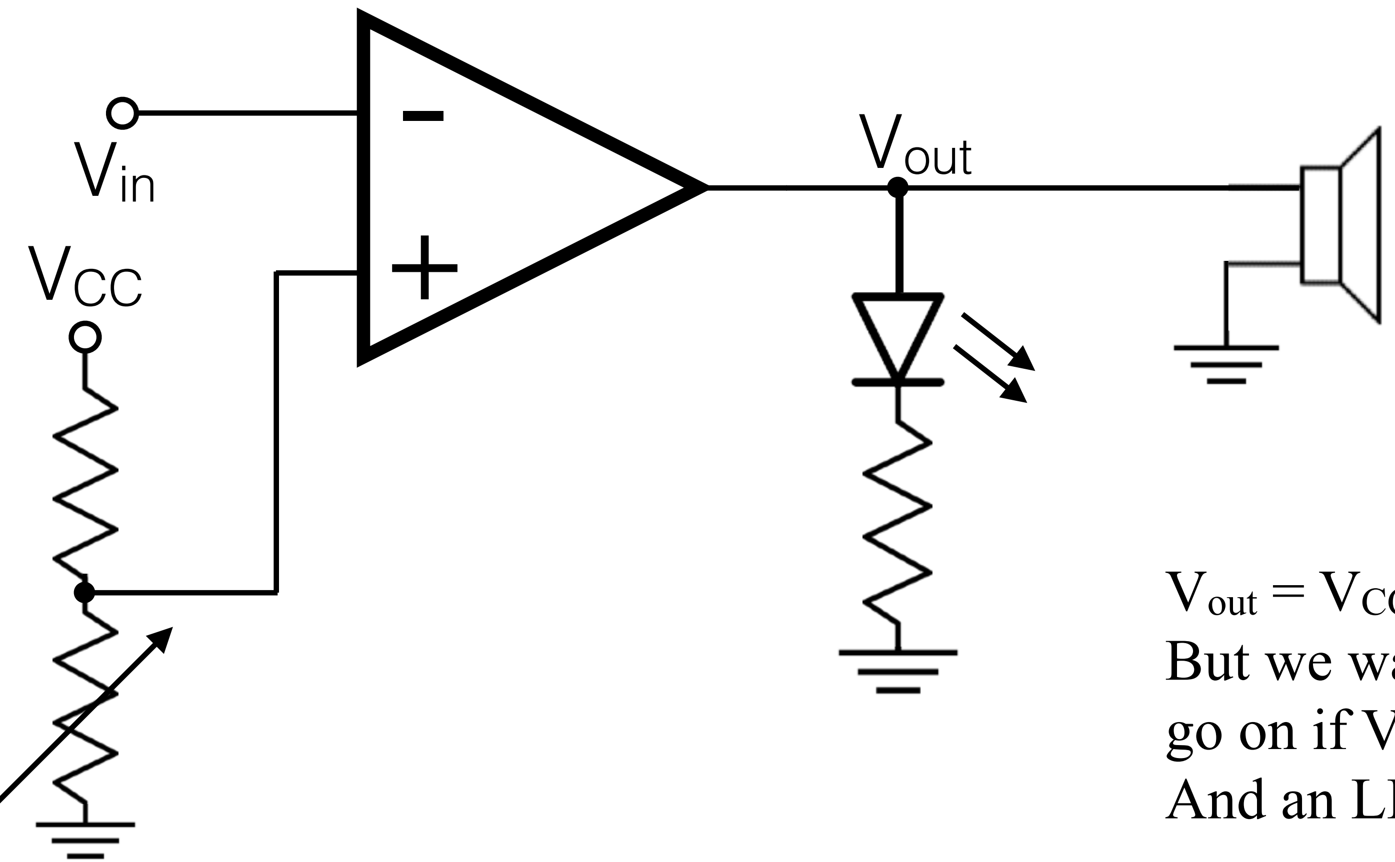

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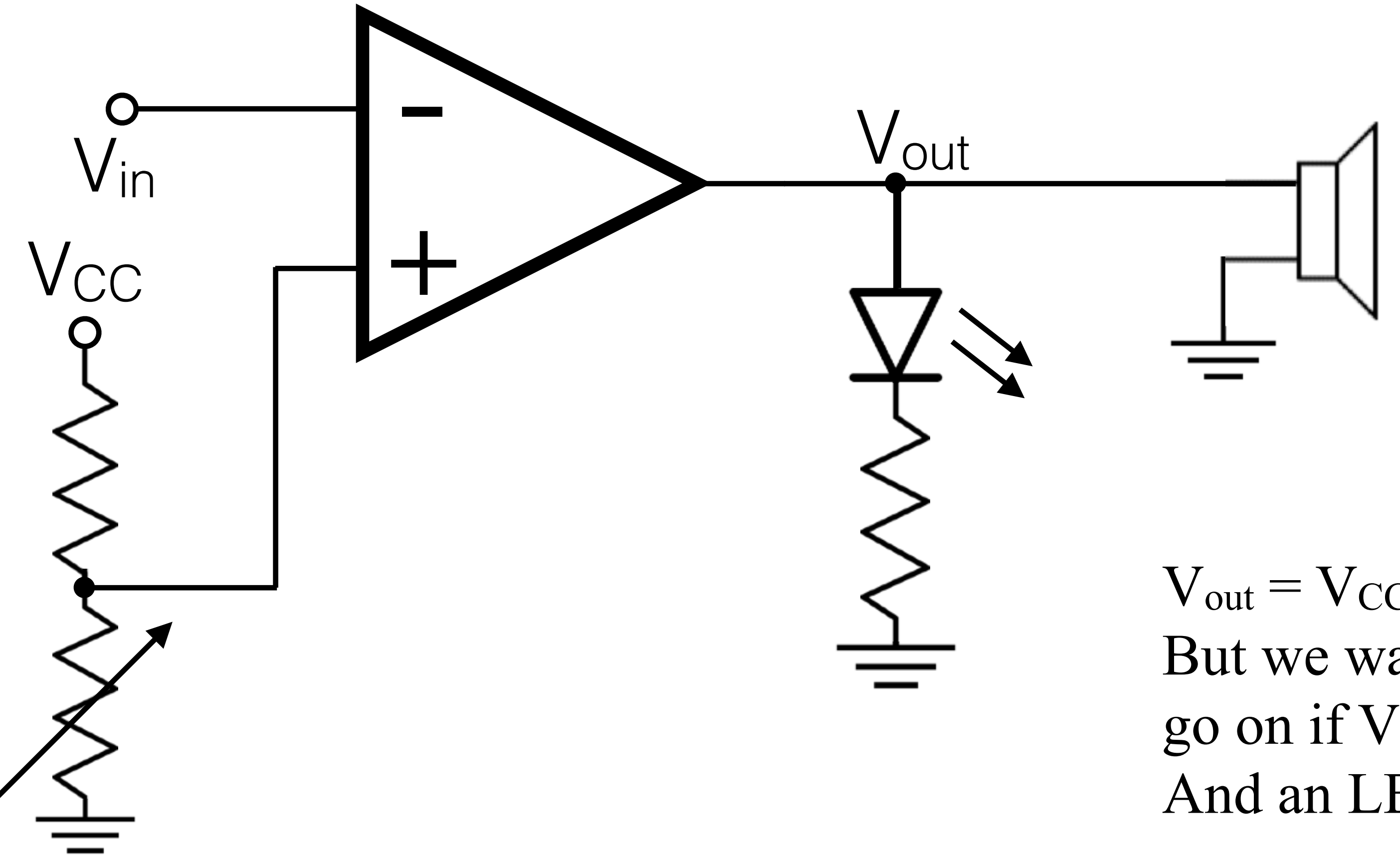

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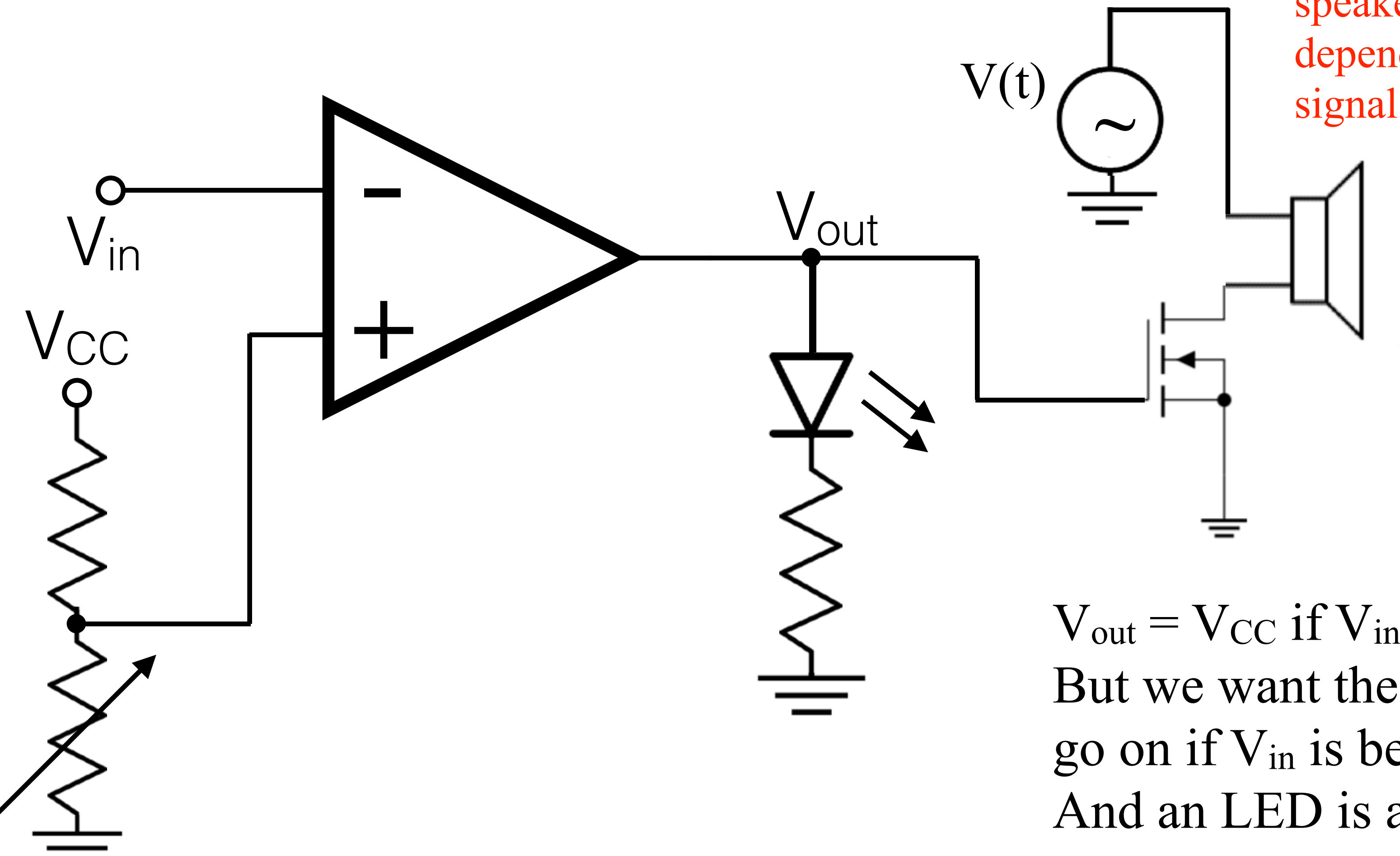
But we want the LED alarm to go on if V_{in} is below V_{Thr}.
And an LED is a wimpy alarm

But a DC level on a speaker isn't going to cause a sound!

Alarm

We need to alarm if the voltage gets below some threshold

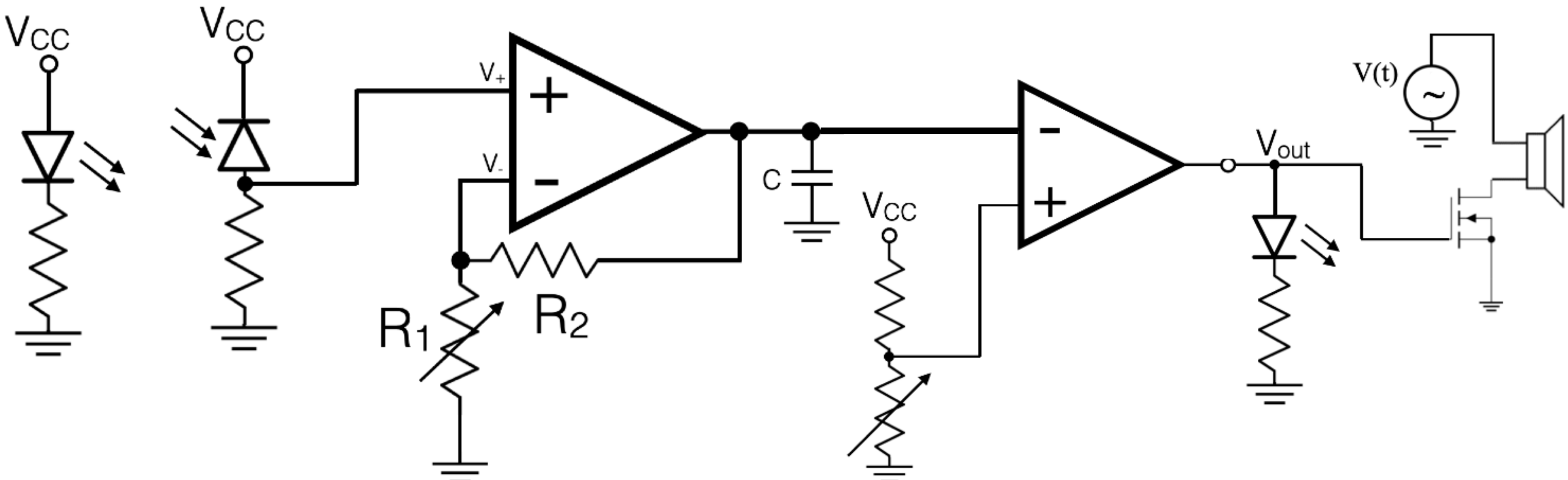
We need to drive the speaker with a time dependent, oscillating signal.



$V_{out} = V_{CC}$ if V_{in} above V_{Thr}.
But we want the LED alarm to go on if V_{in} is below V_{Thr}.
And an LED is a wimpy alarm

But a DC level on a speaker isn't going to cause a sound!

Smoke alarm

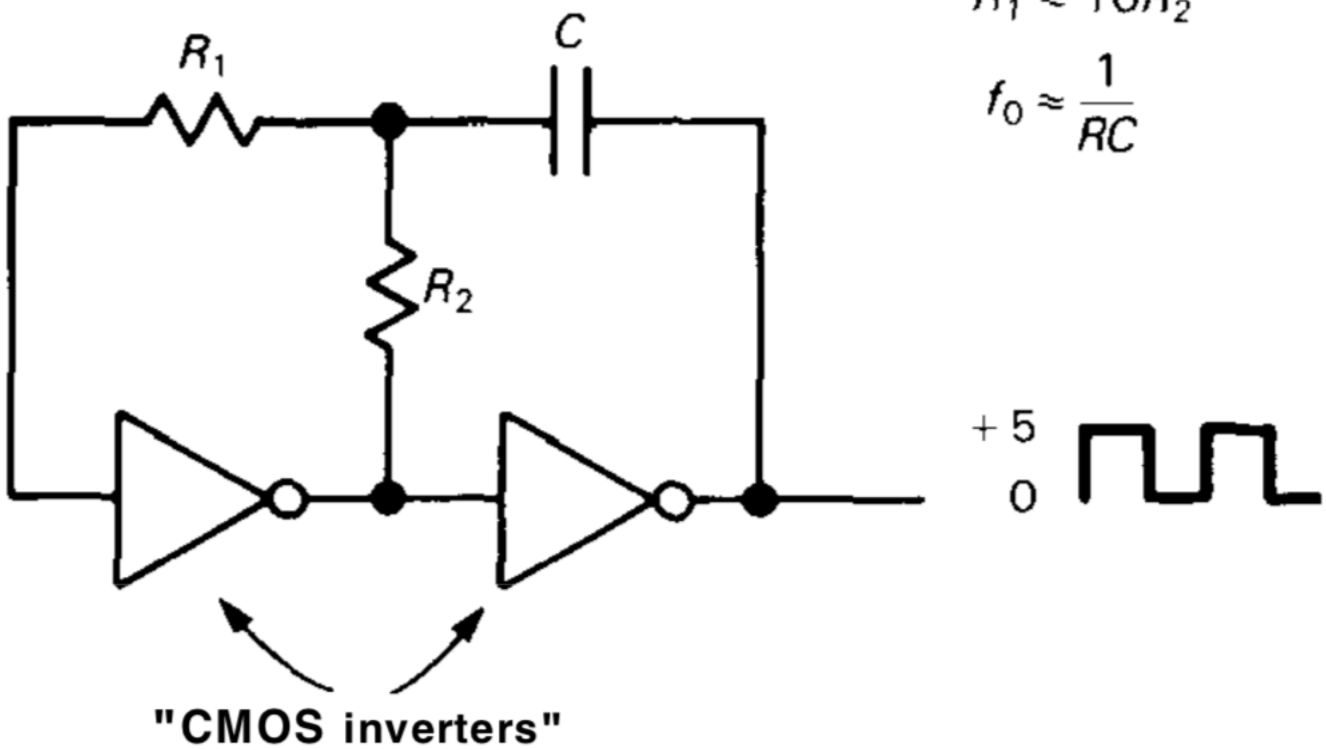


Safety checks:

- Battery warning
- Test feature

Oscillator

We can make an oscillator with any positive feedback

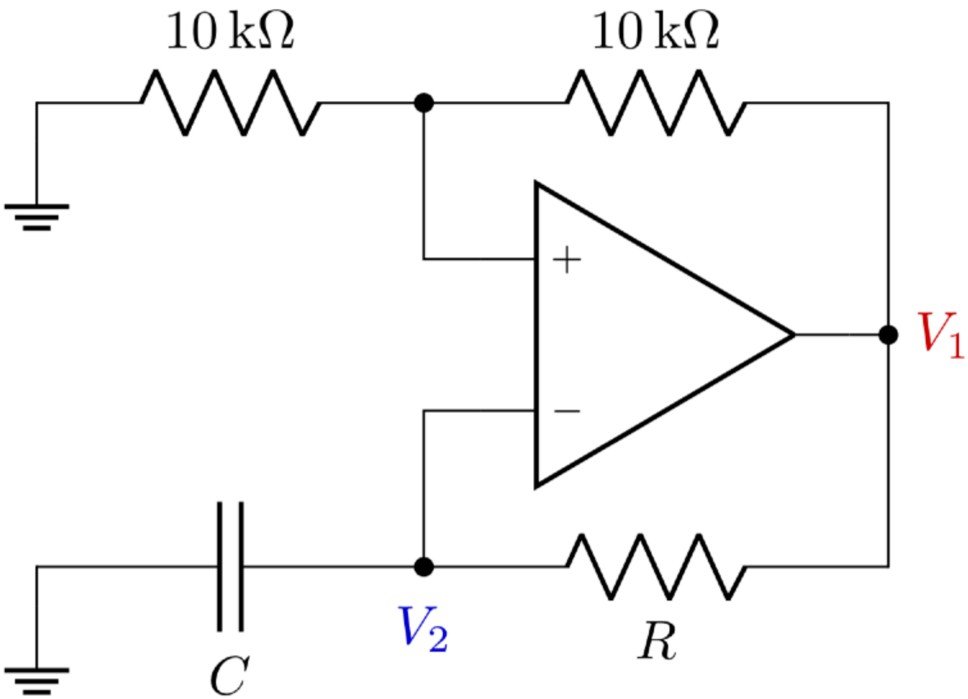


$R_1 \approx 10R_2$

$f_0 \approx \frac{1}{RC}$

Oscillator

We can make an oscillator with an op-amp



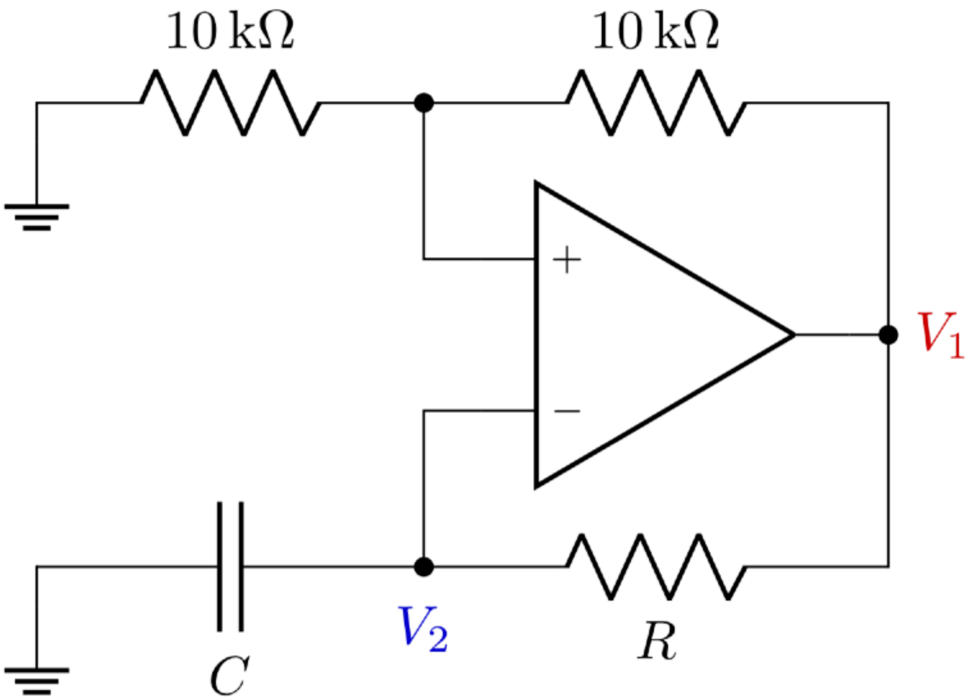
The $I_+ = I_- = 0$ golden rule means we can calculate V_+ and V_- in terms of V_1.

$V_+ = V_1/2$

$V_2 = V_- = V_1 - I\,R$

Oscillator

We can make an oscillator with an op-amp



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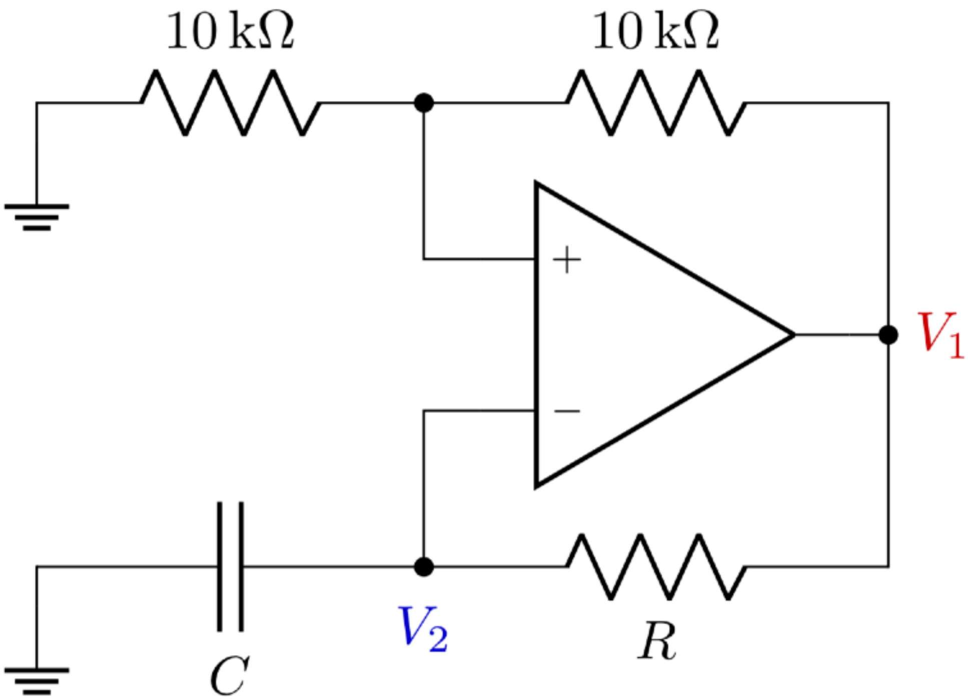
$V_2 = V_- = V_1 - I R$
where $I = C\, dV_2/dt$

Oscillator

We can make an oscillator with an op-amp



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What is V_1?

Oscillator

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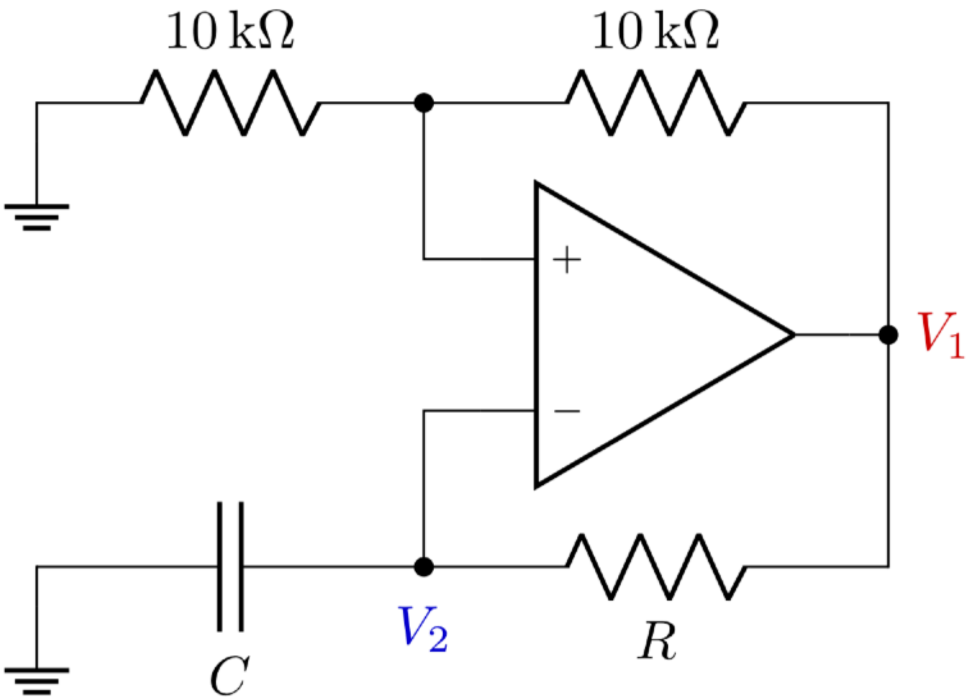

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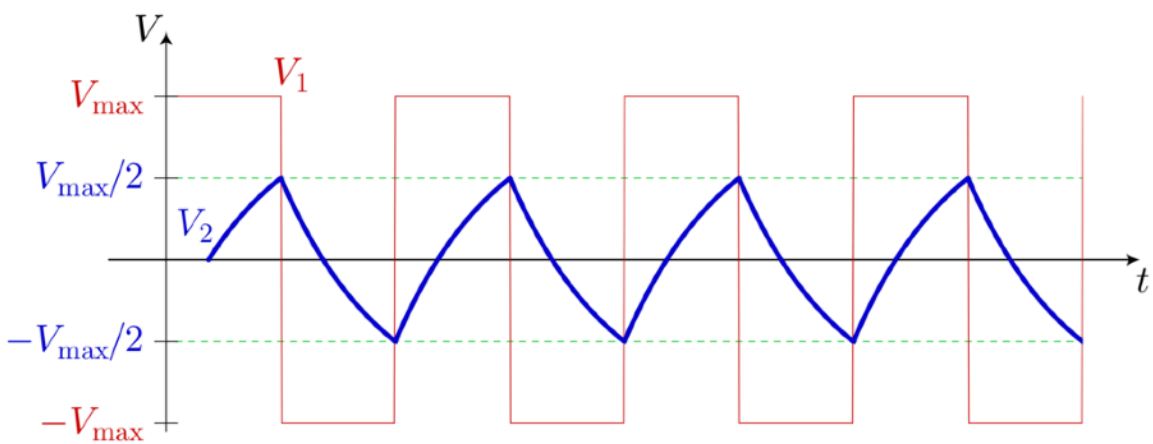
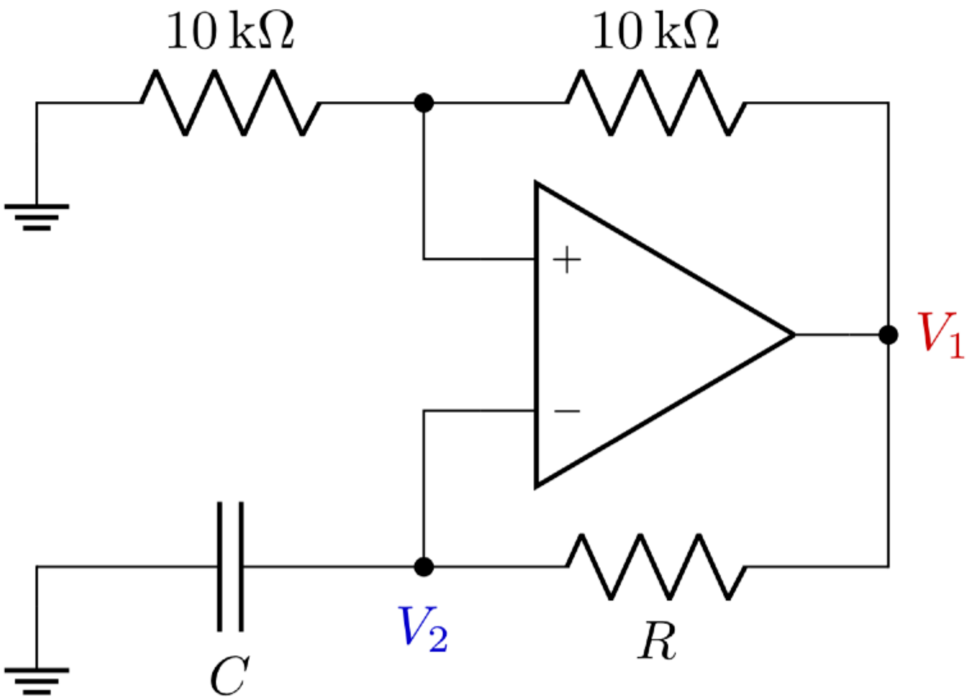


Oscillator

We can make an oscillator with an op-amp



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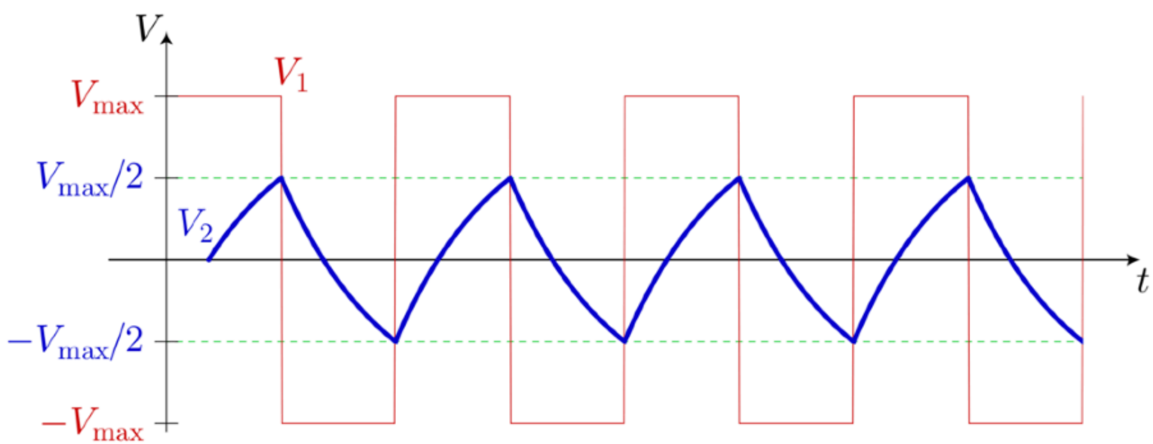
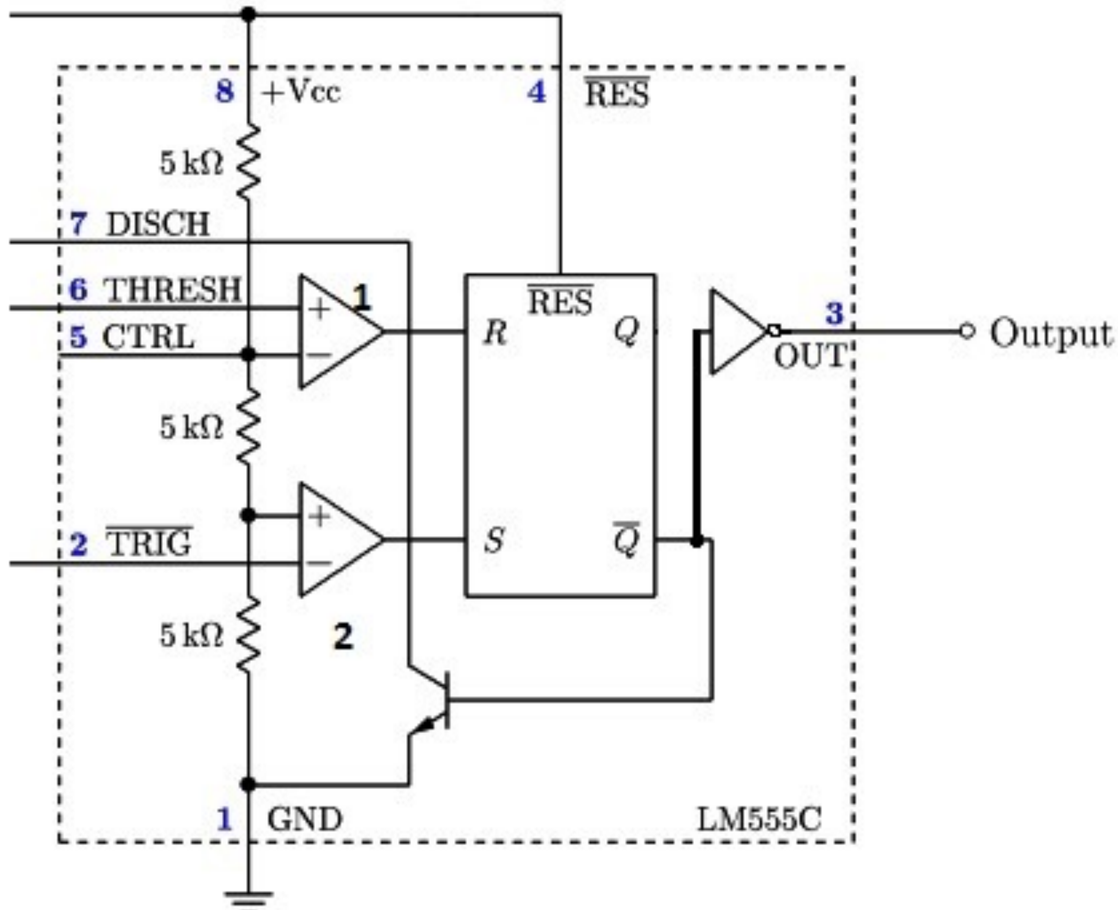
$V_2 = V_- = V_1 - I R$
where $I = C\, dV_2/dt$
What is V_1?

$$T \approx 2.2RC$$



555 timer

Oscillators and other timing applications are common, so there is a timer chip



555 timer

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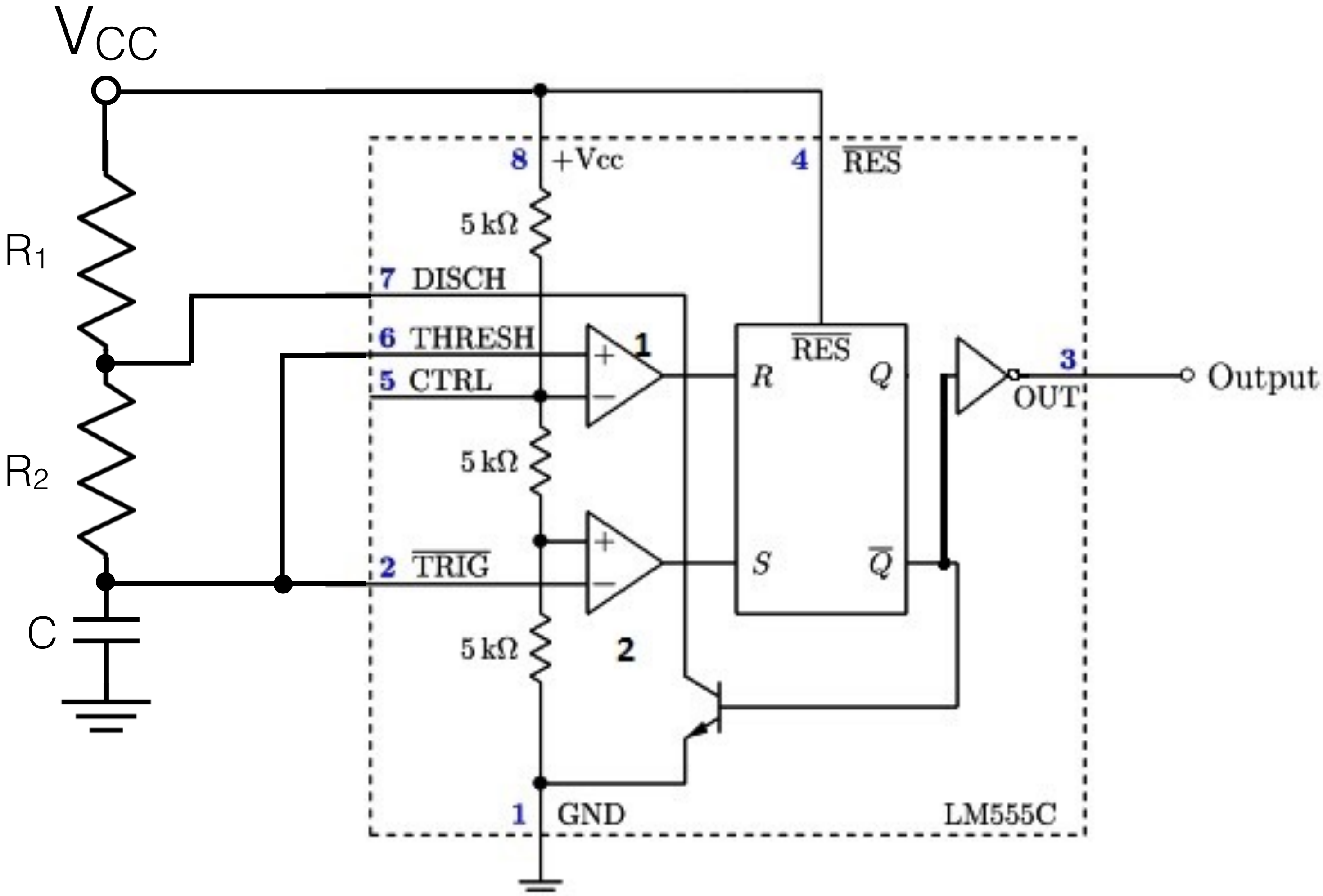

555 timer

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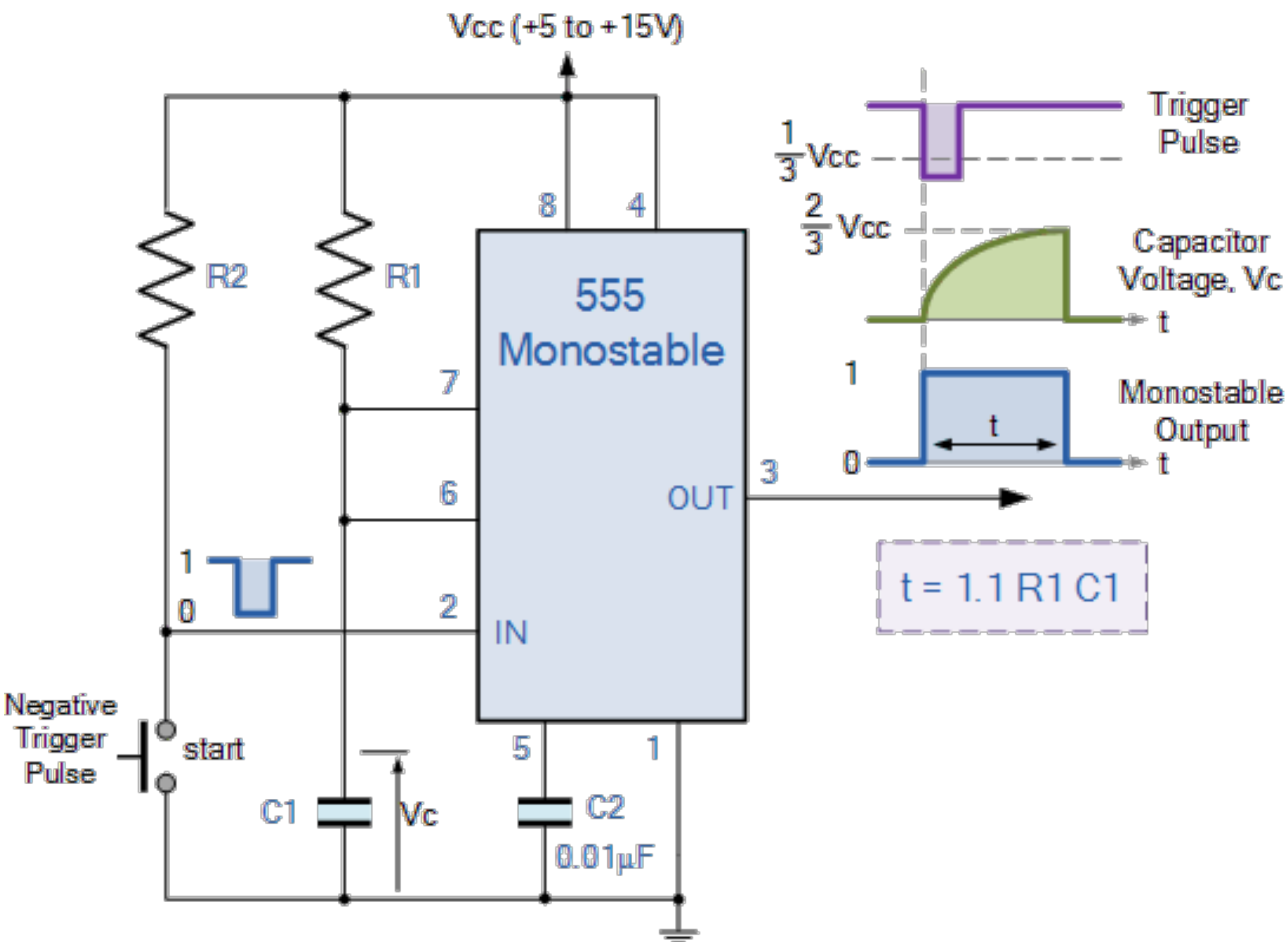

555 timer

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