Purdue University Department of Physics

Physics 53600

Electronics Techniques for Research

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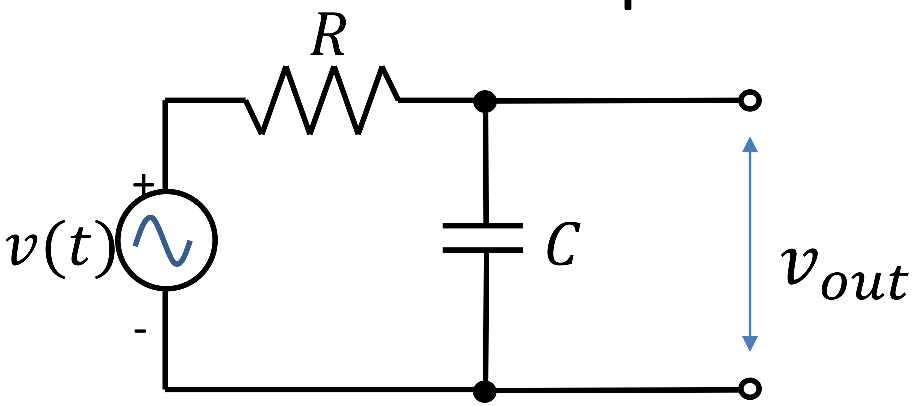
Spring 2020 Semester

Prof. Matthew Jones

Introduction to Active Filters

- First consider a passive low-pass filter circuit:

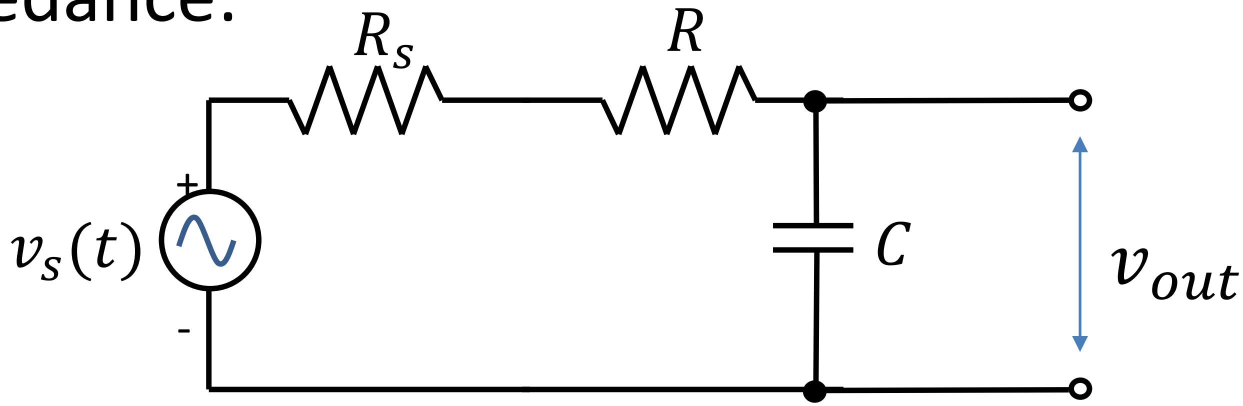


$$Z = R - \frac{i}{\omega C}$$

- Voltage gain: $A = \frac{|v_{out}|}{|v_{in}|} = \frac{1}{\sqrt{1+\omega^2 R^2 C^2}}$
- When $\omega \gg RC$, $A \to \frac{1}{\omega RC}$
- $G = 20\log_{10} A = -20\ \log_{10}\omega + const.$
- Gain falls of at 20 dB per decade.

Introduction to Active Filters

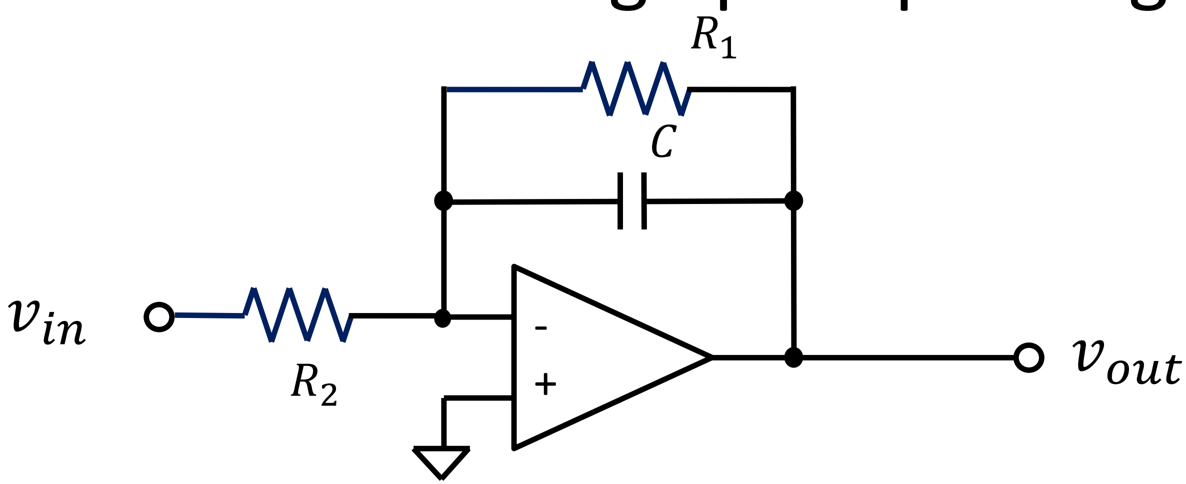
- Even at low frequencies, the circuit attenuates signals from voltage sources with finite output impedance:



- As $\omega \to 0$, the output impedance of the filter circuit is $R_s + Z$. Increasing the number of filter stages also increases the output impedance.

Active Filters

- Consider the following op-amp configuration:



$$v_- = v_+ = 0$$

- Input impedance is R_2. This determines how much current will be drawn from the source.

Active Filters

- Analysis:

$$v_{out}(t) = -i(t)Z$$

$$V_{out} = -\frac{IR_1}{1 + i\omega R_1 C} = -\frac{V_{in} R_1 / R_2}{1 + i\omega R_1 C}$$

$$A = \frac{|V_{out}|}{|V_{in}|} = \frac{R_1}{R_2} \frac{1}{\sqrt{1 + \omega^2 R_1^2 C^2}}$$

- As $\omega \gg 1/R_1 C$, $A \rightarrow \frac{1}{\omega R_2 C}$
- As $\omega \rightarrow 0$, $A \rightarrow R_1/R_2$ and $\phi \rightarrow \pi$
- The output impedance is essentially determined by the non-ideal op-amp properties. Adding a load resistance doesn't change the analysis.

Example: AD8047

ANALOG DEVICES

250 MHz, General Purpose Voltage Feedback Op Amps

AD8047/AD8048

FEATURES

Wide Bandwidth	AD8047, G = +1	AD8048, G = +2
Small Signal	250 MHz	260 MHz
Large Signal (2 V p-p)	130 MHz	160 MHz

5.8 mA Typical Supply Current
Low Distortion, (SFDR) Low Noise
- –66 dBc Typ @ 5 MHz
- –54 dBc Typ @ 20 MHz
- 5.2 nV/$\sqrt{Hz}$ (AD8047), 3.8 nV/$\sqrt{Hz}$ (AD8048) Noise

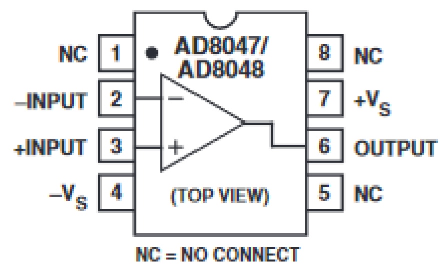
Drives 50 pF Capacitive Load
High Speed
- Slew Rate 750 V/μs (AD8047), 1000 V/μs (AD8048)
- Settling 30 ns to 0.01%, 2 V Step

±3 V to ±6 V Supply Operation

APPLICATIONS

Low Power ADC Input Driver
Differential Amplifiers
IF/RF Amplifiers
Pulse Amplifiers
Professional Video
DAC Current to Voltage Conversion
Baseband and Video Communications
Pin Diode Receivers
Active Filters/Integrators

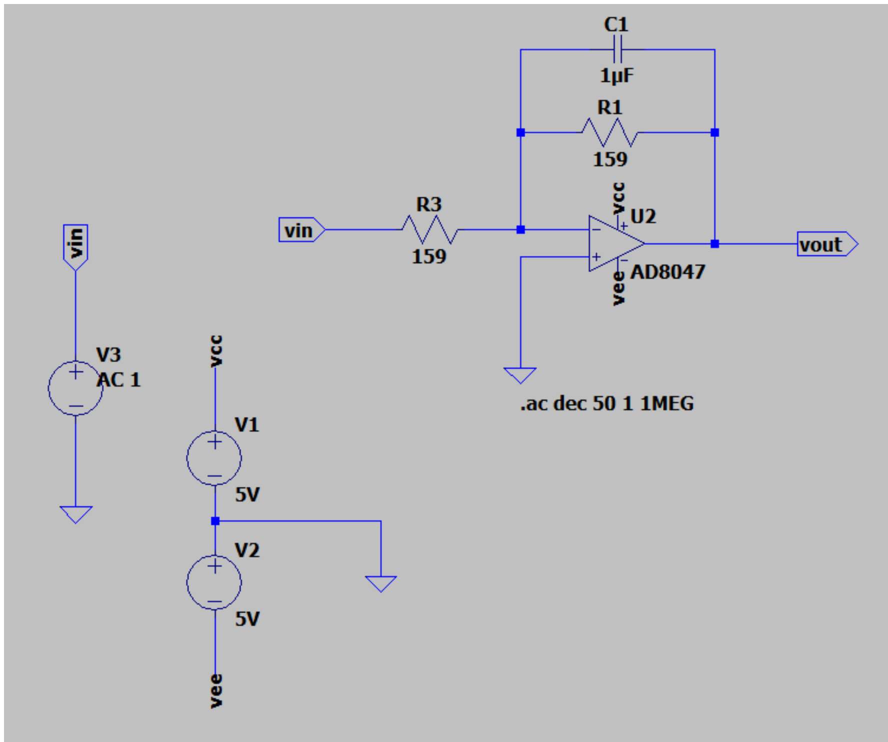
FUNCTIONAL BLOCK DIAGRAM
8-Pin Plastic PDIP (N) and SOIC (R) Packages

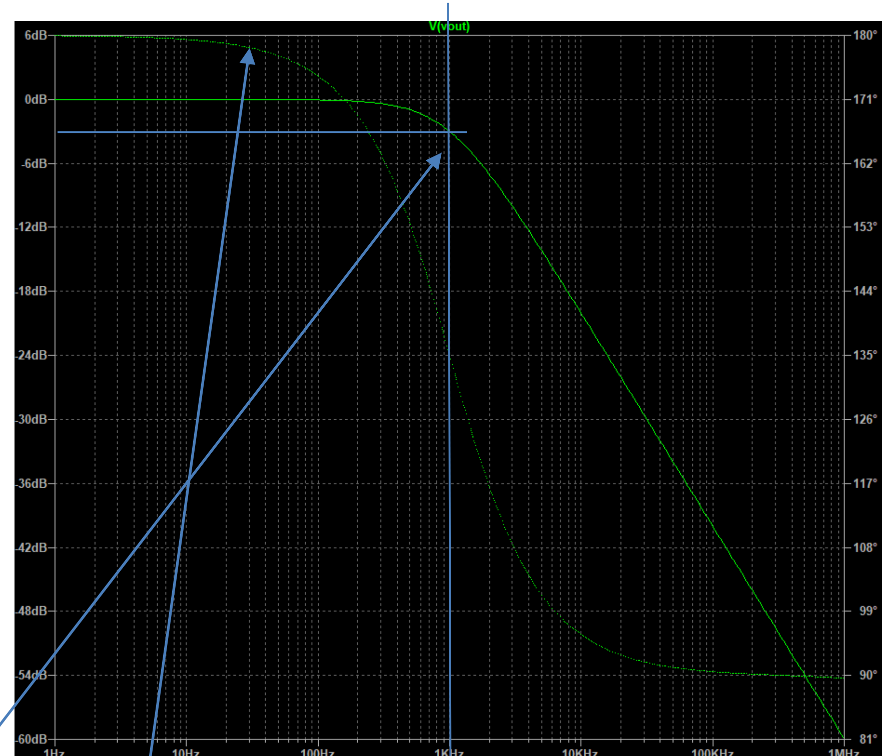


The AD8047 and AD8048's low distortion and cap load drive make the AD8047/AD8048 ideal for buffering high speed ADCs. They are suitable for 12-bit/10 MSPS or 8-bit/60 MSPS ADCs. Additionally, the balanced high impedance inputs of the voltage feedback architecture allow maximum flexibility when designing active filters.

The AD8047 and AD8048 are offered in industrial (–40°C to +85°C) temperature ranges and are available in 8-lead PDIP and SOIC packages.

Example





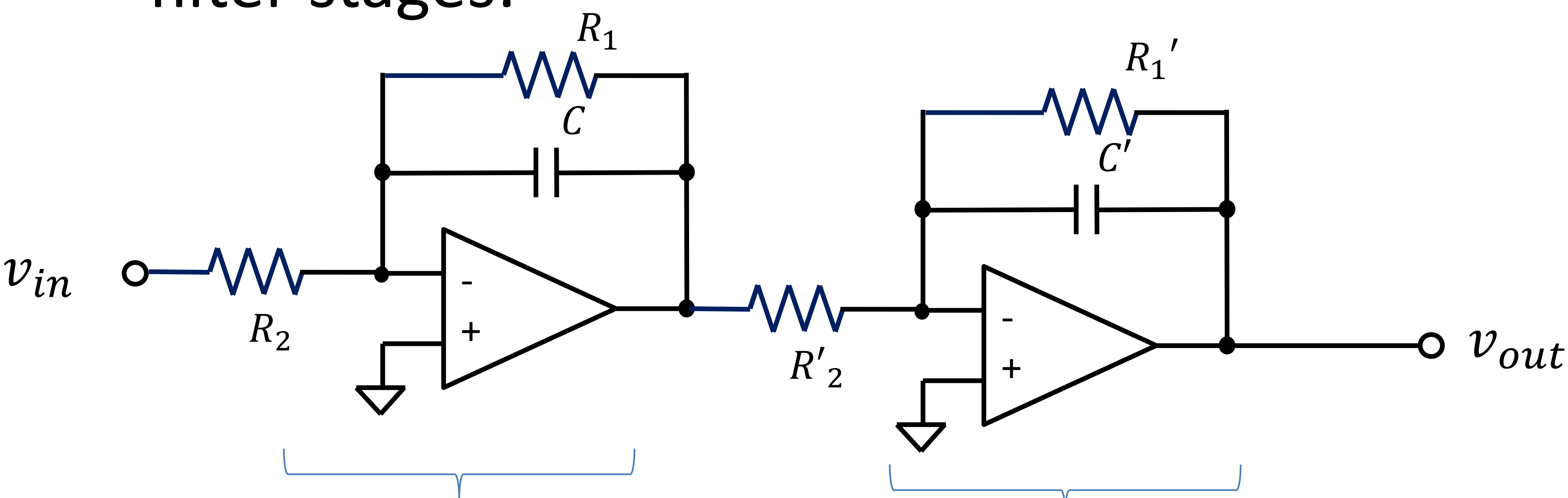
$$R_1 = R_2 = 159\ \Omega$$
$$(1\ k\Omega/2\pi)$$
$$C = 1\ \mu F$$

-3 dB cutoff frequency $= 1\ kHz$

Phase at low frequencies is 180°

Active Filters

- The property of having a low output impedance and an output that is isolated from the input makes it easy to analyze additional filter stages:



$$A = \frac{R_1}{R_2} \frac{1}{\sqrt{1 + \omega^2 R_1^2 C^2}}$$

$$A' = \frac{R'_1}{R'_2} \frac{1}{\sqrt{1 + \omega^2 R'^2_1 C'^2}}$$

Active Filters

- The voltage gains of each stage just multiply:

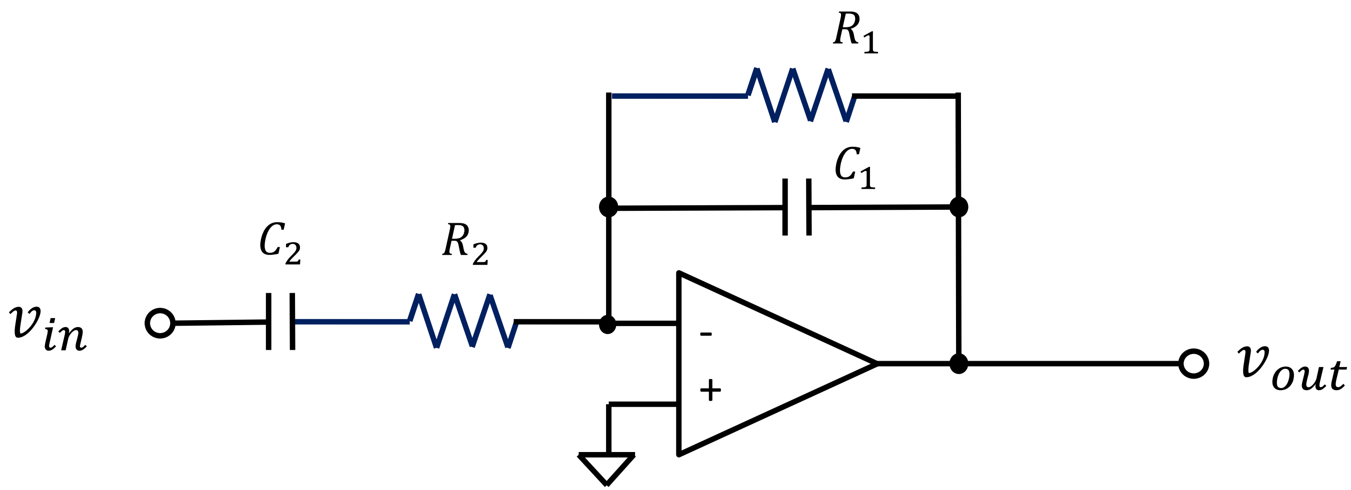
$$A_{total} = A\,A'$$
$$= \frac{R_1}{R_2} \cdot \frac{R_1'}{R_2'} \cdot \frac{1}{\sqrt{(1+\omega^2 R_1^2 C^2)(1+\omega^2 R_1'^2 C'^2)}}$$

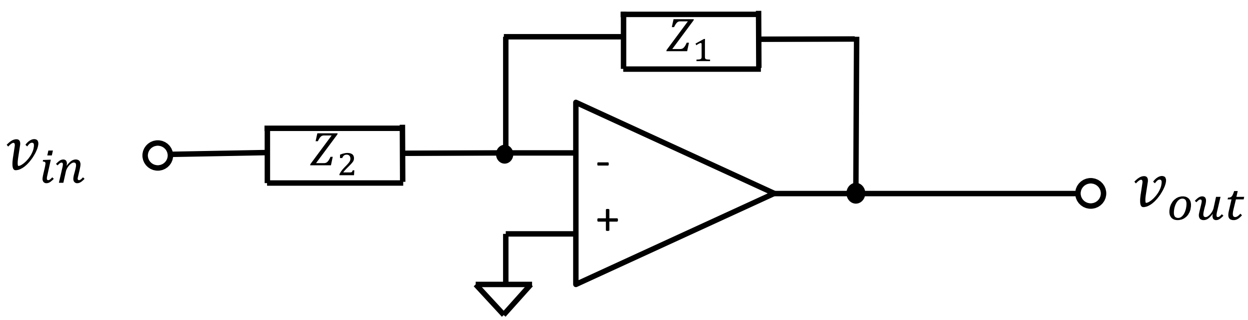
- If $R_1 = R_2 = R_1' = R_2' \equiv R$, and $C' = C$ then

$$A = \frac{1}{1+\omega^2 R^2 C^2}$$

- Unity gain at low frequencies,
- Gain falls off at 40 dB per decade for $\omega \gg 1/RC$

Active Band-Pass Filter





$$v_- = v_+ = 0$$

$$i_{in} = \frac{v_{in}}{Z_2} \qquad v_{out} = -i_{in}Z_1 = -v_{in}\frac{Z_1}{Z_2}$$

Active Band-Pass Filter

$$Z_1 = \frac{R_1}{1+i\omega R_1 C_1} \quad \text{(parallel R and C)}$$

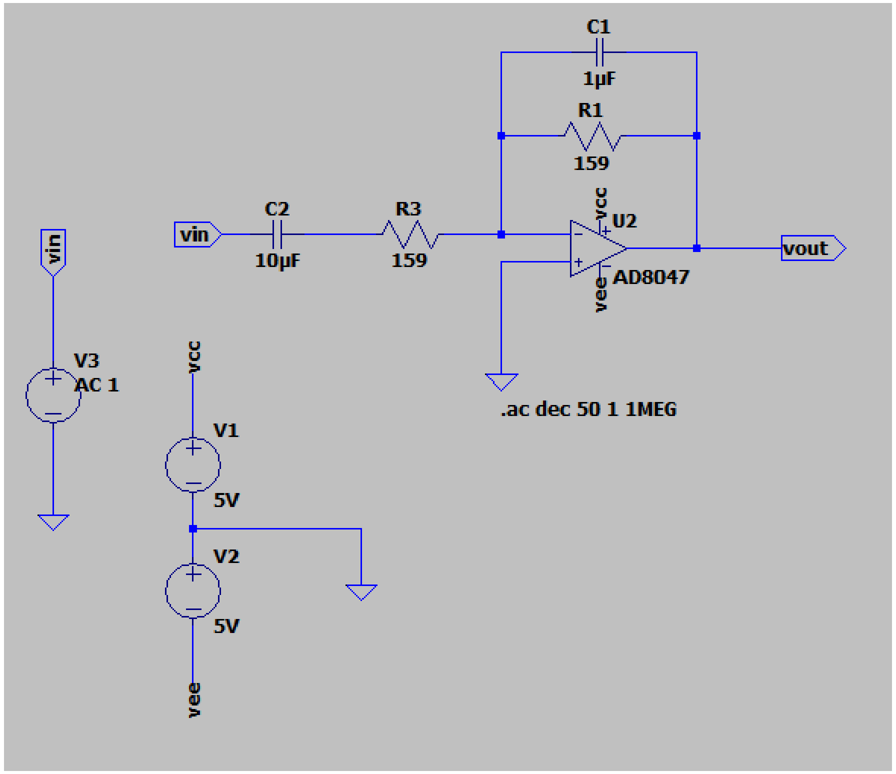
$$Z_2 = R_2 - \frac{i}{\omega C_2} \quad \text{(series R and C)}$$

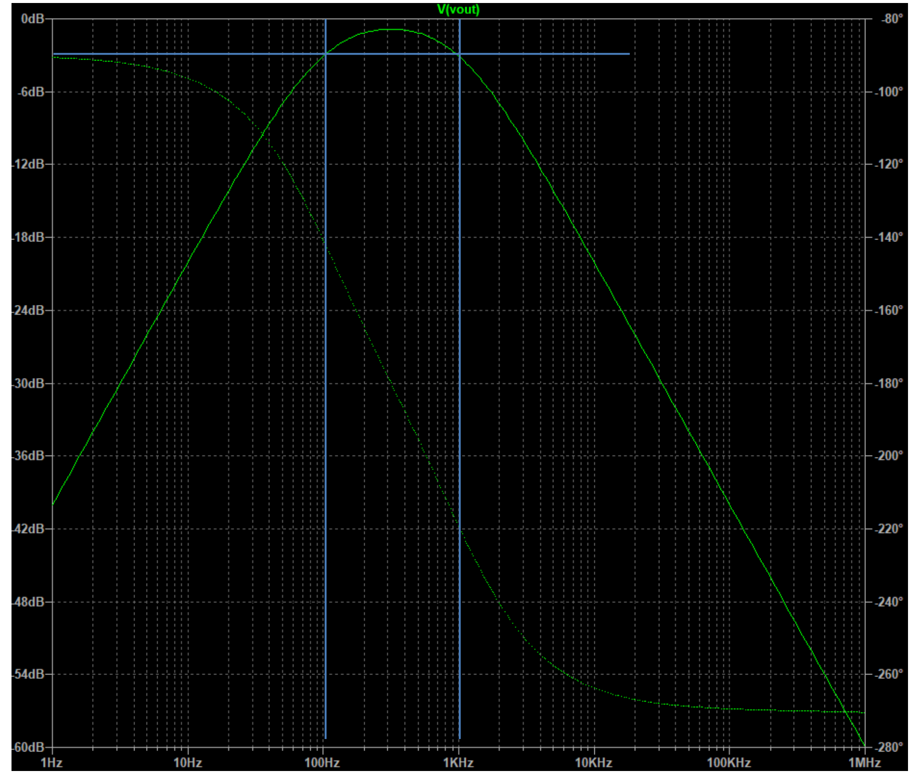
- From analogy with only resistors, the gain will be

$$A = \left|\frac{Z_1}{Z_2}\right| = \frac{R_1}{R_2} \frac{1}{\sqrt{\left(1 + \frac{R_1 C_1}{R_2 C_2}\right)^2 + \left(\omega R_1 C_1 - \frac{1}{\omega R_2 C_2}\right)^2}}$$

- Cutoff frequencies ($A = 1/\sqrt{2}$):
  - Low frequency: $\omega_- = 1/R_2 C_2$
  - High frequency: $\omega_+ = 1/R_1 C_1$

Example

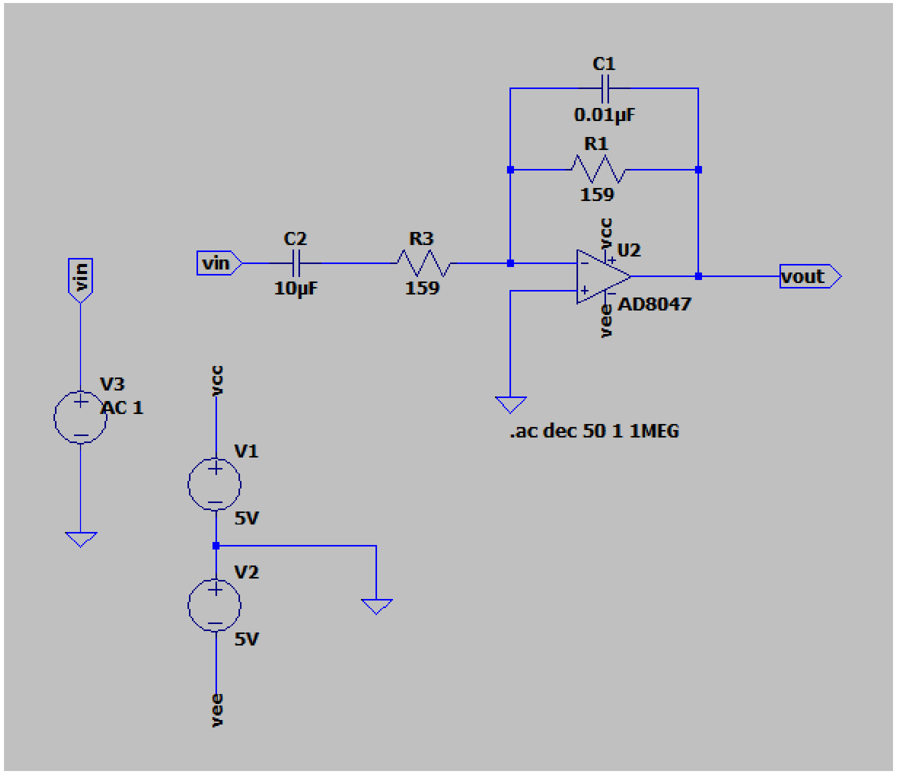


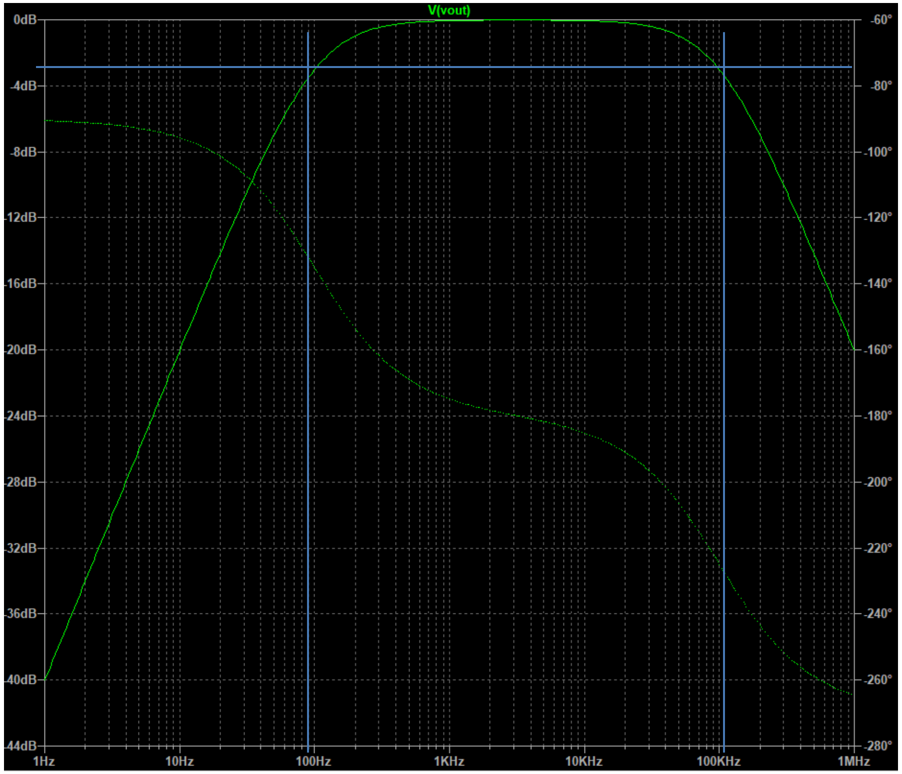


$$\omega_- = \frac{1}{R_2 C_2} = 628.9\ s^{-1} \rightarrow f_- = 100\ Hz$$

$$\omega_+ = \frac{1}{R_1 C_1} = 6289\ s^{-1} \rightarrow f_+ = 1000\ Hz$$

Example

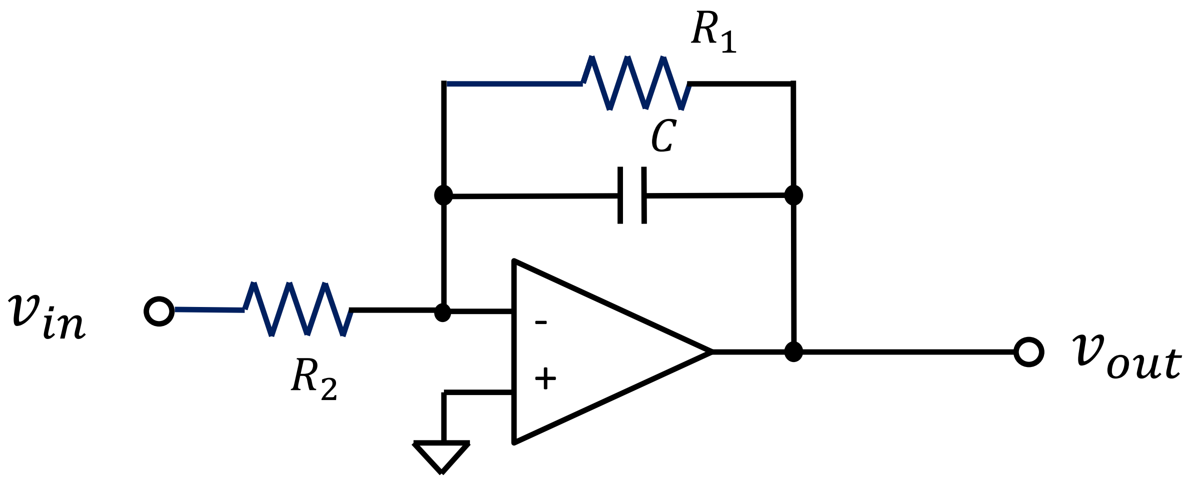




$$\omega_{-} = \frac{1}{R_2 C_2} = 628.9\ s^{-1} \rightarrow f_{-} = 100\ Hz$$

$$\omega_{+} = \frac{1}{R_1 C_1} = 628900\ s^{-1} \rightarrow f_{+} = 100\ kHz$$

Oscillators

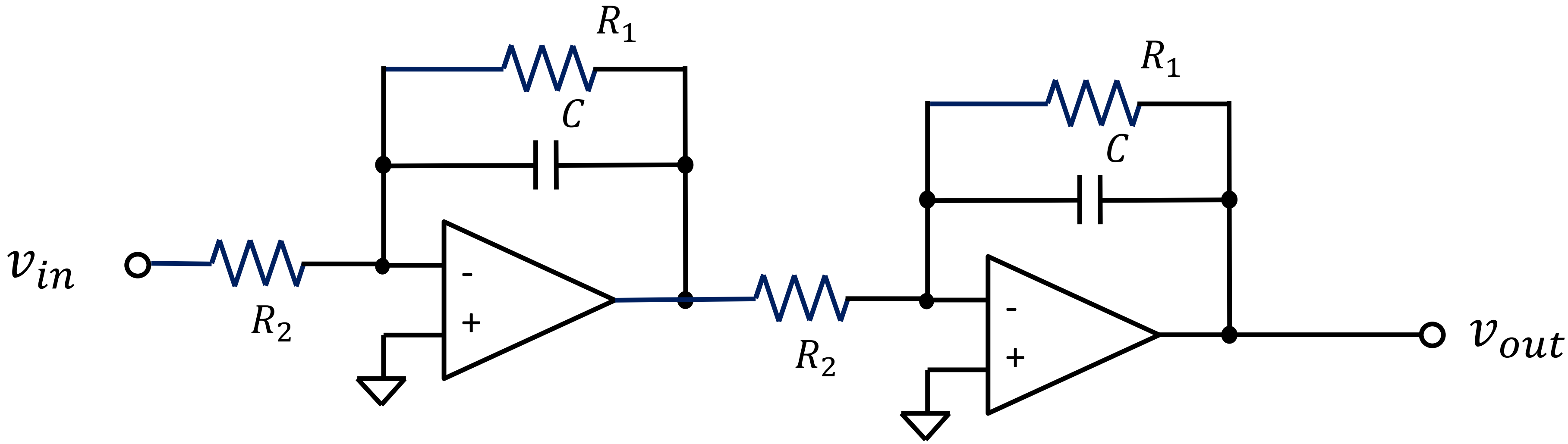


$$V_{out} = -V_{in}\frac{R_1}{R_2}\frac{1}{1 + i\omega R_1 C}$$

$$A = \frac{R_1}{R_2}\frac{1}{\sqrt{1 + \omega^2 R_1^2 C^2}}$$

$$\tan\phi = -\omega R_1 C$$

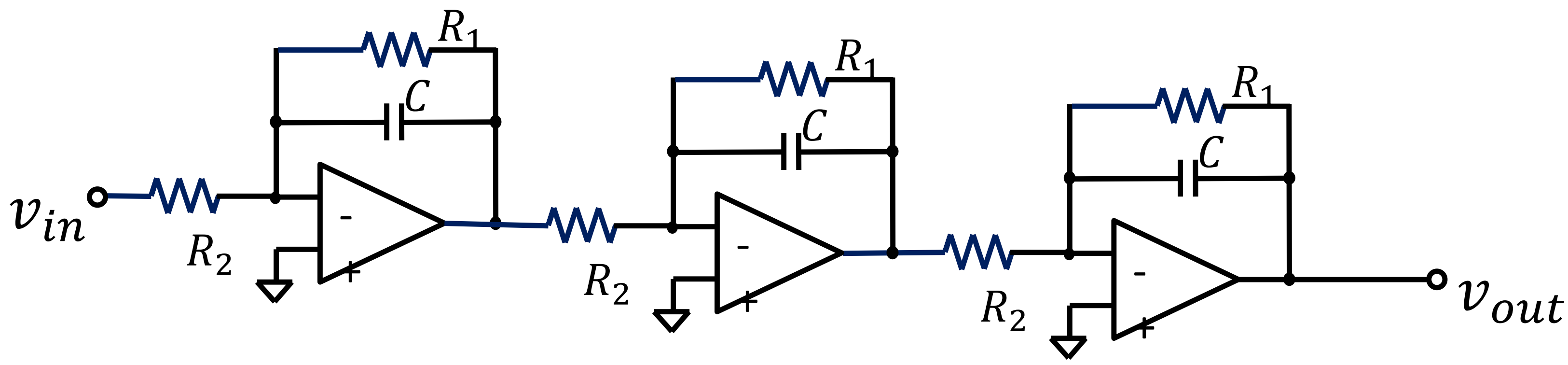
Oscillators



$$A = \left(\frac{R_1}{R_2}\right)^2 \frac{1}{1 + \omega^2 R_1^2 C^2}$$

$$\tan\phi \approx -2\omega R_1 C$$

Oscillators

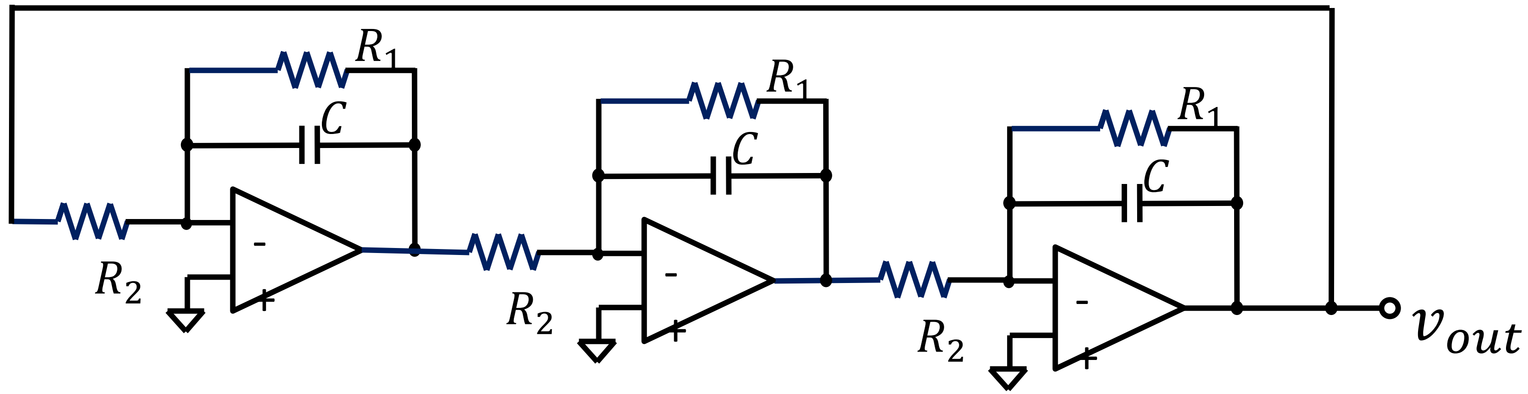


$$A = \left(\frac{R_1}{R_2}\frac{1}{\sqrt{1+\omega^2 R_1^2 C^2}}\right)^3$$

$$\tan\phi \approx -3\omega R_1 C$$

Oscillators

- Now connect the output to the input:



- Total phase shift:

$$\phi = 2n\pi$$

- Individual phase shift:

$$\tan\frac{2\pi}{3} = -\omega R_1 C = -\sqrt{3}$$

- Oscillation frequency is $\omega = \frac{\sqrt{3}}{R_1 C}$