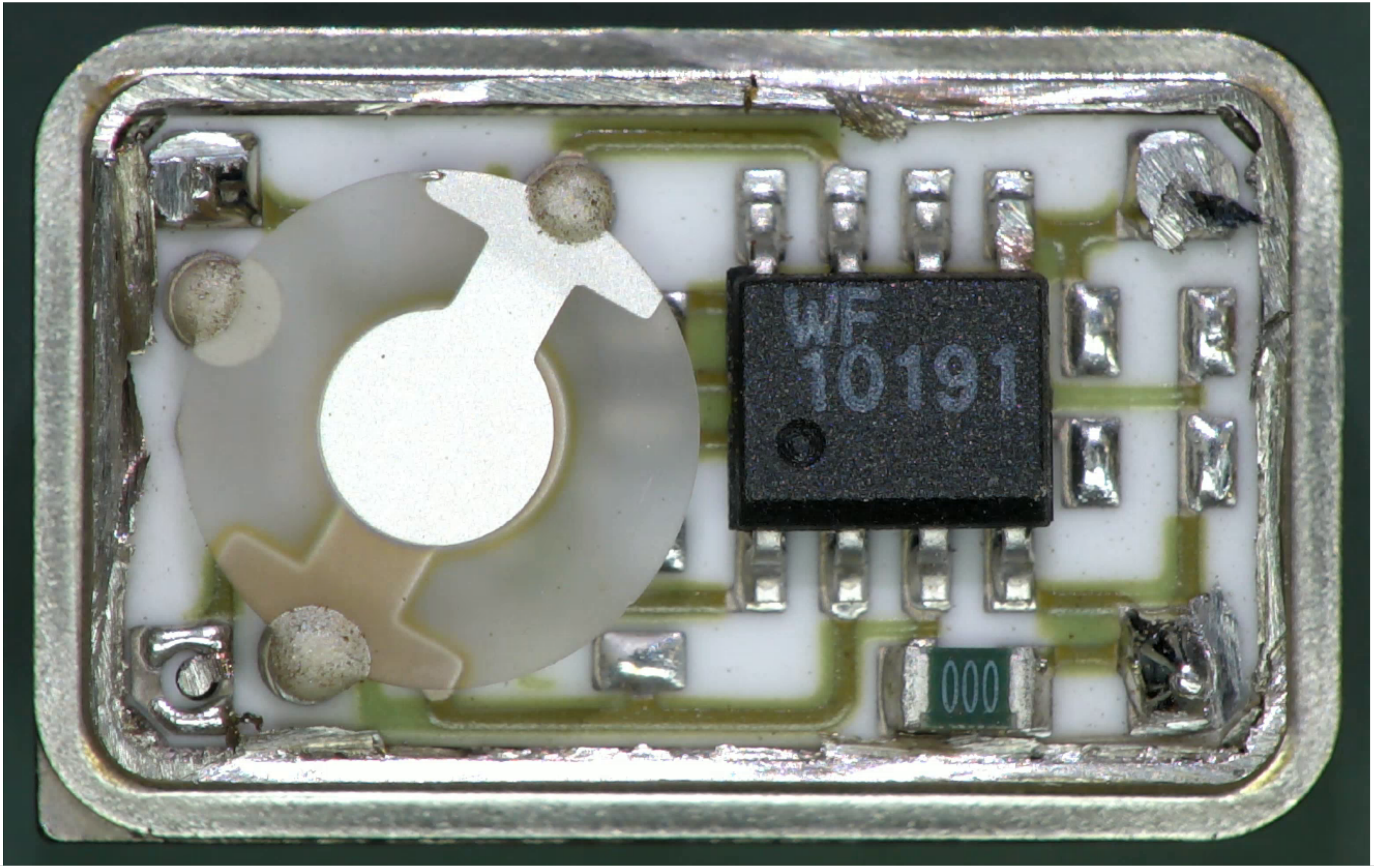
PHYS127AL Lecture 13

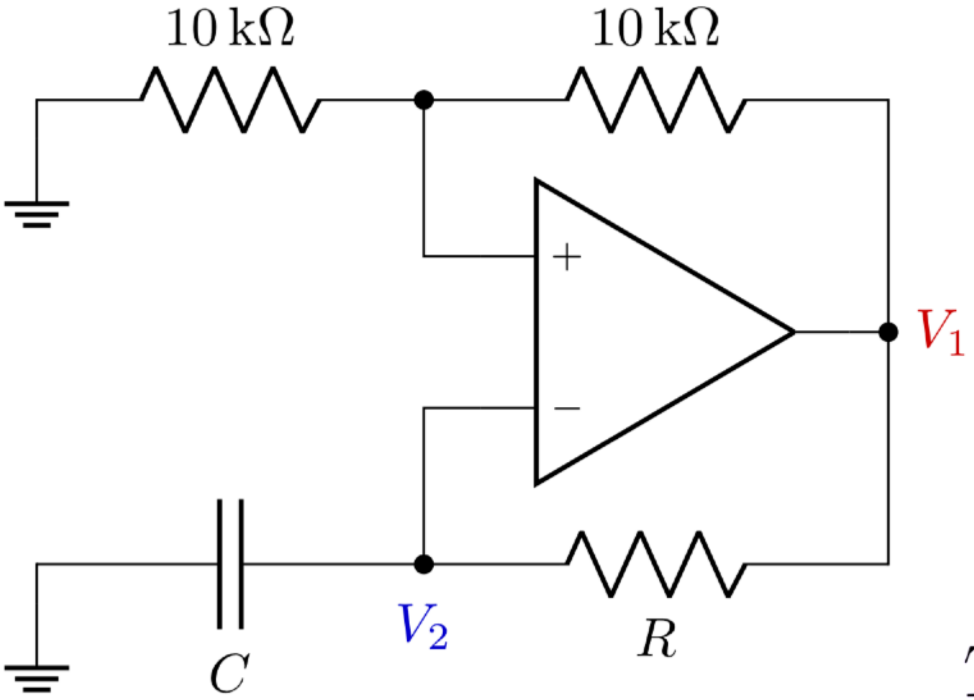
David Stuart, UC Santa Barbara, May 11, 2021

More oscillators



Review: Oscillator

We made an oscillator with an op-amp

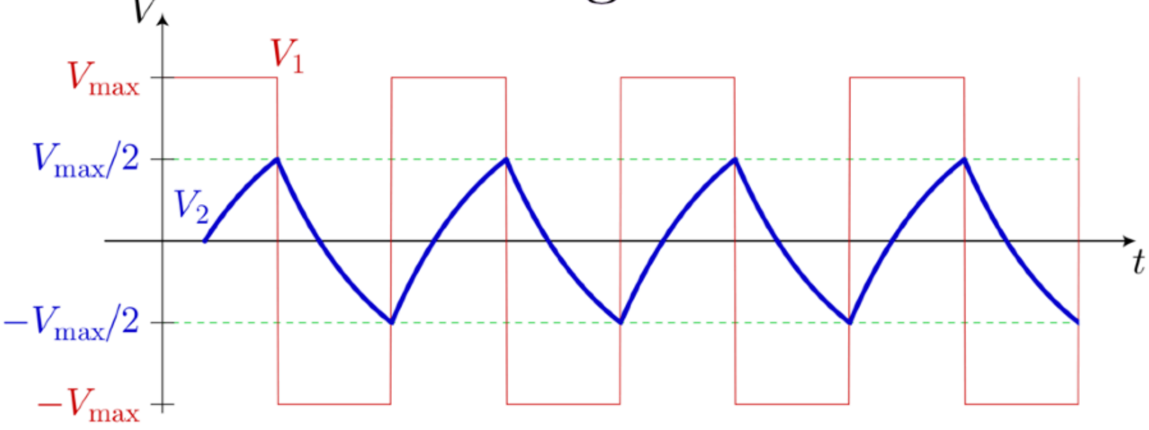


The $I_+ = I_- = 0$ golden rule means we can calculate V_+ and V_- in terms of V_1.

$V_+ = V_1/2$

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

$$T = RC \log 9 \approx 2.2\,RC$$



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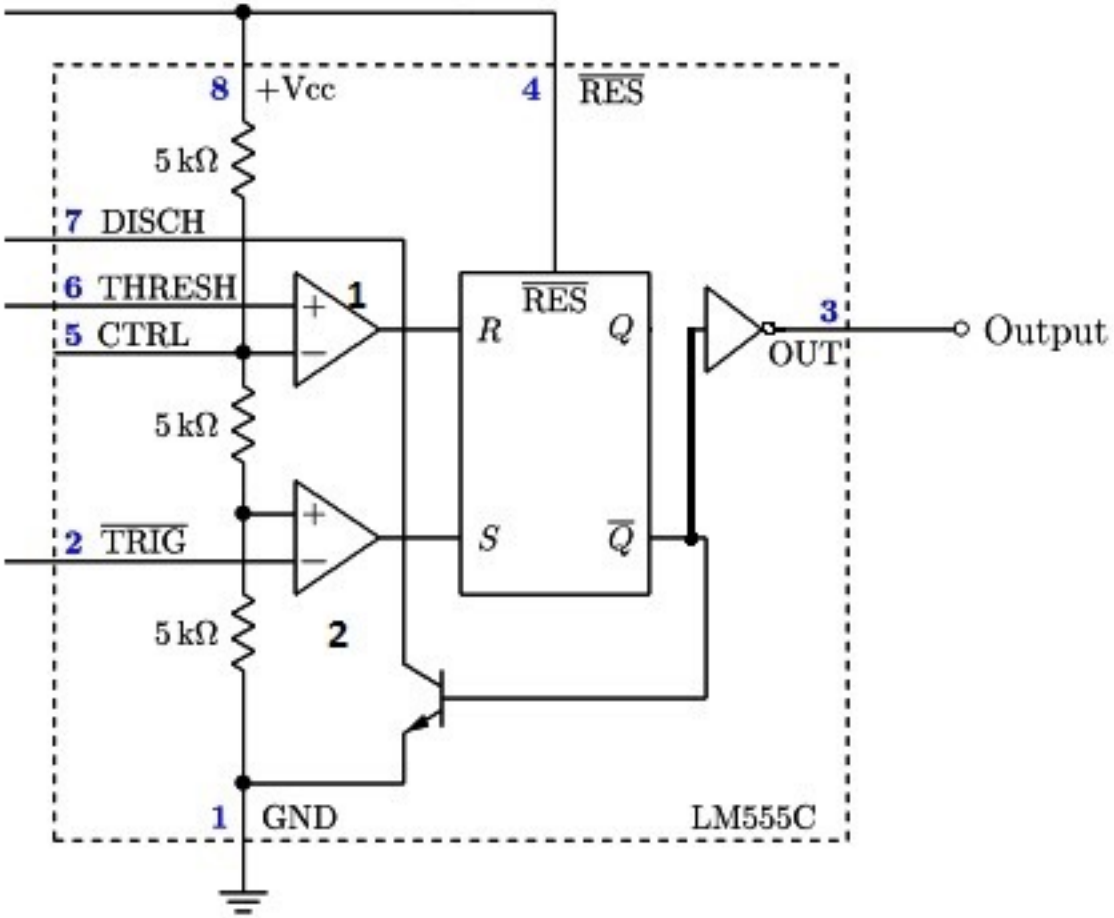
Review: 555 timer

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



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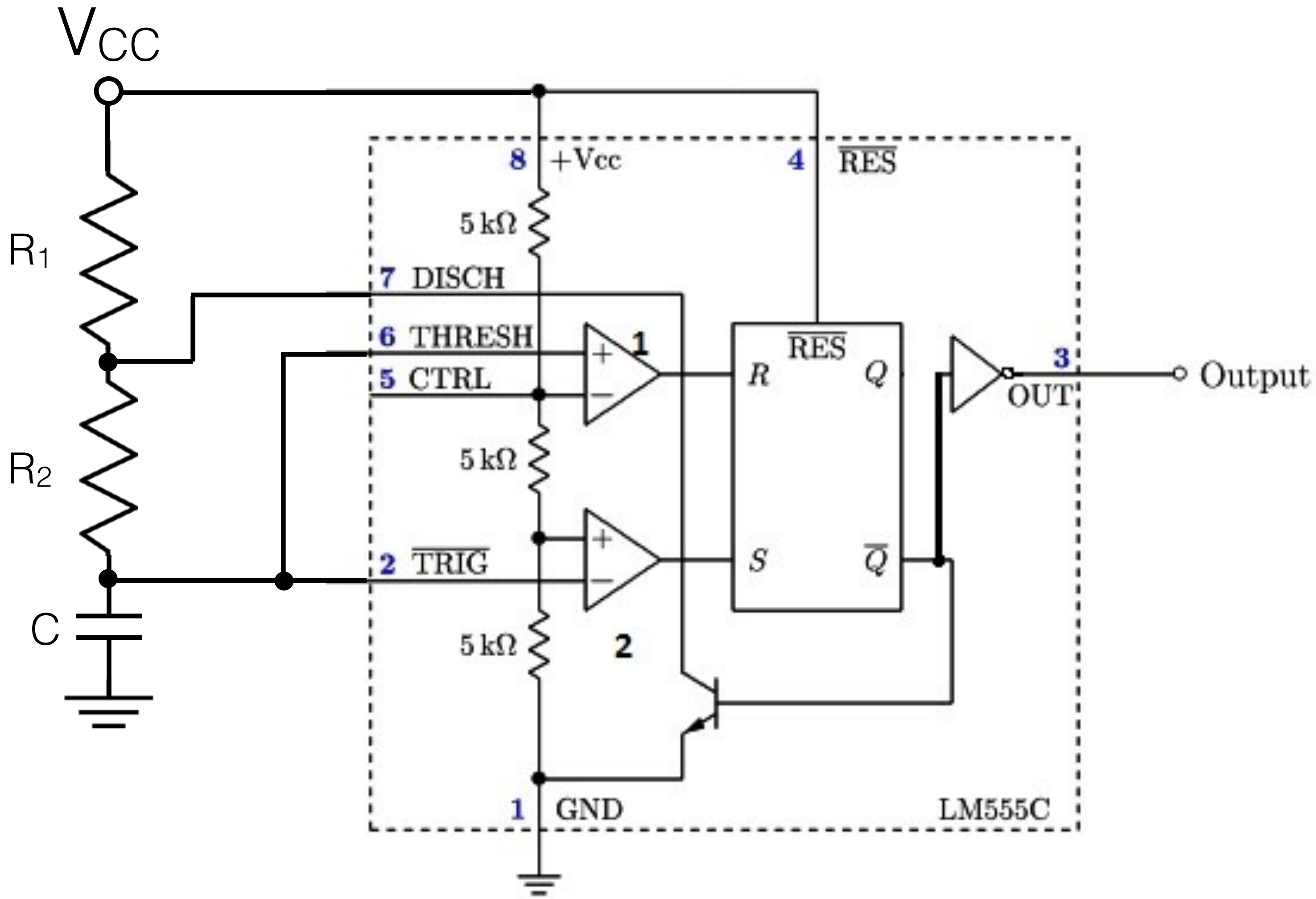
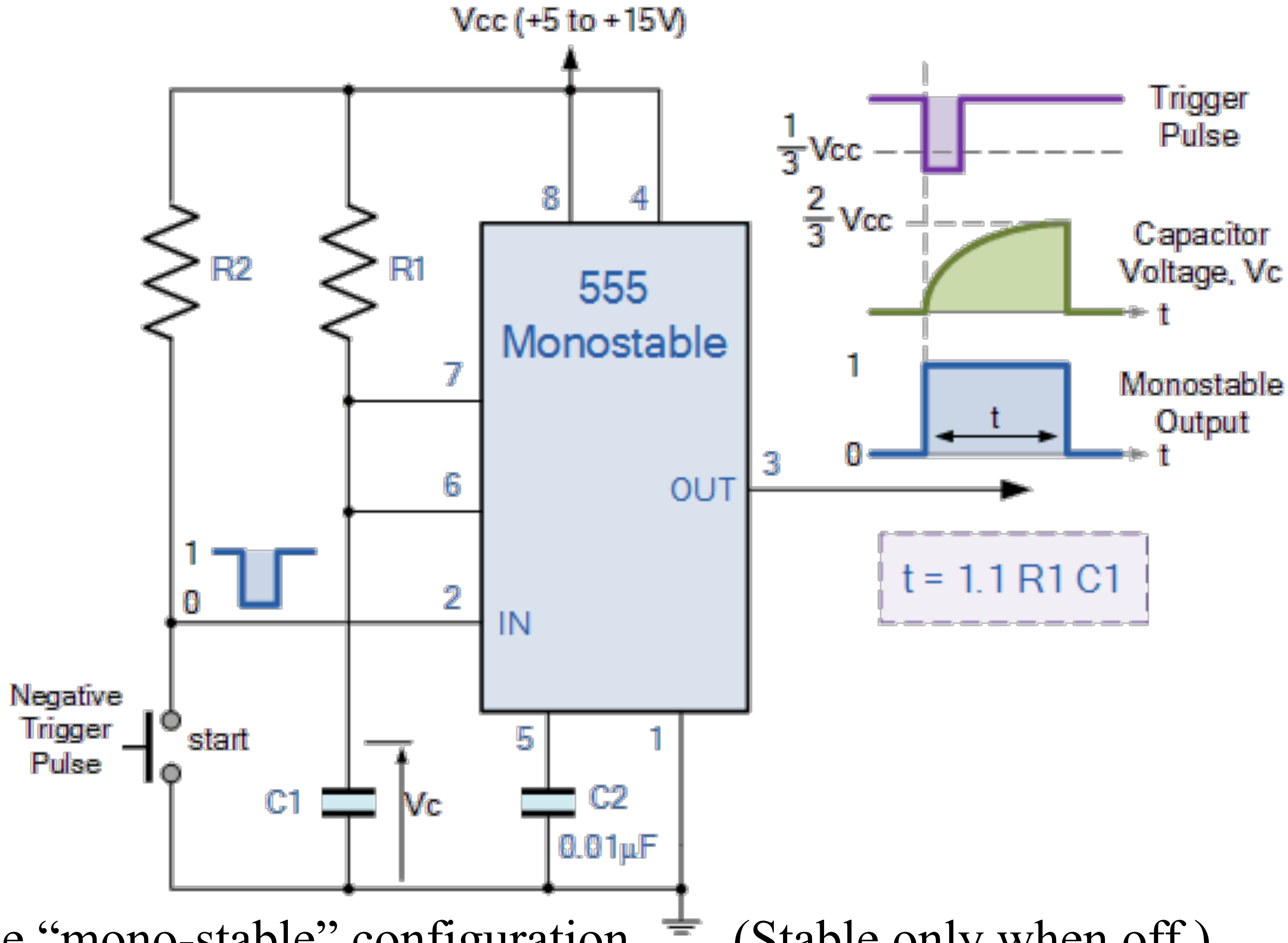


This is the “astable” configuration. (Not stable in either configuration.)

Review: 555 timer

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



t = 1.1 R1 C1

This is the "mono-stable" configuration. (Stable only when off.)

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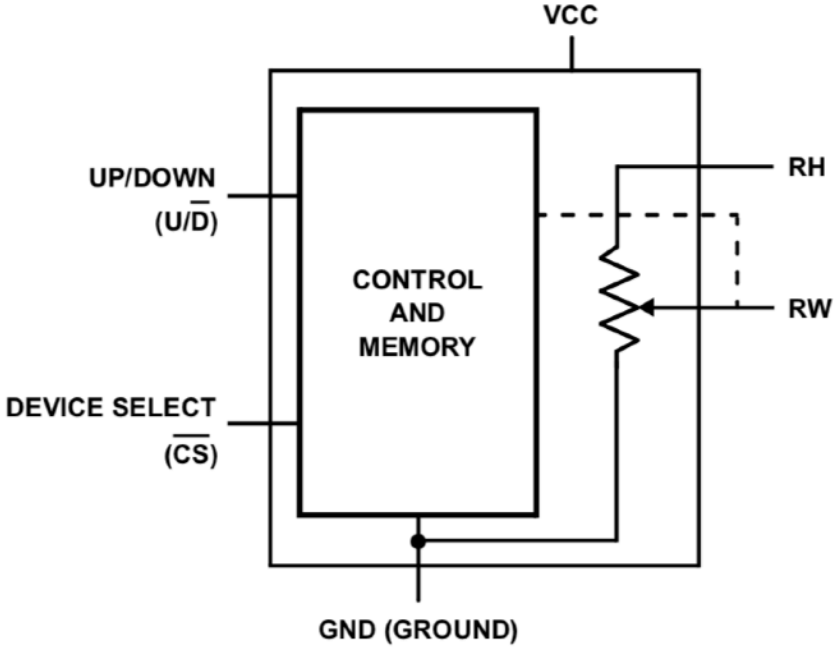
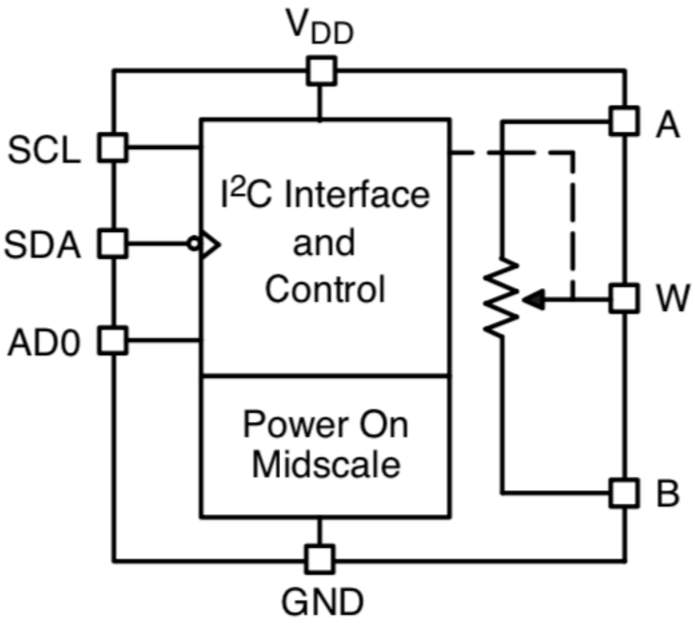
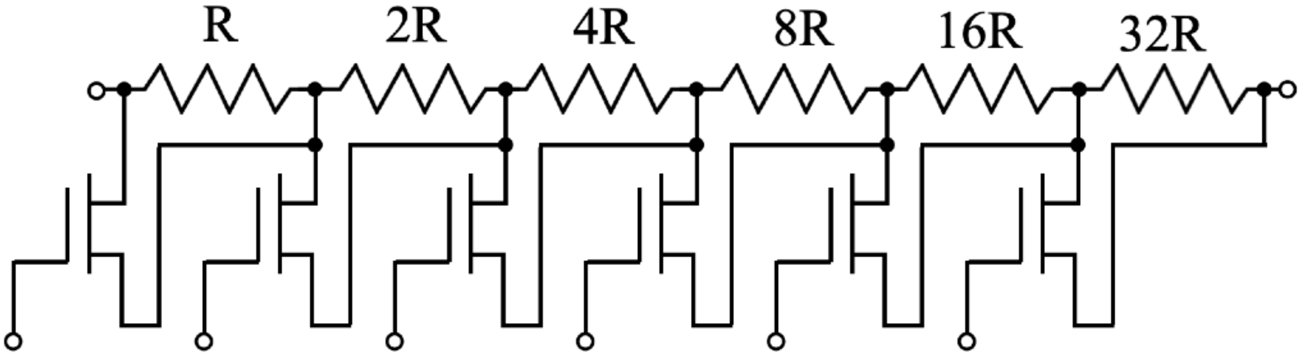
Digital potentiometer

We can adjust the frequency by changing the resistance with a potentiometer.
It is more common now to use a “digital potentiometer” (cheaper than trimpot).







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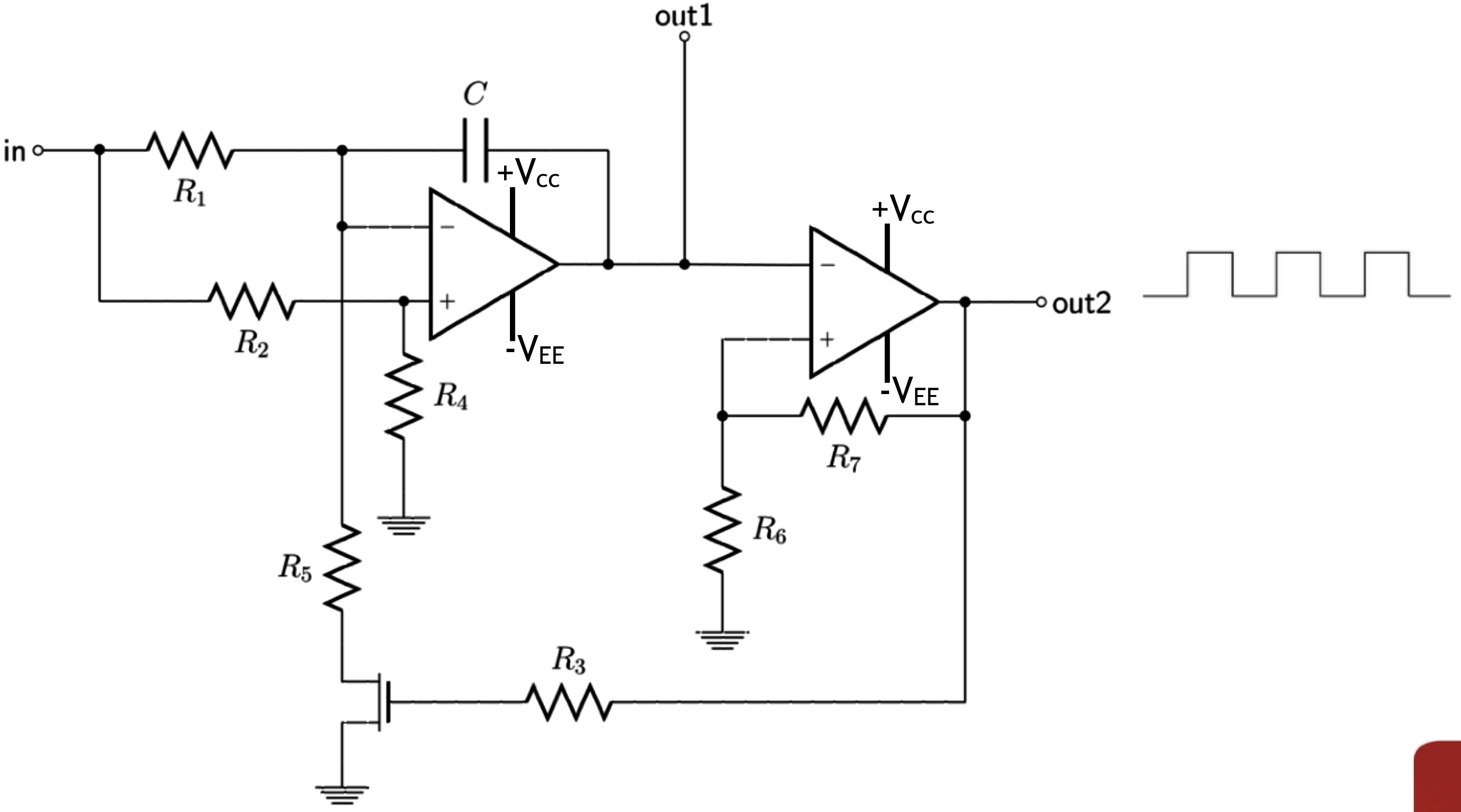
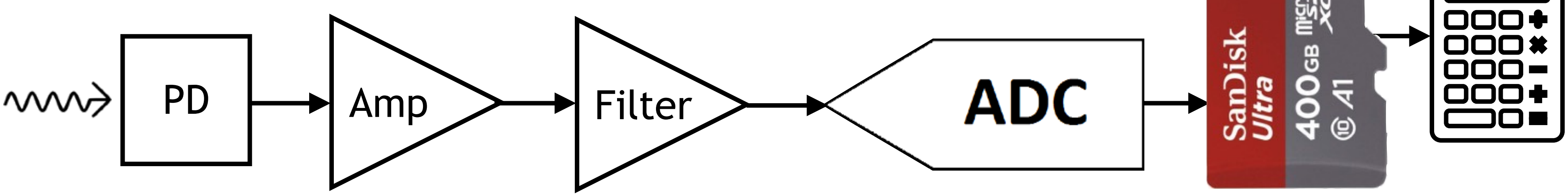
Voltage controlled oscillator

It is sometimes useful to control an oscillator with a voltage, or to encode a voltage as a frequency.




PD

Amp

Filter

ADC

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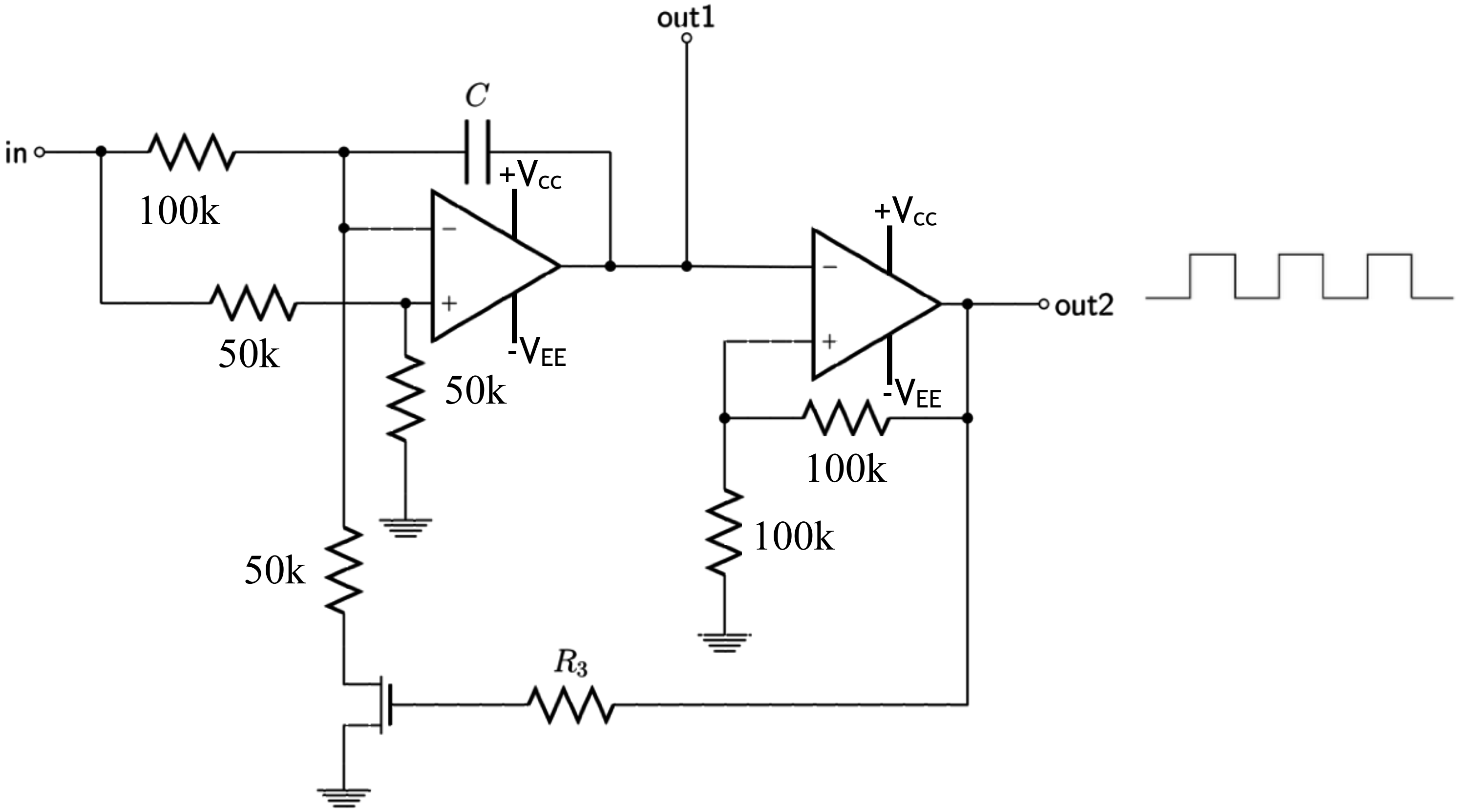

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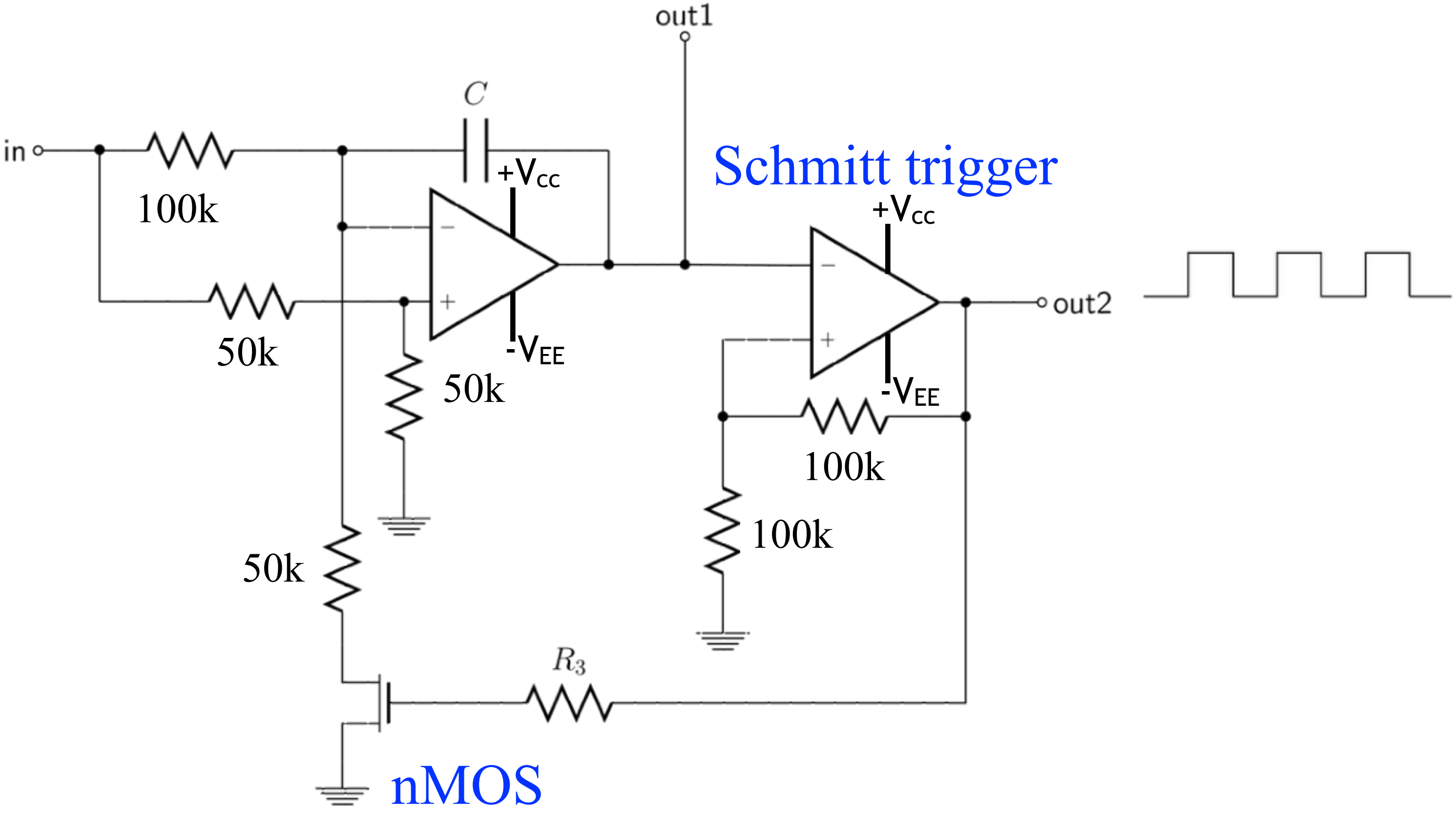
It is sometimes useful to control an oscillator with a voltage, or to encode a voltage as a frequency.

Out2 is either high or low as output of comparator.



Out1 linearly ramps down until $V_{EE}/2$, then Out2 flips to V_{CC}.
Ramp rate proportional to V_{in}.

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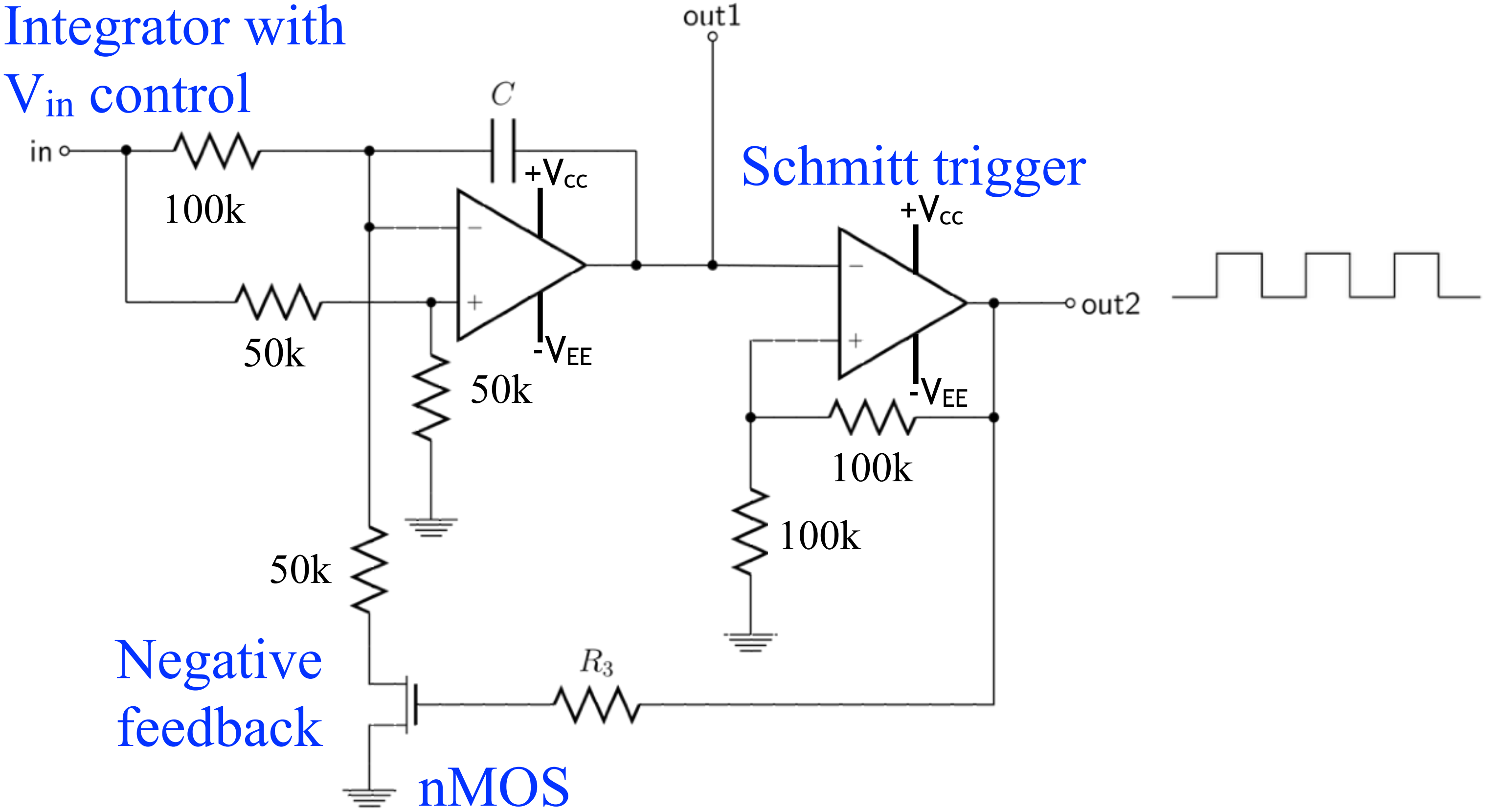

Integrator with V_{in} control

Schmitt trigger

Negative feedback

nMOS

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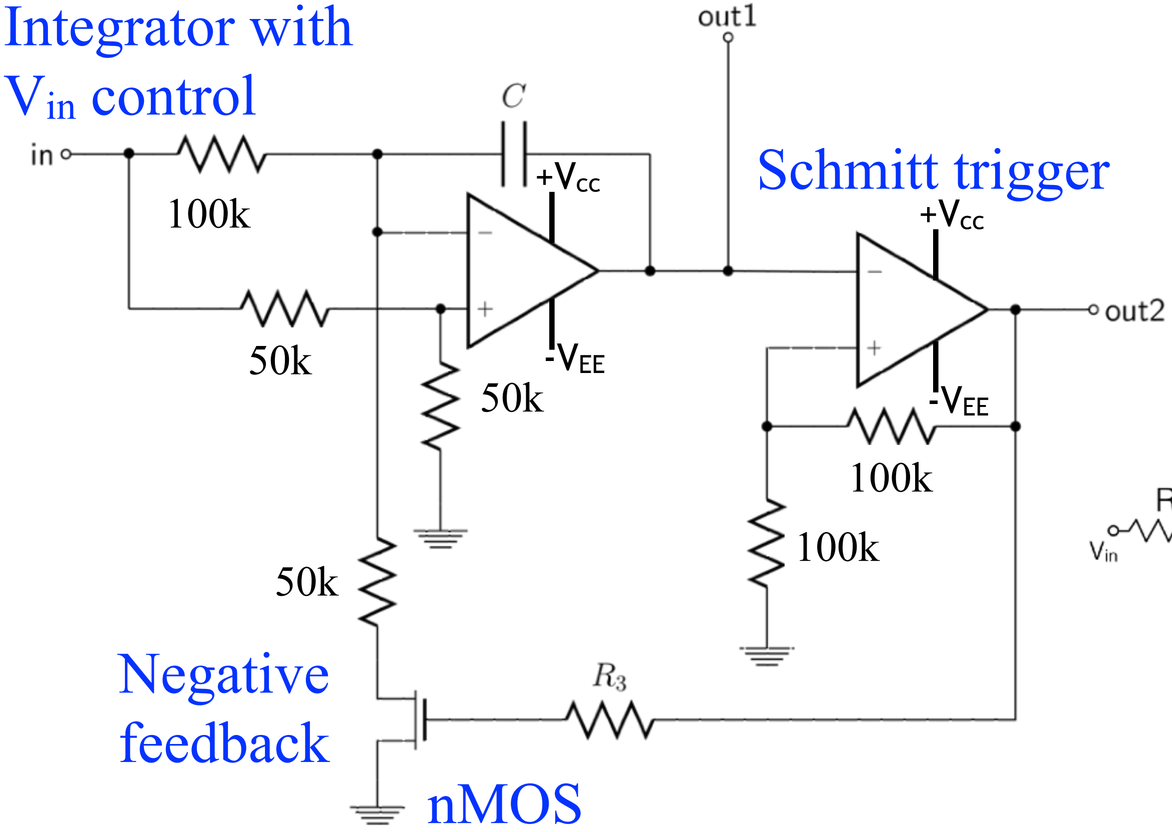
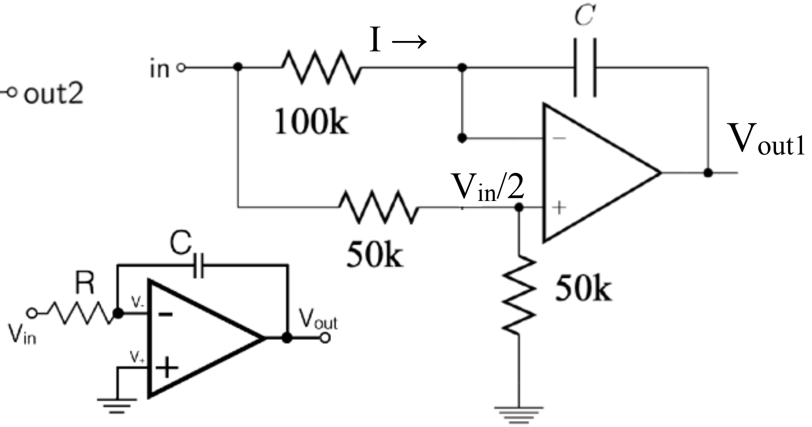


If Out1>0 & Out2=V_{EE},
then nMOS=off.
C charges as an integrator



$I = (V_{in} - V_{in}/2) / 100k = V_{in} / 200k$

$I = C\, dV/dt = V_{in} / 200k$

$C\, d(V_{in}/2 - V_{out1})/dt = V_{in} / 200k$

$C\, dV_{out1}/dt = -V_{in} / 200k$

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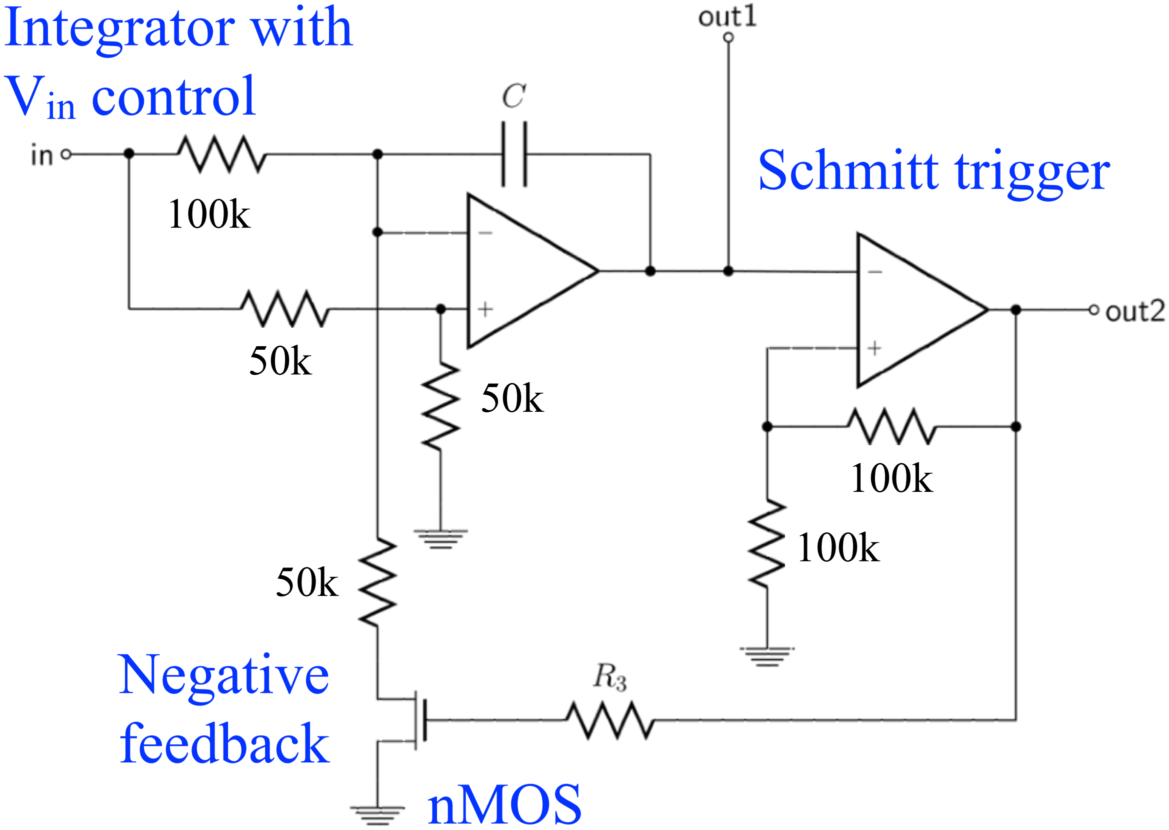

Integrator with V_{in} control

Schmitt trigger

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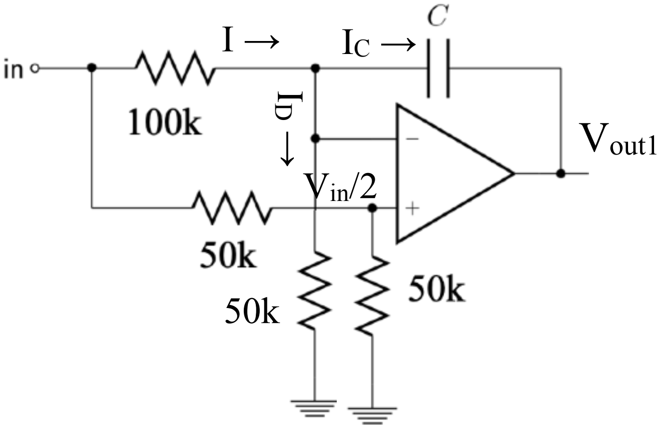
nMOS

If Out1<0 & Out2=V_{CC},
then nMOS=on.
C charges as an integrator



$$I = (V_{in}-V_{in}/2)/100k = V_{in}/200k$$

$$I_D = (V_{in} / 2) / 50k = V_{in} / 100k$$

$$I_C = I-I_D = V_{in} (1/200k - 1/100k)$$

$$I_C = I-I_D = -V_{in}/200k$$

$$C\, d(V_{in}/2-V_{out1})/dt = -V_{in} / 200k$$

$$C\, dV_{out1}/dt = V_{in} / 200k$$

Out1 linearly ramps up until $V_{CC}/2$, then Out2 flips to V_{EE}.
Ramp rate proportional to V_{in}.

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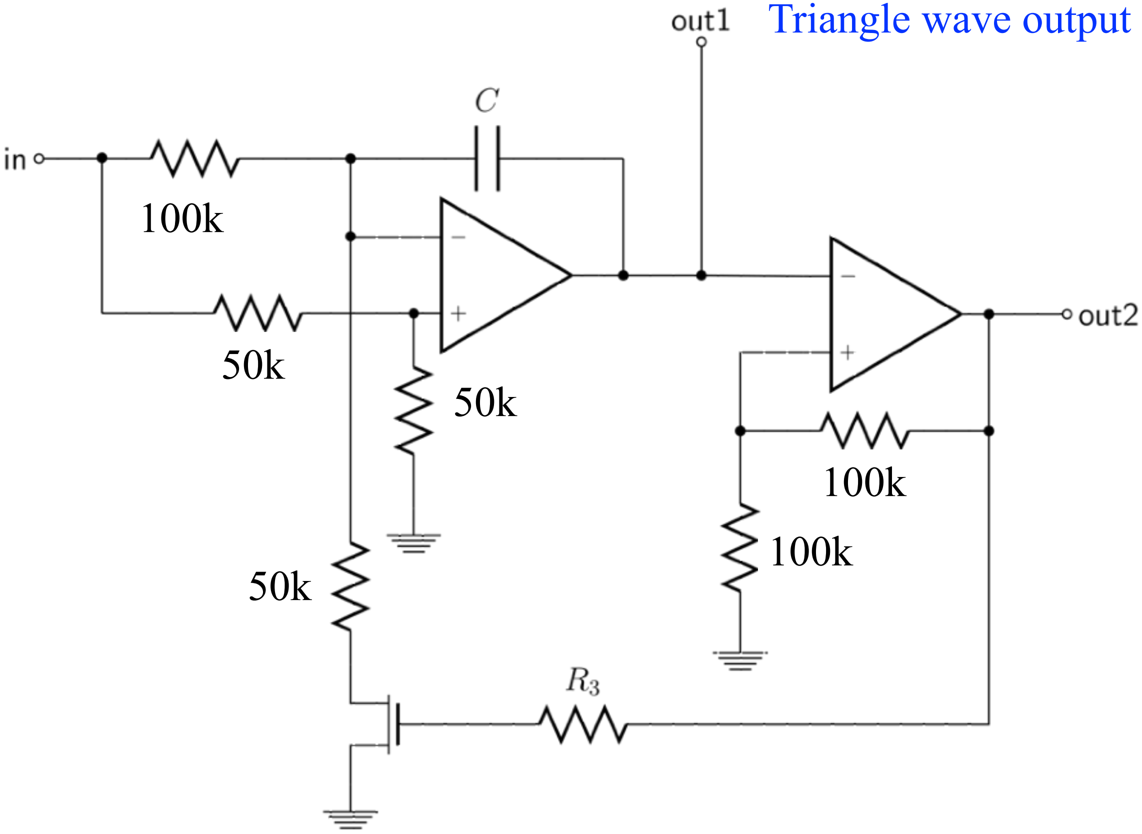
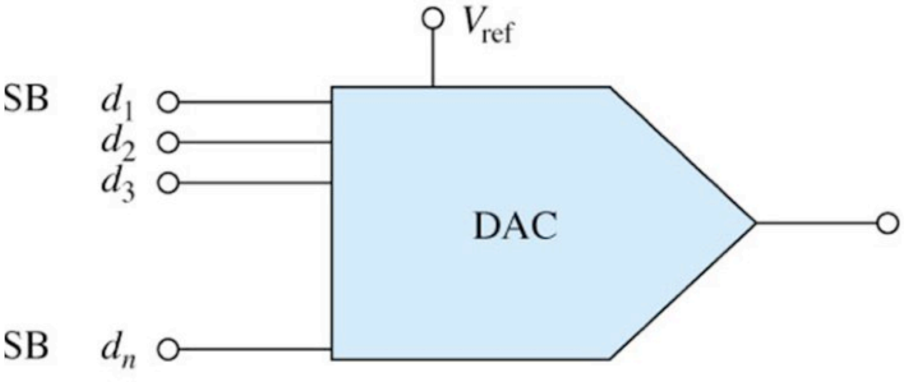


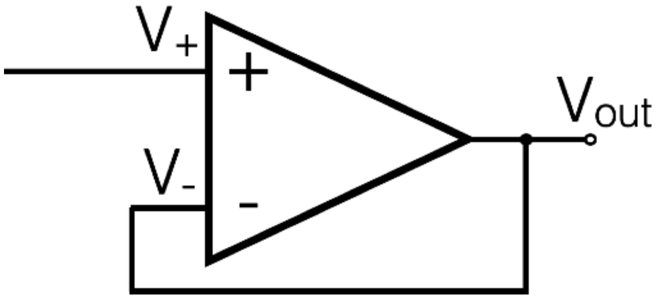
Triangle wave output

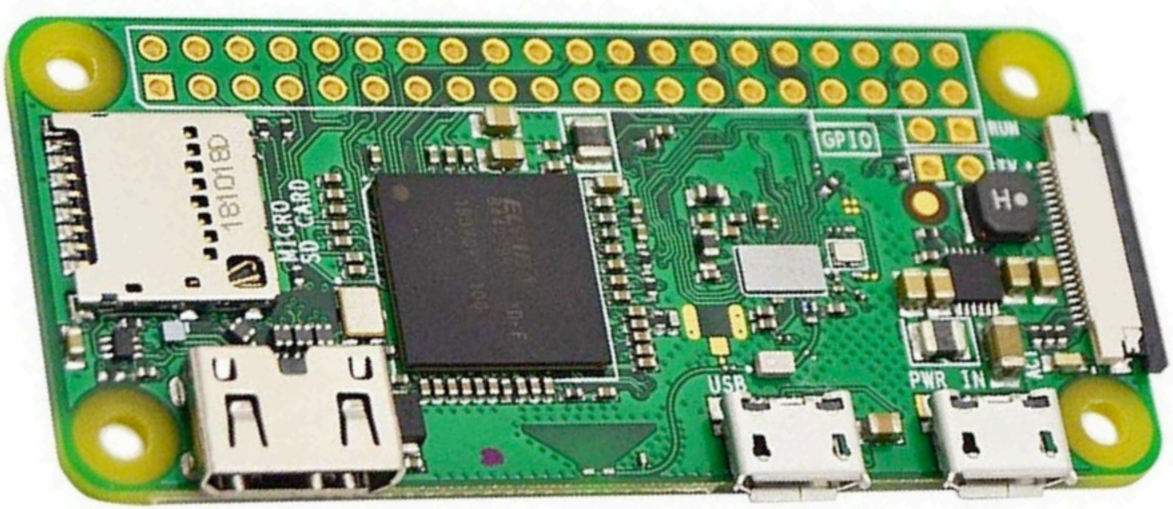
Square wave output

Sine wave oscillator

We could get a sine wave oscillator in a few ways:
0). Use a computer to rapidly change the resistance in a digital potentiometer used in a voltage divider







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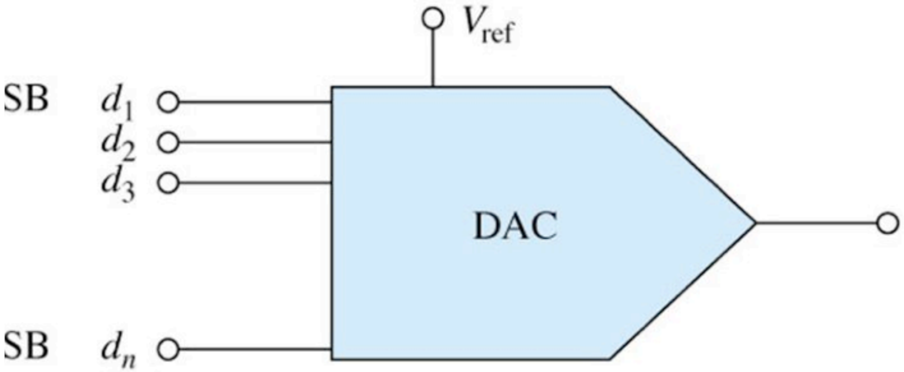

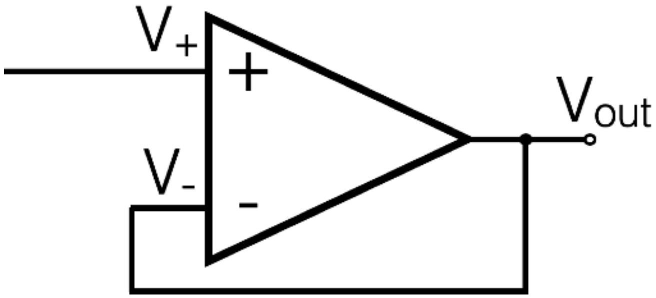

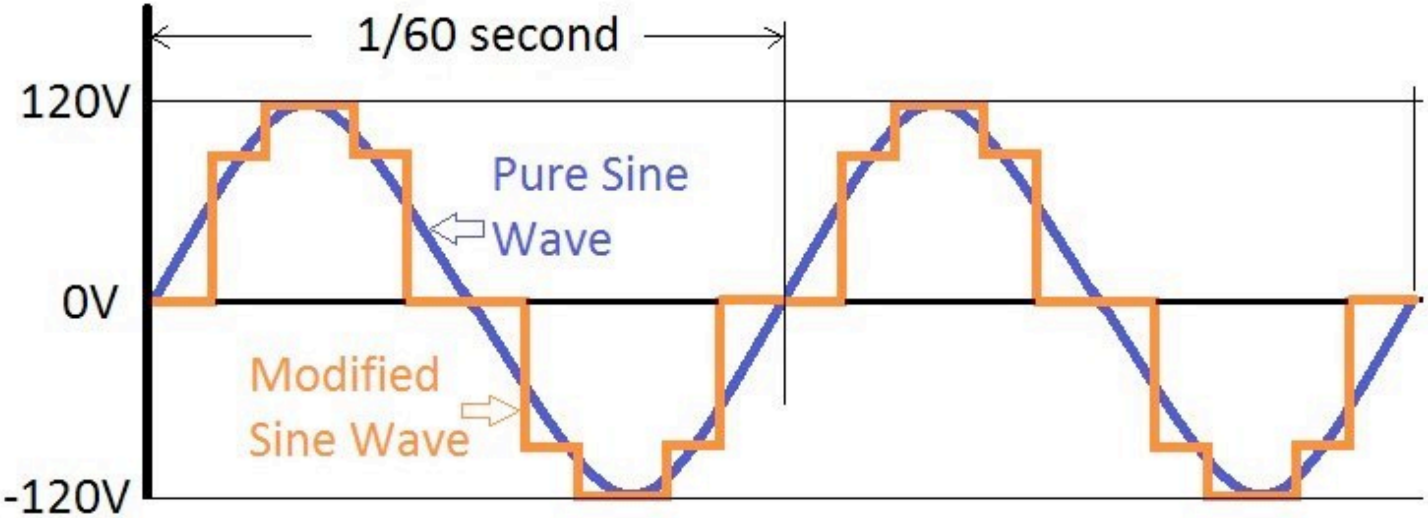

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Sine wave oscillator

We could get a sine wave oscillator in a few ways:

1). Filter square wave with low-pass filter: $f(x) = \sin(x)+\sin(3x)/3+\sin(5x)/5 + \ldots$

2). Chop the triangle wave

3). Tune resonance

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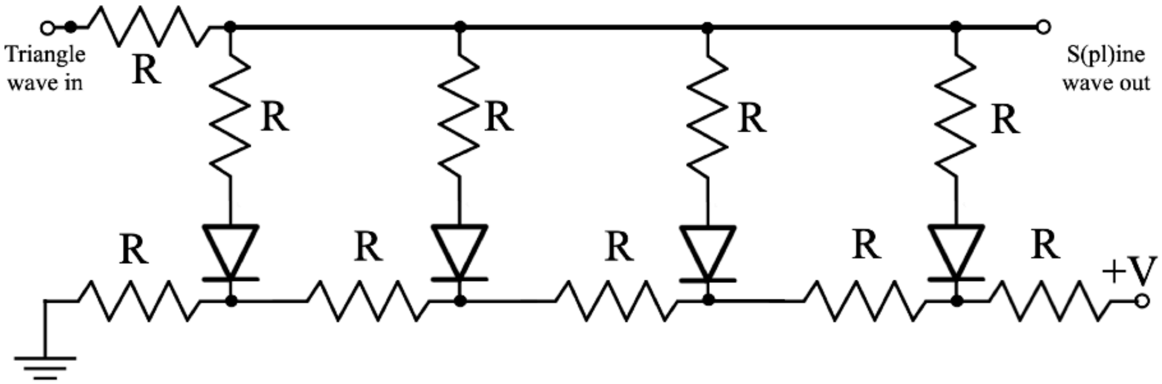

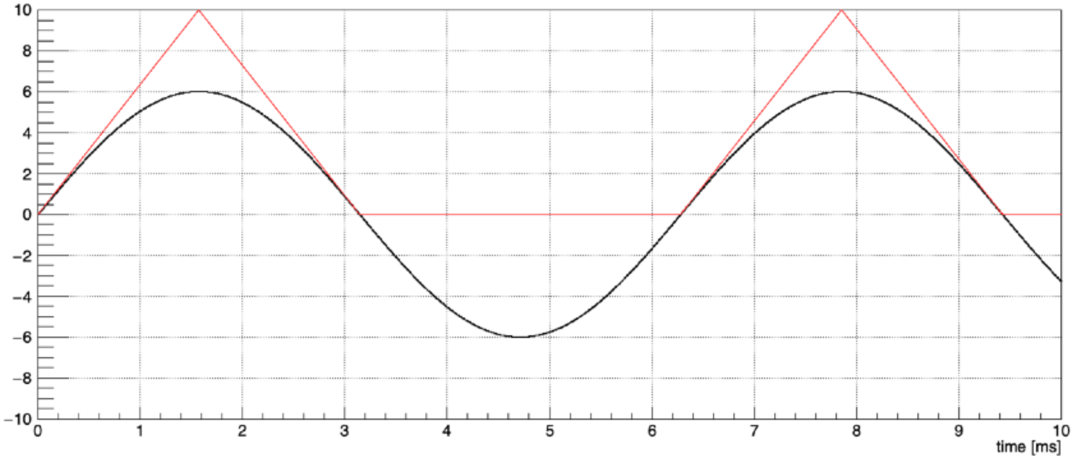

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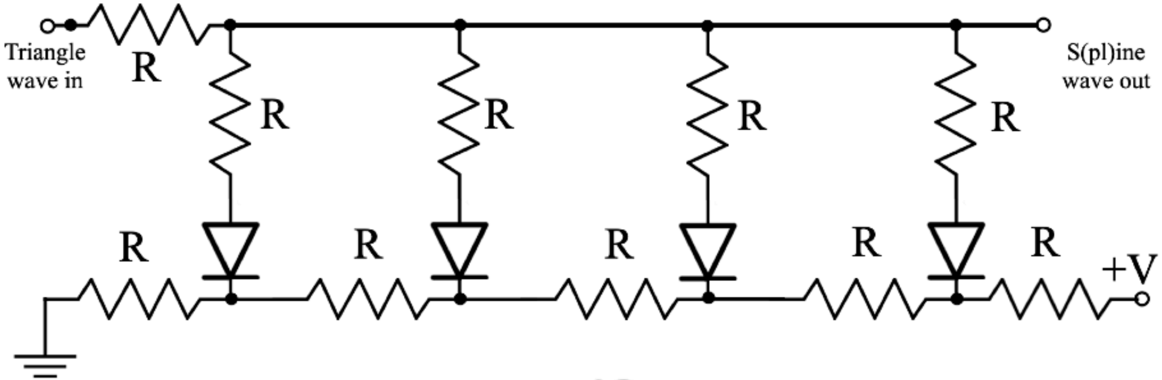

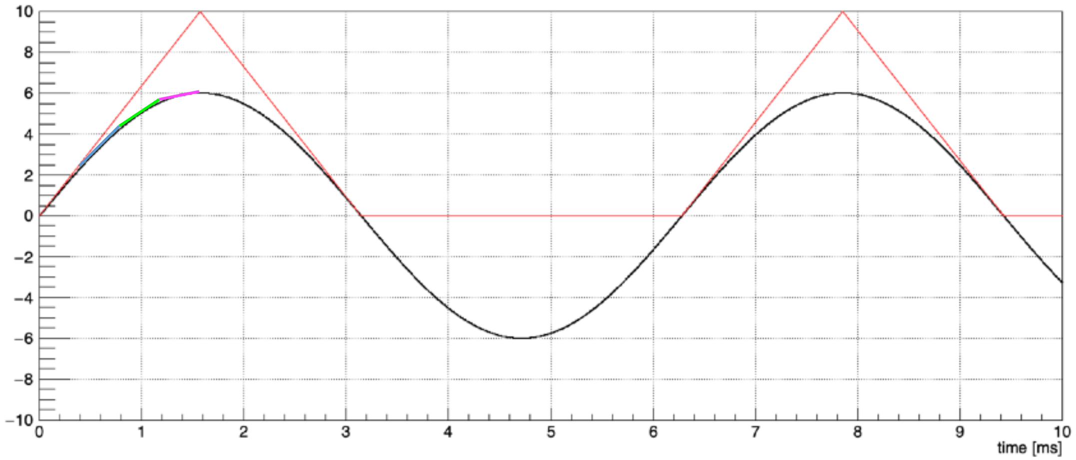

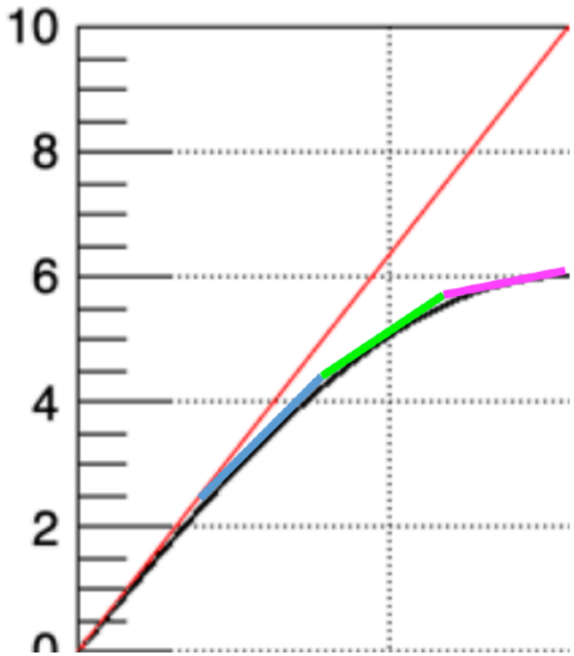

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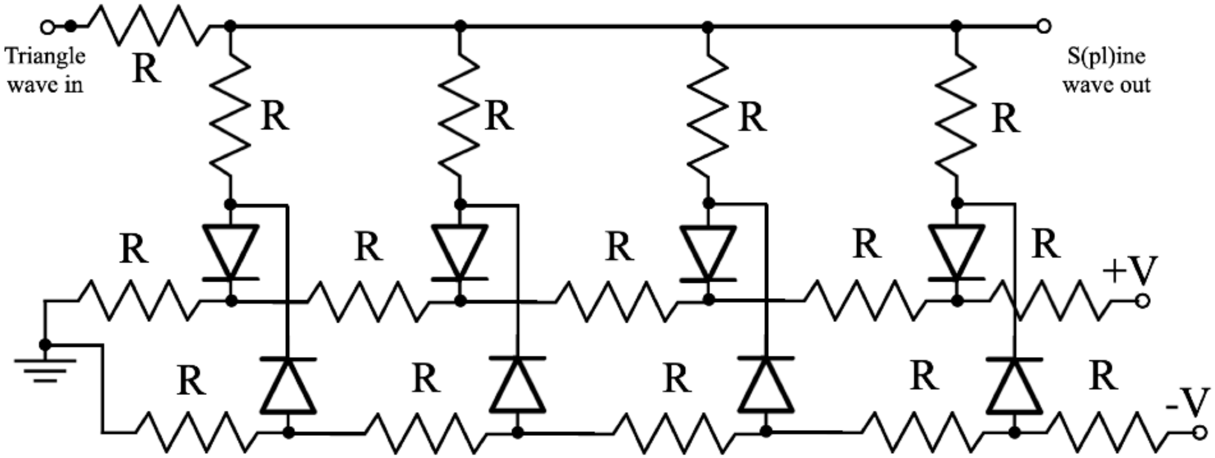

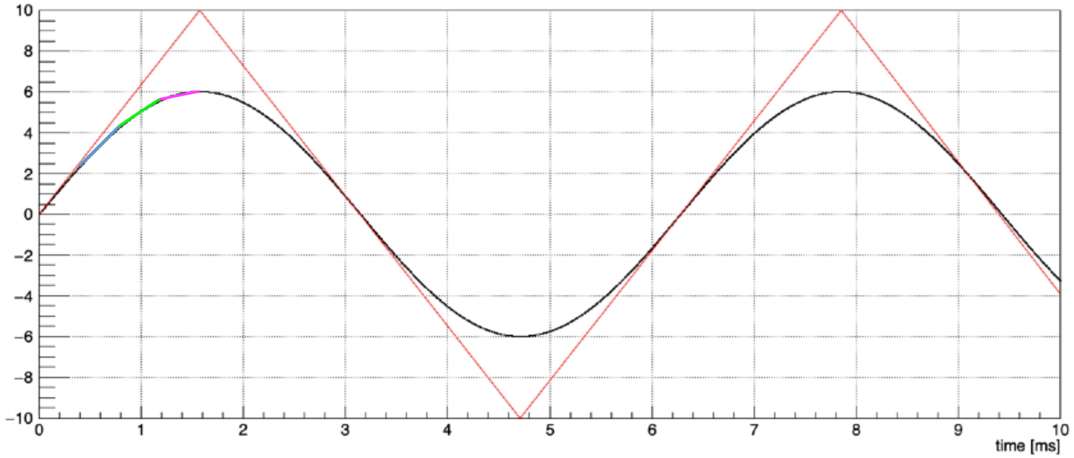

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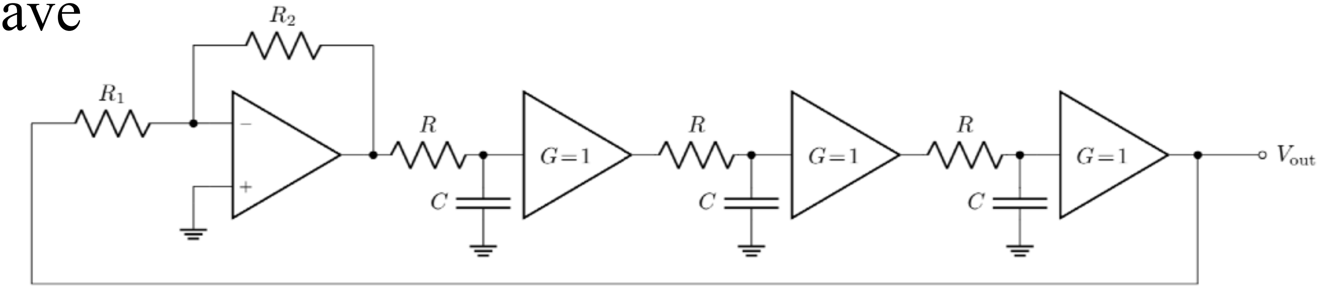

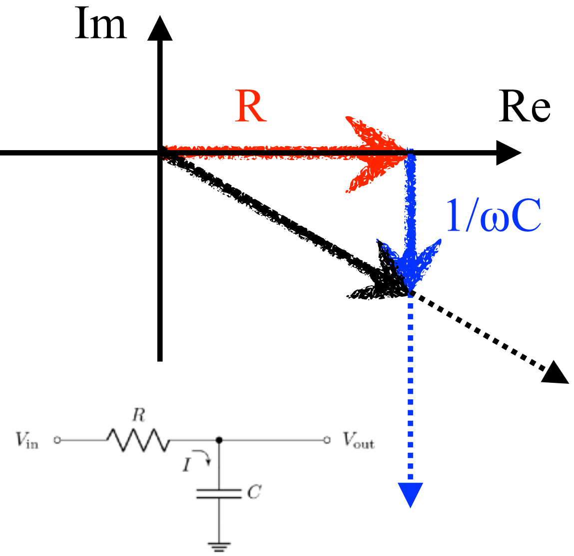

Initially have an inverting amp, then RC filters that phase shift. At just the right frequency,

$\omega = \frac{\sqrt{3}}{RC}$, they each have 60° phase shift.

So net effect is 180° so another inverter. Positive feedback at the resonant ω.

Lose a factor of $\frac{1}{\sqrt{1+(\omega RC)^2}} = 1/2$ at each step.

So $R_2/R_1 = 8$ to get stable oscillation.

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Sine wave from Wien bridge oscillator

We could get a sine wave oscillator in a few ways:

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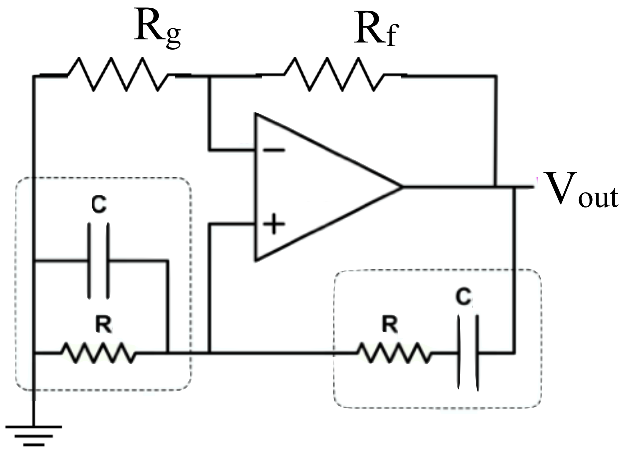
3). Tune resonance



The CR-RC are a hi&low pass filter.
At ω=1/RC, phase shift at V_+ is 0°
so positive feedback, and $V_+=V_{out}/3$.
If we could finely adjust $R_g = R_f/2$ to get the non-inverting amp gain of $G = 1+R_f/R_g = 3$, net gain=1.

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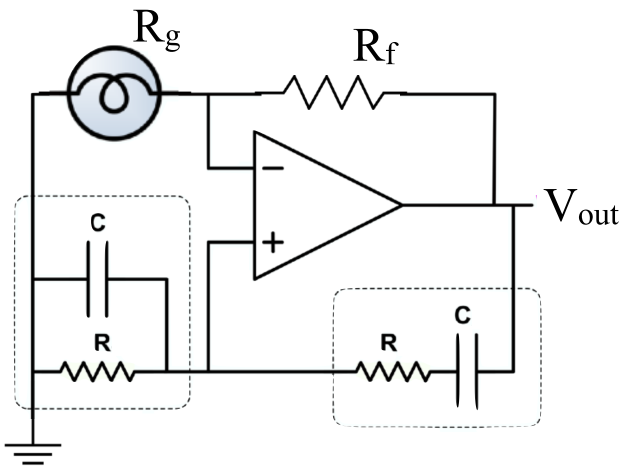

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Do this with thermal negative feedback using a lamp.
A lamp's resistance is low at low temperature and increases as its temperature increases.

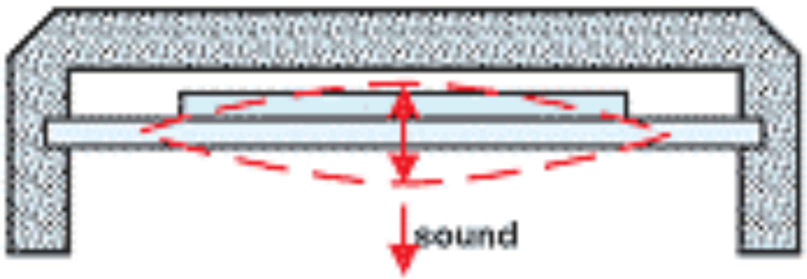
If V_{out} gets too big, more current flows through R_g, which increases R_g, which decreases the gain and hence decreases V_{out}. Negative feedback.

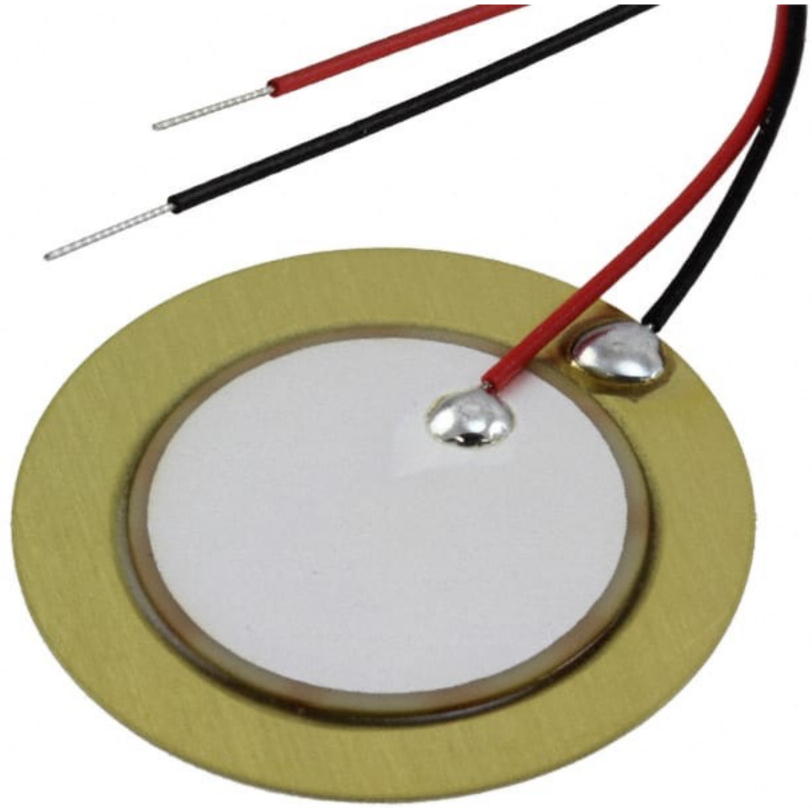
If V_{out} gets too small, less current flows through R_g, which decreases R_g, which increases the gain and hence increases V_{out}. Negative feedback.

Equilibrium at just the right gain to oscillate at $\omega=1/RC$.

Piezo-buzzer

The buzzer you will use in lab this week is not a speaker.
It is just a mechanical resonator, with thin ceramic and metal disks.
The ceramic deforms due to the electric field of an applied voltage.
Small ceramic deformations cause larger vibrations in the metal disk.





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Quartz crystal oscillator

The resonant frequency depends on the size and tension.
To get very high resonant frequency, need a small & stiff material ⇒ quartz.

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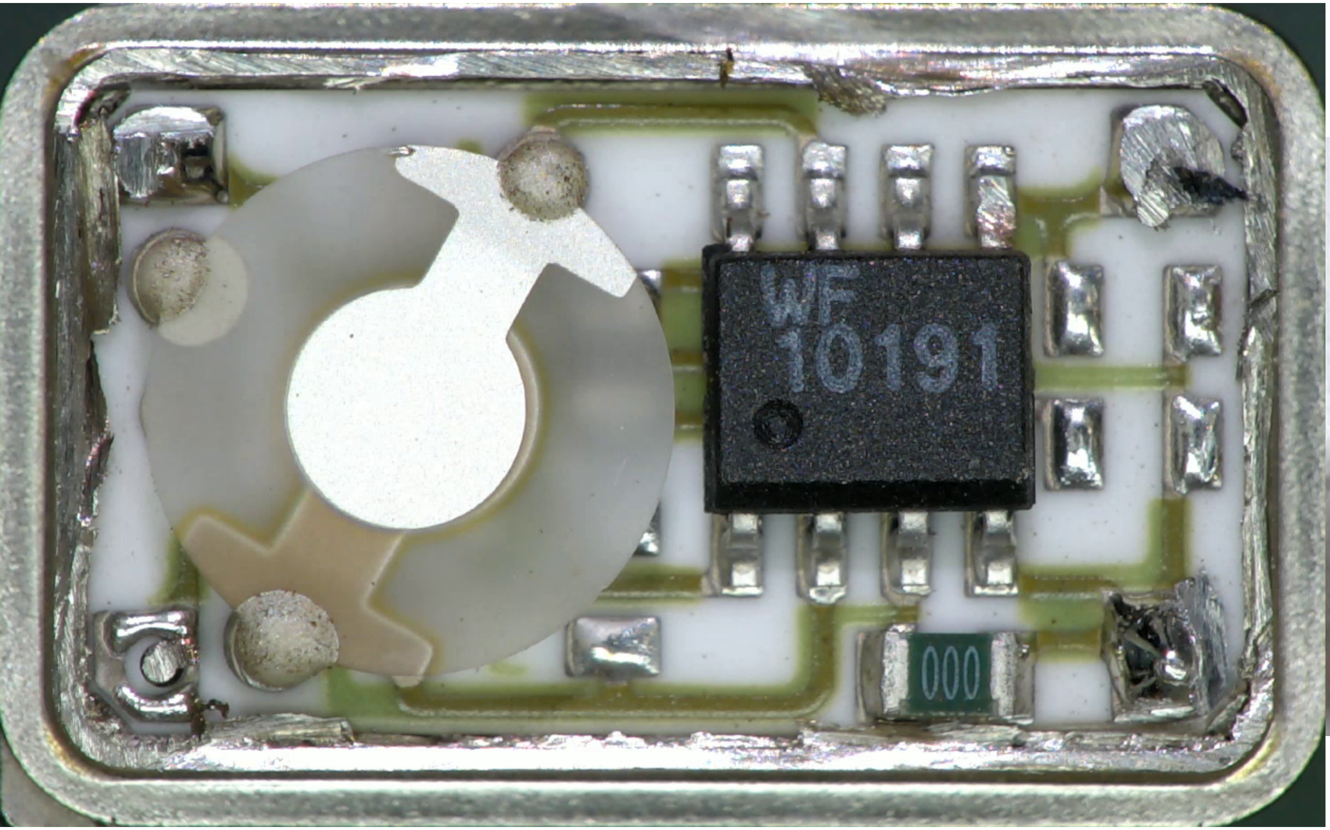
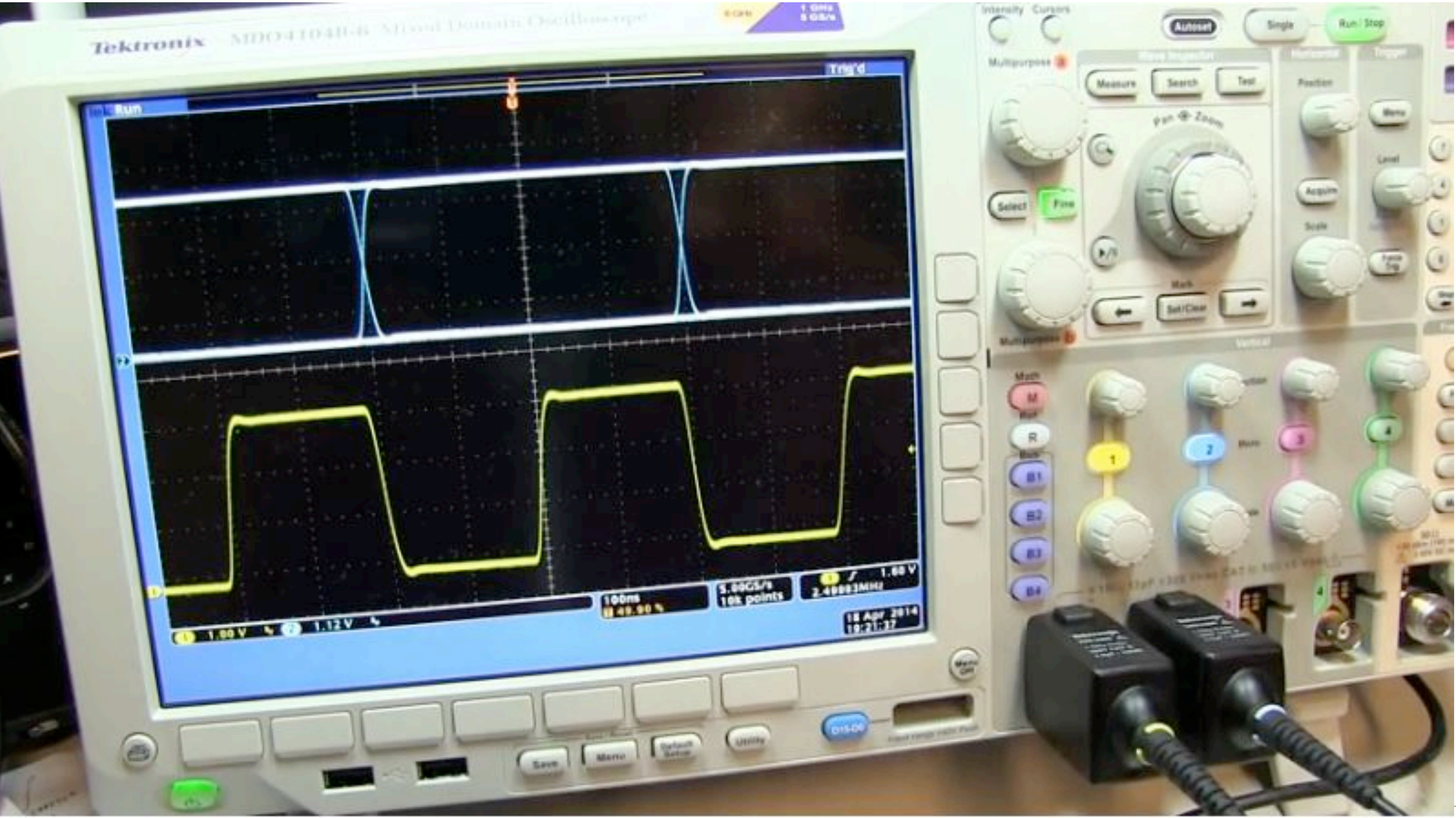


Can get high frequencies, with higher harmonics of resonance.
High Q oscillators so can get low drift. Temperature compensation helps.

Oscillator performance

A measure of oscillator performance is the frequency drift and phase jitter.

"Eye diagram":



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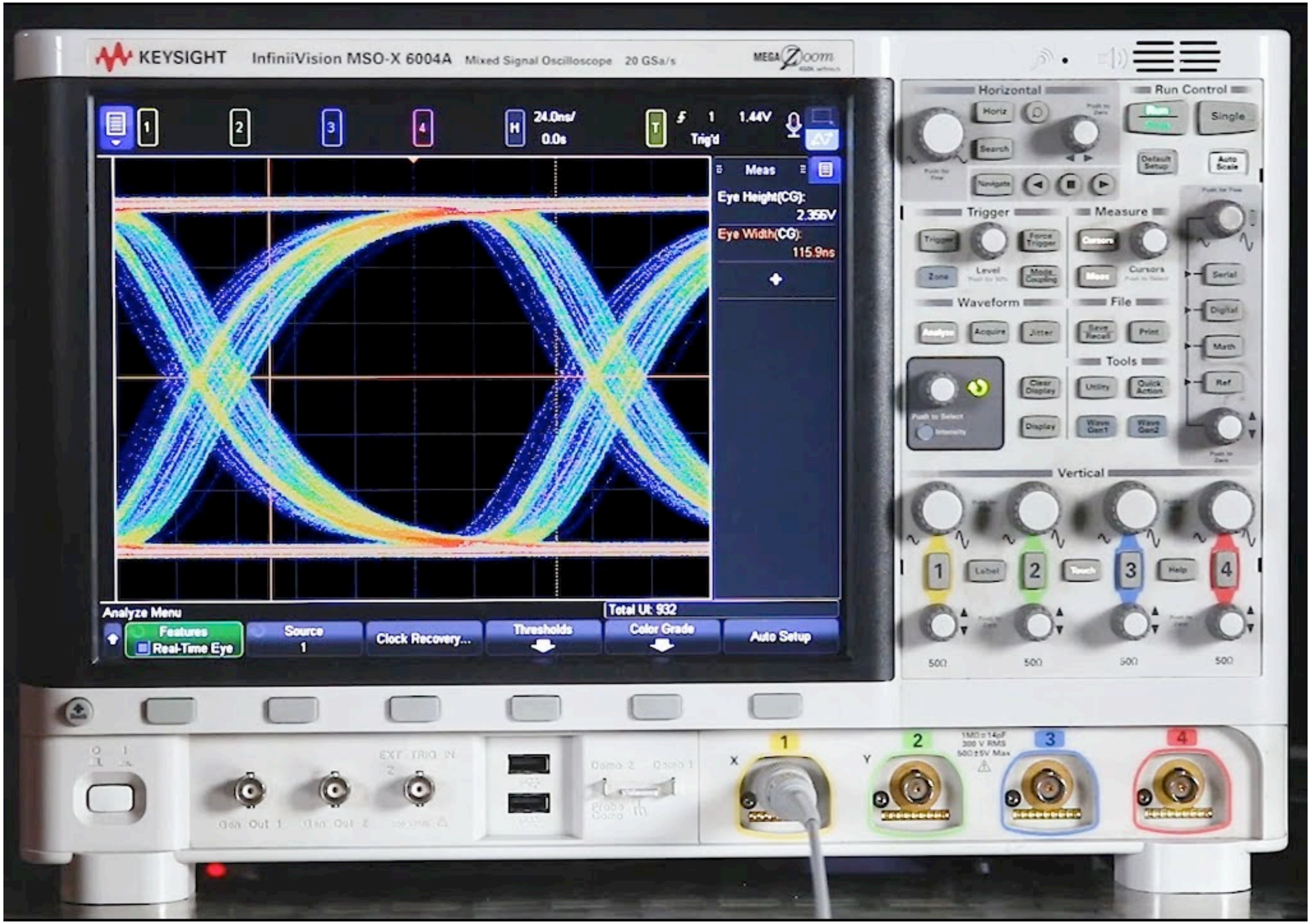

Eye Height(CG): 2.355V

Eye Width(CG): 115.9ns

Total UI: 932

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Oscillator performance

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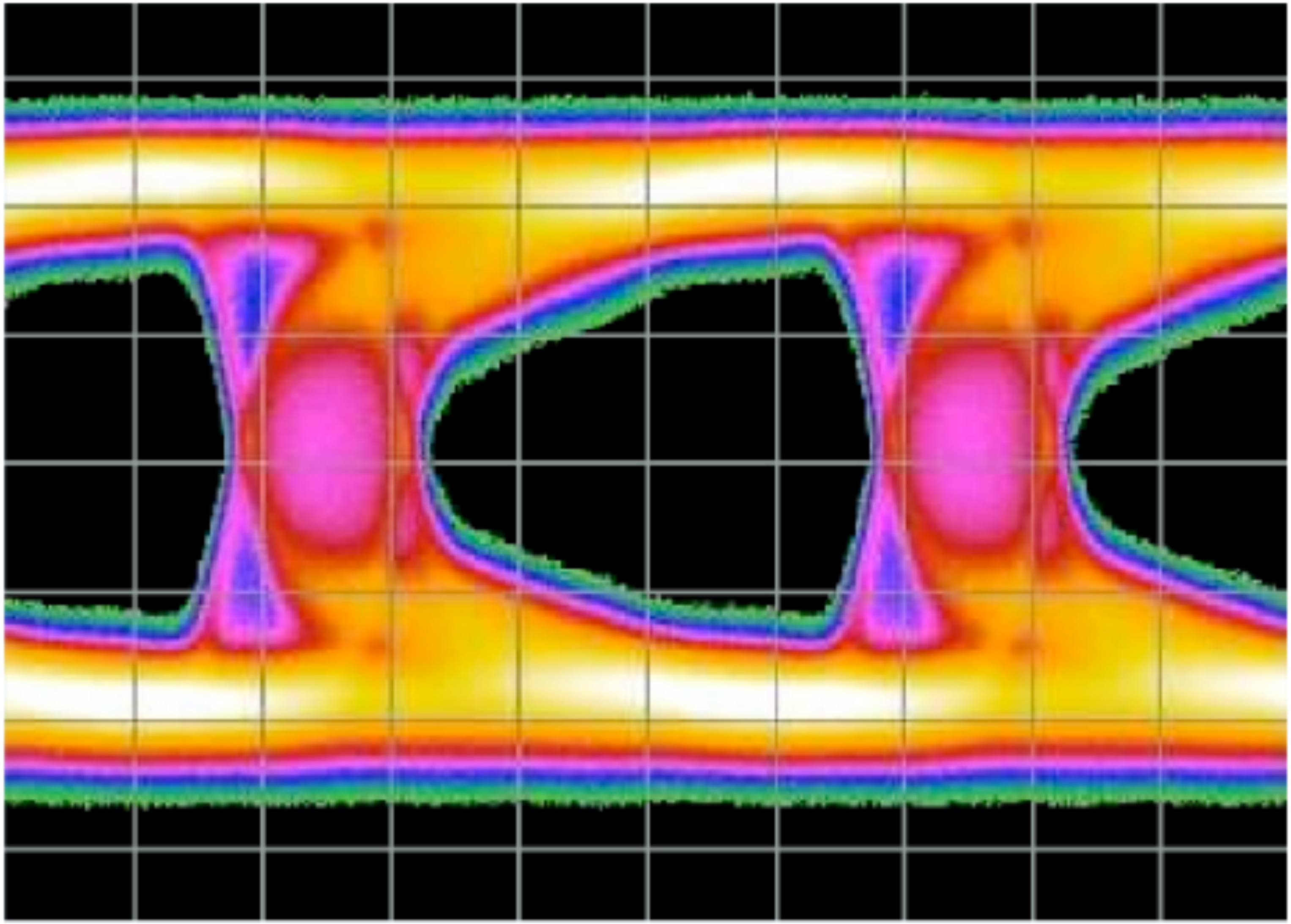
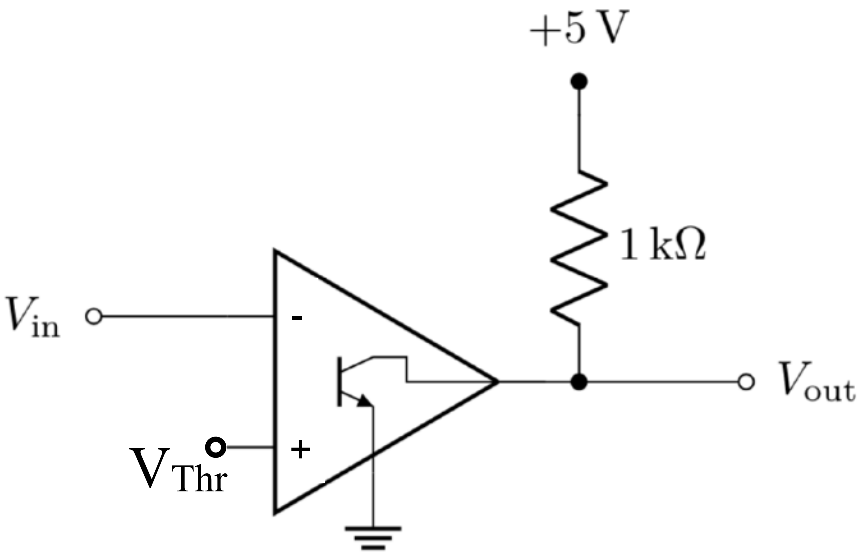


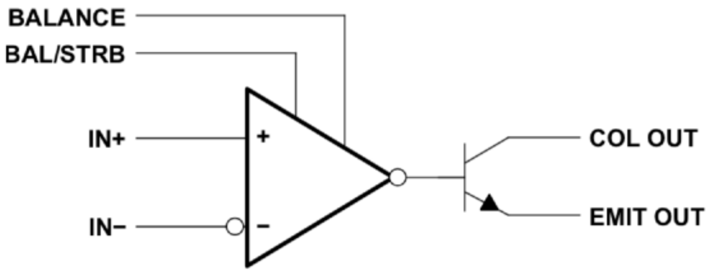
Open collector comparator

Recall that comparator ICs differ from a simple op-amp wired as a comparator.



LM311

Simplified Schematic



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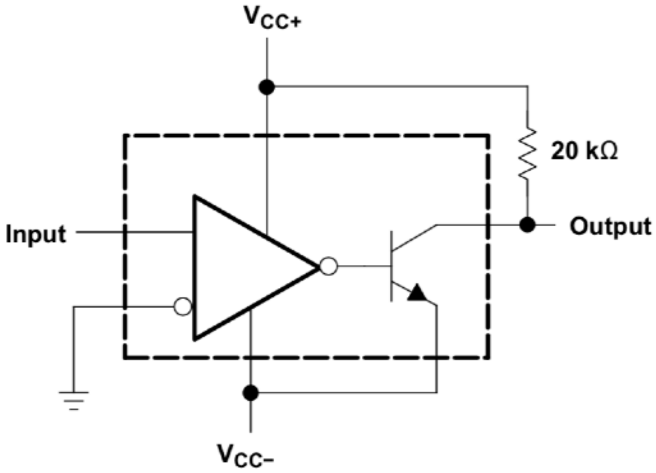

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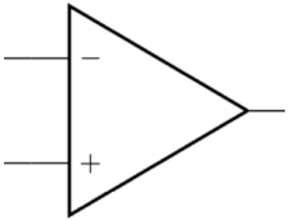
Figure 13. Zero-Crossing Detector

Differential amplifier

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



Differential amplifier

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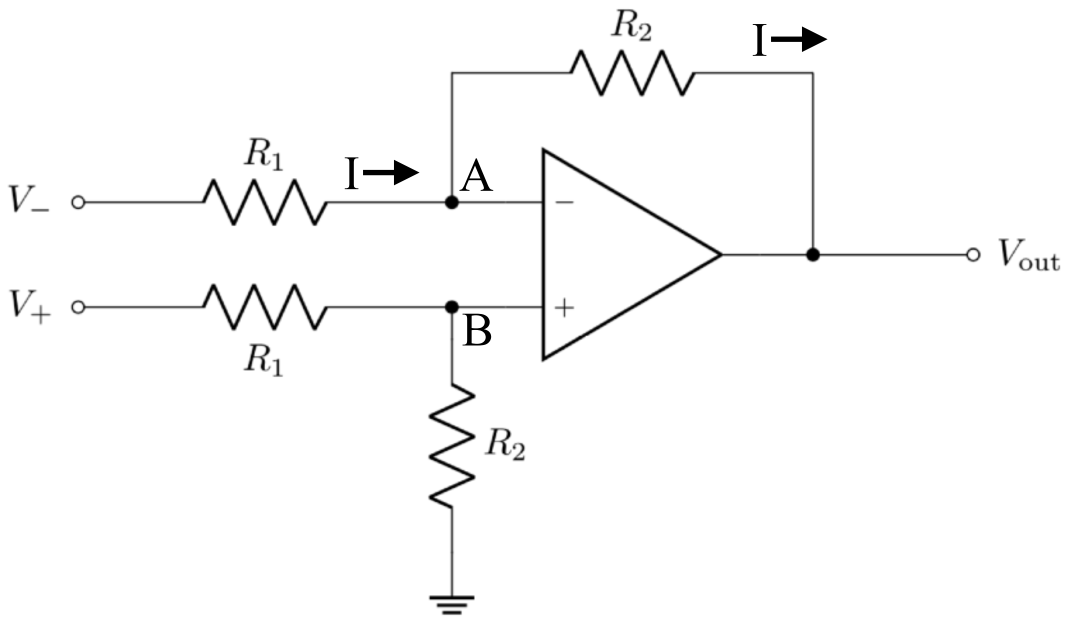

$V_B = V_+ R_2/(R_1+R_2) = V_A$

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

$V_{out} = V_A - I R_2$

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

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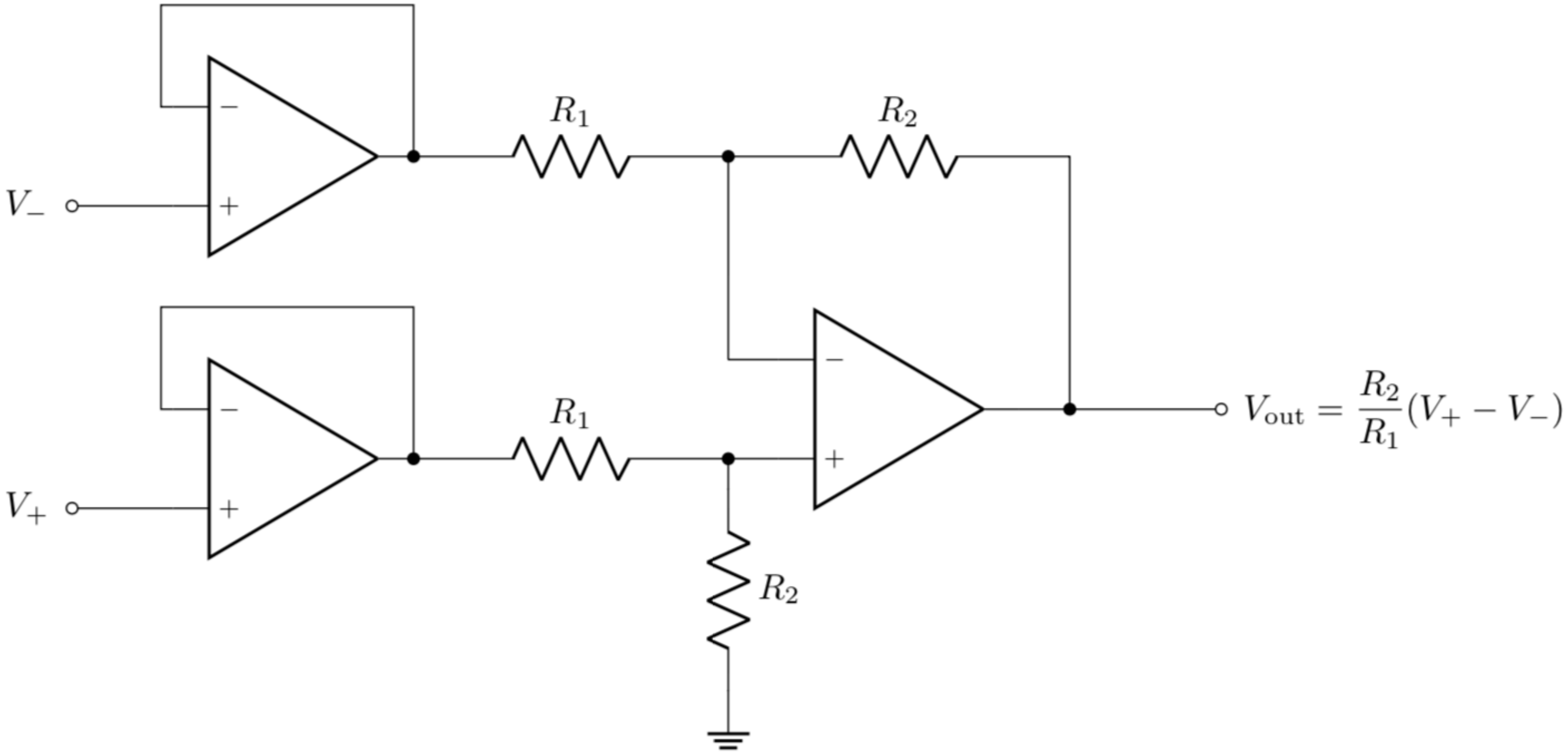
An optimal, general purpose differential amplifier

Ideally, we would“buffer” the inputs and precisely match the resistors.
Worth making this a standard IC.



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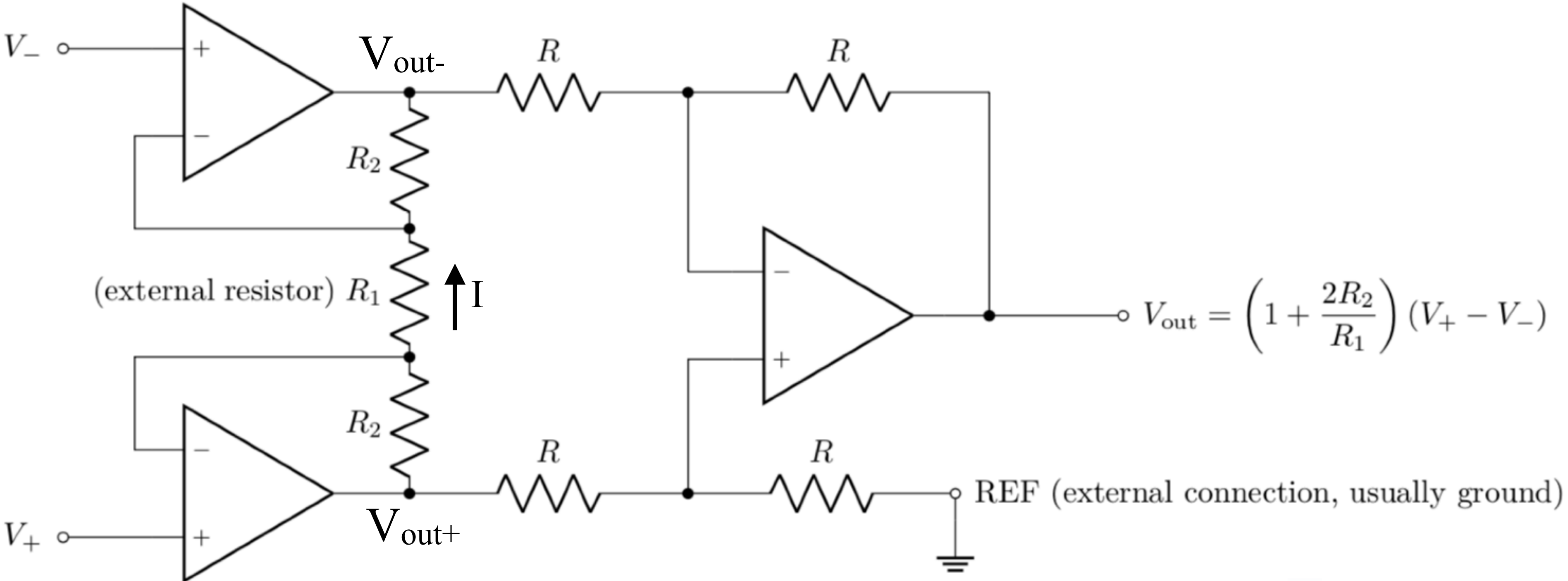
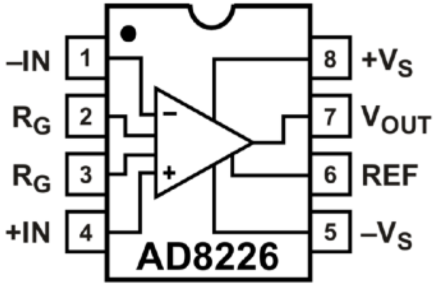
Ideally, we would"buffer" the inputs and precisely match the resistors.
Worth making this a standard IC. Called an "instrumentation amp".





An optimal, general purpose differential amplifier

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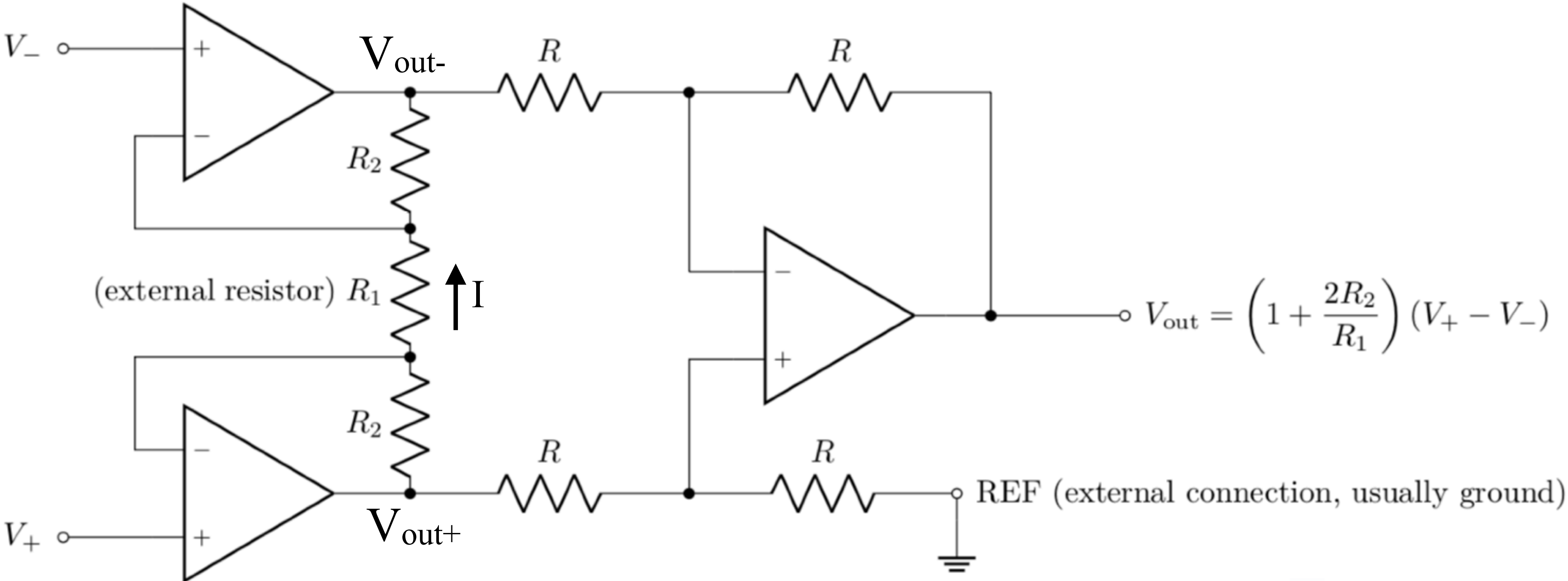
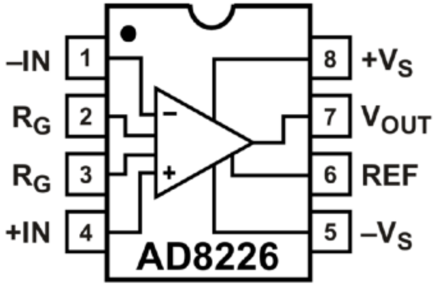


$$V_{out} = (V_{out+} - V_{out-})R/R = V_{out+} - V_{out-}$$



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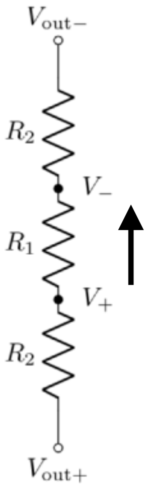
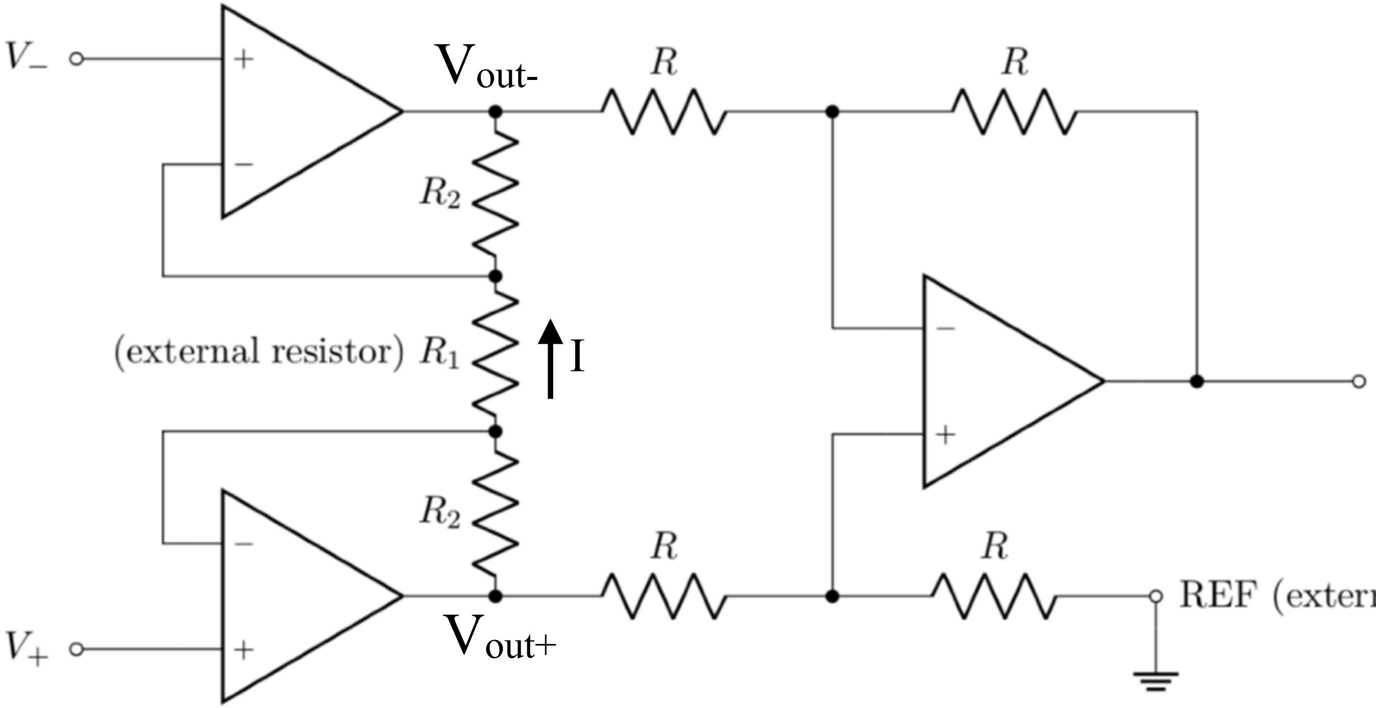
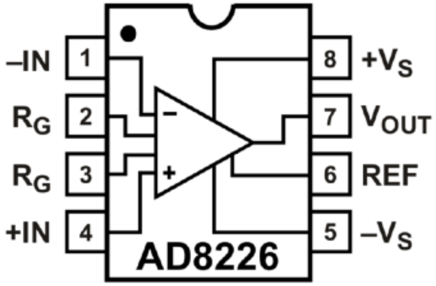




$$V_{\text{out}} = \left(1 + \frac{2R_2}{R_1}\right)(V_+ - V_-)$$

REF (external connection, usually ground)



$V_{out} = (V_{out+} - V_{out-})R/R = V_{out+} - V_{out-}$

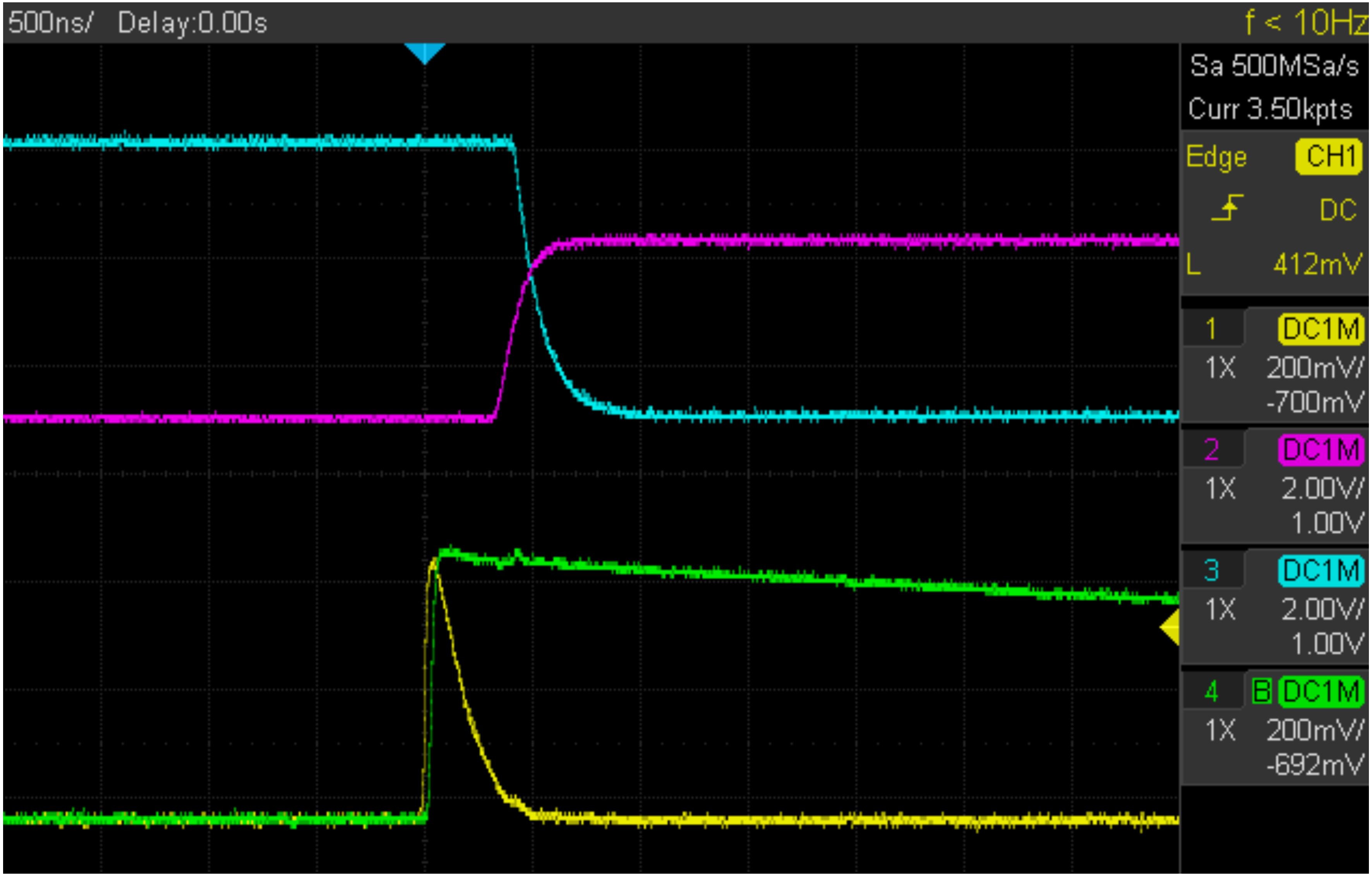
$I = (V_+ - V_-)/R_1$

$V_{out+} = V_+ + I R_2$ and $V_{out-} = V_- - I R_2$

$$V_{\text{out}} = \left(1 + \frac{2R_2}{R_1}\right)(V_+ - V_-)$$

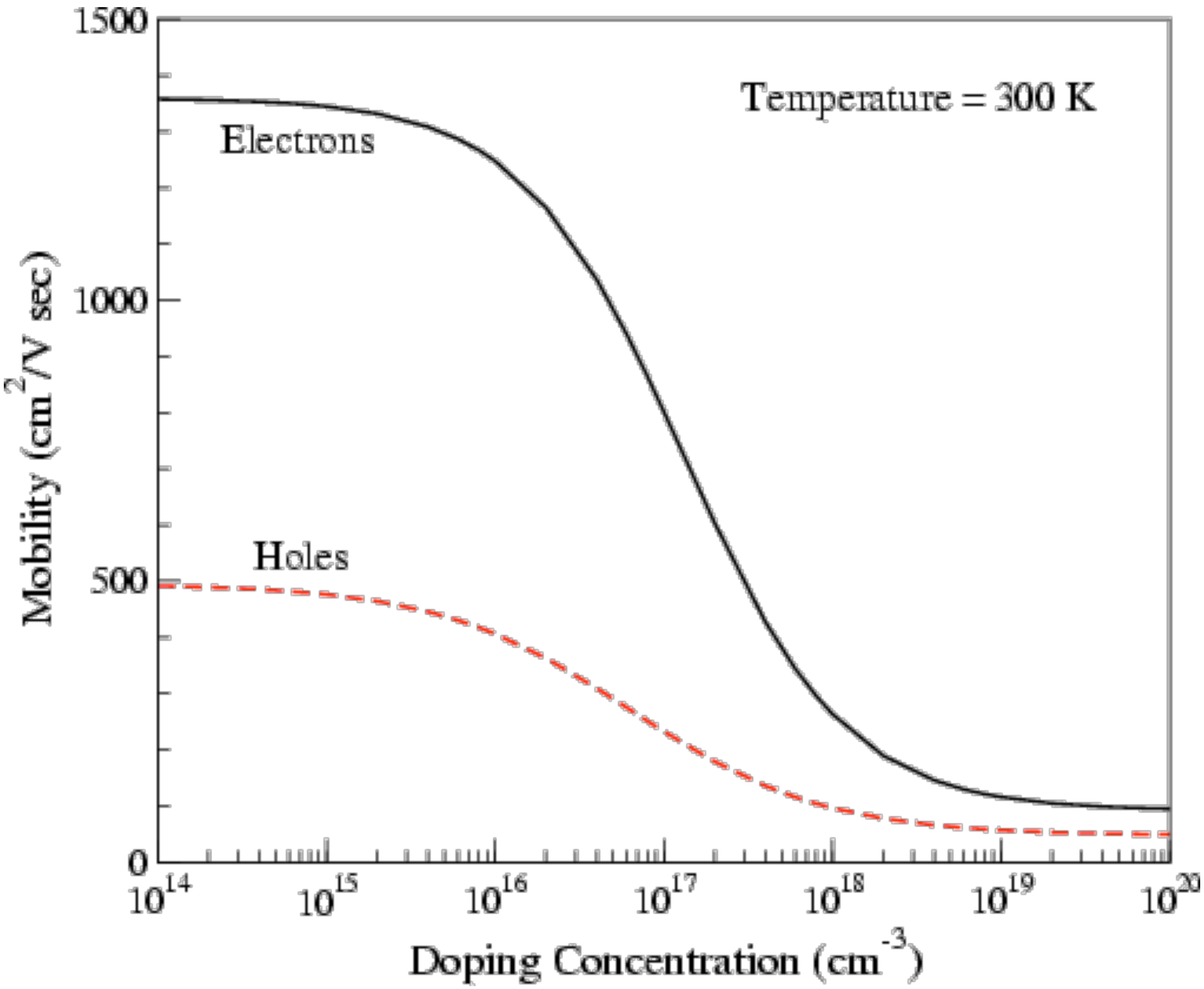
Mobility

The speed of charge carriers is determined by "mobility"



Mobility

The speed of charge carriers is determined by "mobility", μ



$$I = nAqv_d$$

$$v_d = \mu E$$

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