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_- = V_1 - I_ R \\
where \ I = C \frac{dV_2}{dt} \\
What is \( V_1 \)?
\]

\[ T = RC \log 9 \approx 2.2 RC \]
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

This is the “mono-stable” configuration. (Stable only when off.)
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).
Voltage controlled oscillator

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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 $V_{in}$. 

Schmitt trigger
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Integrator with $V_{in}$ control

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Negative feedback

nMOS
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Integrator with $V_{in}$ control

$\text{Out}_1$ linearly ramps down until $V_{EE}/2$, then $\text{Out}_2$ flips to $V_{CC}$.

Ramp rate proportional to $V_{in}$.

If $\text{Out}_1 > 0$ & $\text{Out}_2 = V_{EE}$, then nMOS=off.

C charges as an integrator

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

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

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

$C \frac{dV_{out1}}{dt} = -\frac{V_{in}}{200k}$
Voltage controlled oscillator

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.

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}. 

Integrator with \( V_{in} \) control

Schmitt trigger

Negative feedback

nMOS

\[ \text{Out1 linearly ramps up until } V_{CC}/2, \text{ then Out2 flips to } V_{EE}. \text{ Ramp rate proportional to } V_{in}. \]
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It is sometimes useful to control an oscillator with a voltage, or to encode a voltage as a frequency.

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

![Diagram of sine wave oscillator](image)
Sine wave oscillator

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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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![Diagram of a sine wave oscillator circuit](image)
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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 \( \omega \).

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.
Sine wave from Wien bridge oscillator

We could get a sine wave oscillator in a few ways:
1). Filter square wave with low-pass filter: \( f(x) = \sin(x) + \frac{\sin(3x)}{3} + \frac{\sin(5x)}{5} + \ldots \)
2). Chop the triangle wave
3). Tune resonance

The CR-RC are a hi&low pass filter. At \( \omega = 1/RC \), phase shift at \( V_+ \) is 0° so positive feedback, and \( V_+ = V_{\text{out}}/3 \).

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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If we could finely adjust \( R_g = \frac{R_f}{2} \) to get the non-inverting amp gain of \( G = 1 + \frac{R_f}{R_g} = 3 \), net gain=1.

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 \( \omega = \frac{1}{RC} \).
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.
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":

![Oscilloscope image showing an eye diagram](image-url)
Oscillator performance

A measure of oscillator performance is the frequency drift and phase jitter. "Eye diagram":

![Eye diagram image]
Oscillator performance

A measure of oscillator performance is the frequency drift and phase jitter. "Eye diagram":

![Eye diagram image]
Open collector comparator

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

![Diagram of an open collector comparator with labels: \( V_{in} \), \( V_{Thr} \), \( +5 \text{ V} \), \( 1 \text{ k}\Omega \), \( V_{out} \).]

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**Figure 13. Zero-Crossing Detector**

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Differential amplifier

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

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

\[ V_B = \frac{V_+ R_2}{R_1 + R_2} = V_A \]
\[ I = \frac{V_+ - V_A}{R_1} \]
\[ V_{out} = V_A - I R_2 \]

\[
V_{out} = \frac{V_+ R_2}{R_1 + R_2} - \frac{(V_- - V_A) R_2}{R_1} \\
= R_2 \left[ \frac{V_+}{R_1 + R_2} - \frac{V_-}{R_1} + \frac{V_+ R_2}{R_1 (R_1 + R_2)} \right] \\
= R_2 \left[ \frac{V_+ (1 + R_2/R_1)}{(R_1 + R_2)} - \frac{V_-}{R_1} \right] \\
= R_2 \left[ \frac{V_+ (R_1/R_1 + R_2/R_1)}{(R_1 + R_2)} - \frac{V_-}{R_1} \right] \\
= R_2 \left[ \frac{V_+}{R_1} - \frac{V_-}{R_1} \right] \\
= \frac{(V_+ - V_-) R_2}{R_1}
\]
An optimal, general purpose differential amplifier

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

\[ V_{\text{out}} = \frac{R_2}{R_1} (V_+ - V_-) \]
An optimal, general purpose differential amplifier

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

\[ V_{\text{out}} = \left(1 + \frac{2R_2}{R_1}\right)(V_+ - V_-) \]
An optimal, general purpose differential amplifier

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

\[
V_{\text{out}} = (V_{\text{out}+} - V_{\text{out}-})R/R = V_{\text{out}+} - V_{\text{out}-}
\]

\[
V_{\text{out}} = \left(1 + \frac{2R_2}{R_1}\right) (V_+ - V_-)
\]
An optimal, general purpose differential amplifier

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

\[ V_{out} = \frac{(V_{out+} - V_{out-})}{R} = V_{out+} - V_{out-} \]

\[ I = \frac{(V_+ - V_-)}{R_1} \]

\[ V_{out+} = V_+ + I R_2 \quad \text{and} \quad V_{out-} = V_- - I R_2 \]

\[ V_{out} = \left(1 + \frac{2R_2}{R_1}\right)(V_+ - V_-) \]
Mobility

The speed of charge carriers is determined by "mobility"
Mobility

The speed of charge carriers is determined by "mobility", $\mu$

$$ I = nAq\nu_d $$

$$ \nu_d = \mu E $$