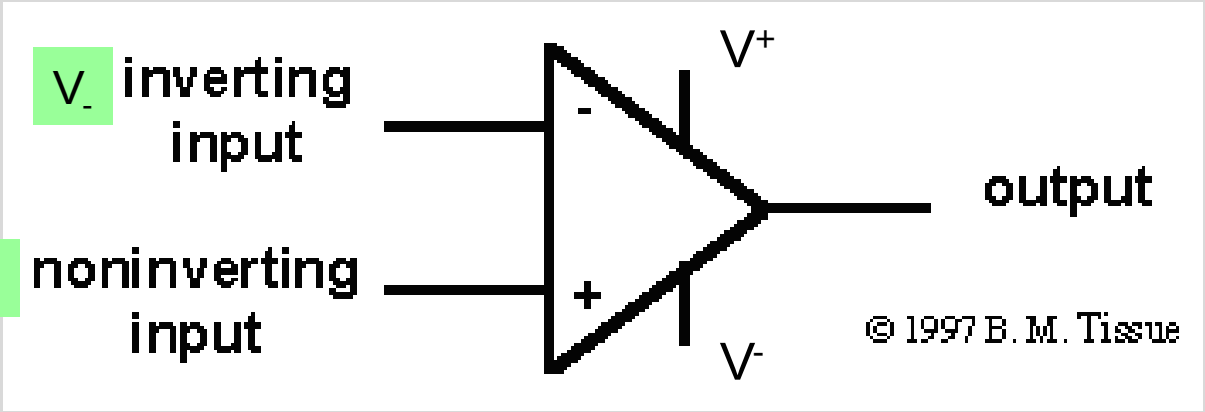
E80 Spring 2014

Op Amps Circuits

Agenda: Operational Amplifier

- Recap: Non-inverting amplifier and unity gain buffer
- Inverting amplifier (multiplication)
- Summing amplifier (add and subtract)
- Differentiator and integrator
- Difference amplifier
- Instrumentation amplifier
- Transimpedance amplifier
- Active filters

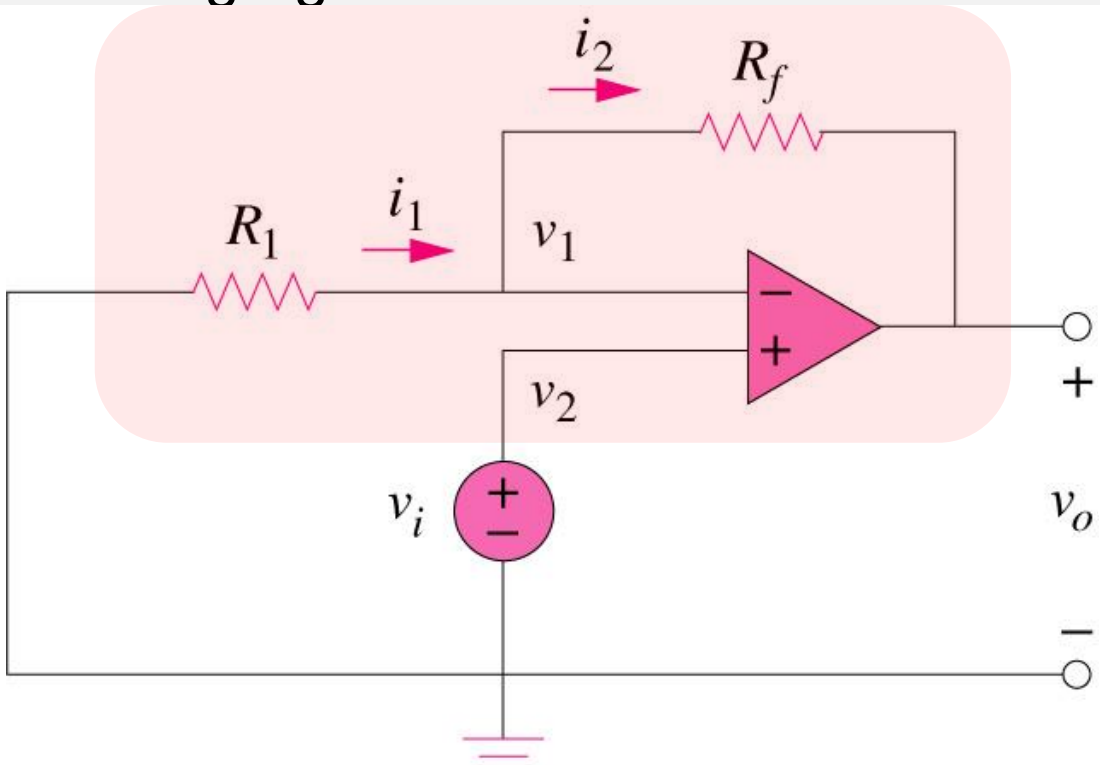
Recap: Opamp Model

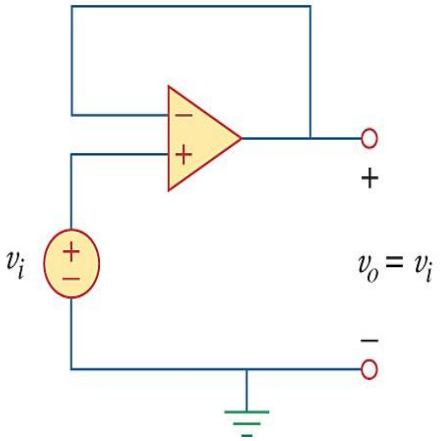


$$(1) v_+ = v_- \qquad (2)\ i_+ = 0, \quad i_- = 0$$

Recap: Non-inverting Amplifier

- Non-inverting amplifier is designed to produce positive voltage gain



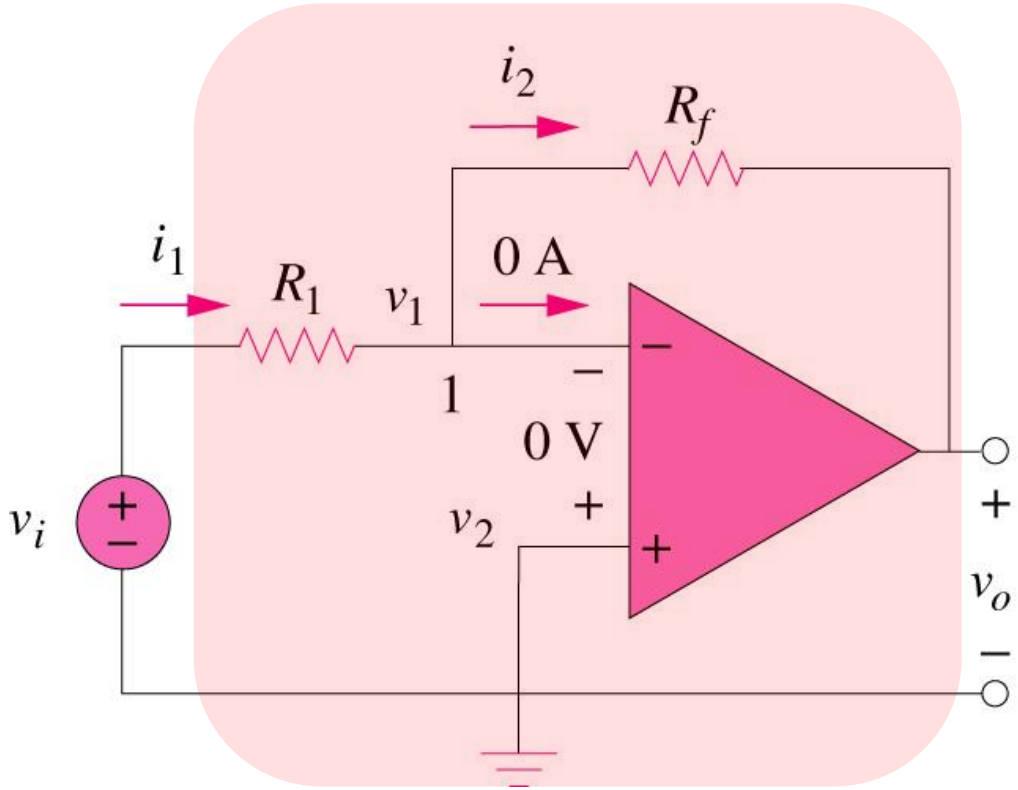


Special case:
$R_1 = \infty$, $R_f = 0$
Unity-gain buffer

$$v_0 = (1 + \frac{R_f}{R_1})v_i$$

Inverting amplifier

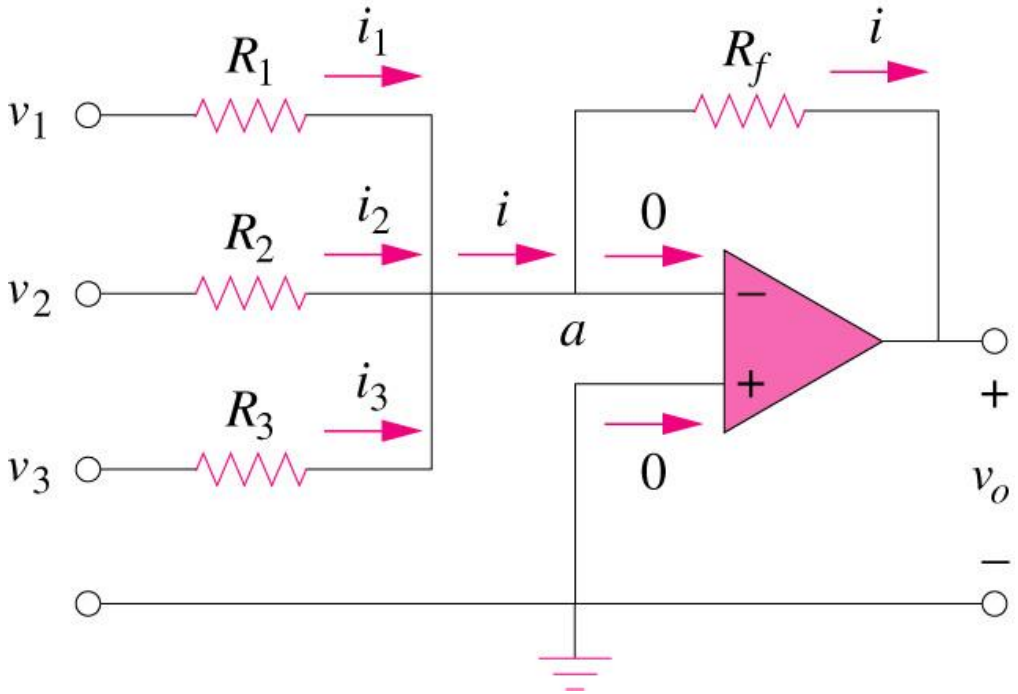
- Inverting amplifier reverses the polarity of the input signal while amplifying (or attenuating) it



$$v_o = -\frac{R_f}{R_1} v_i$$

Summing amplifier

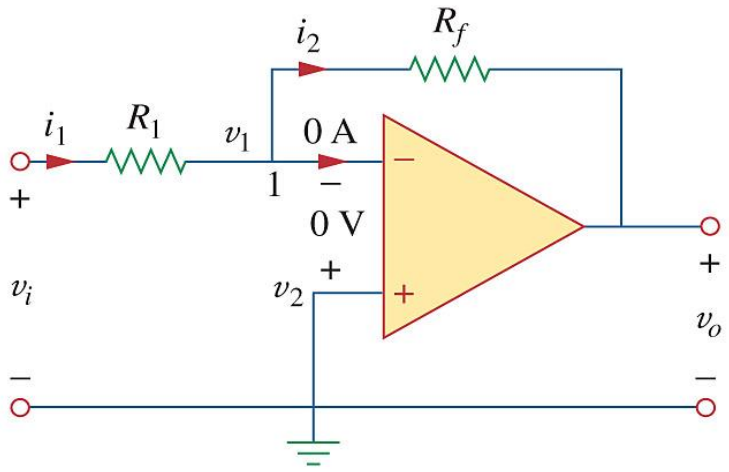
- Summing Amplifier is an op amp circuit that combines several inputs and produces an output that is the weighted sum of the inputs.



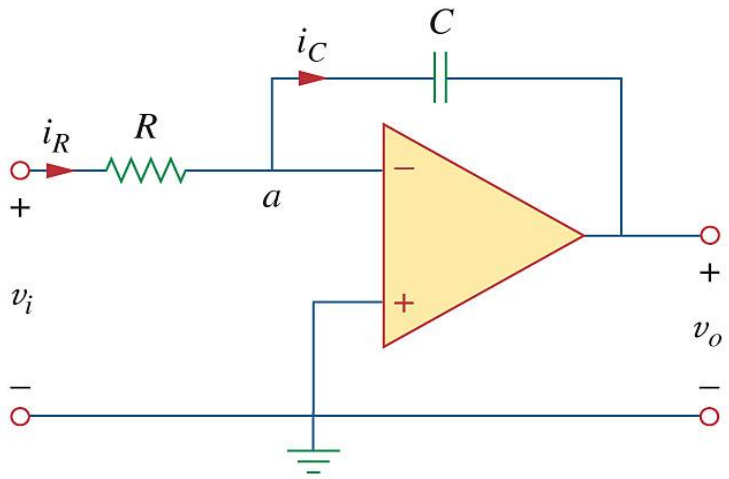
$$v_o = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3\right)$$

Q: Is it possible to construct a non-inverting summing amp?

Opamp Circuit With Capacitor



(a)

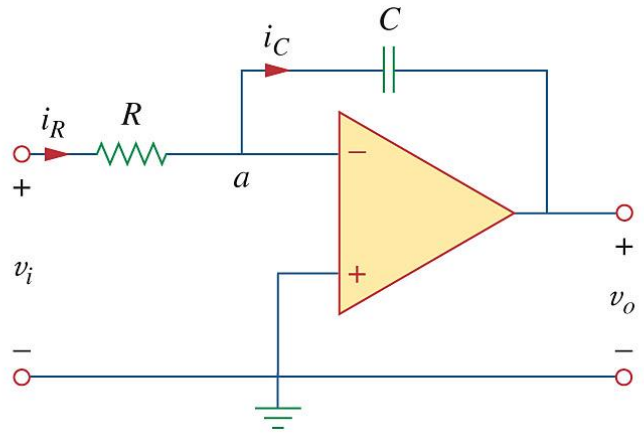


(b)

Inverting amplifier

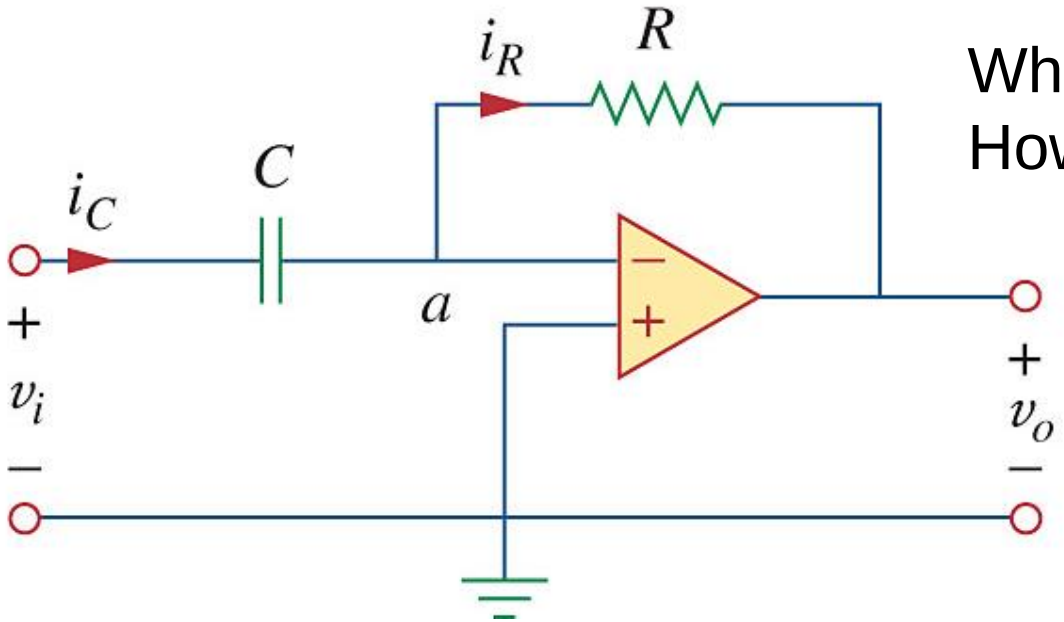
What does this circuit do?
How is *V*o related to *V*i?

Opamp Circuit With Capacitor



Integrator circuit

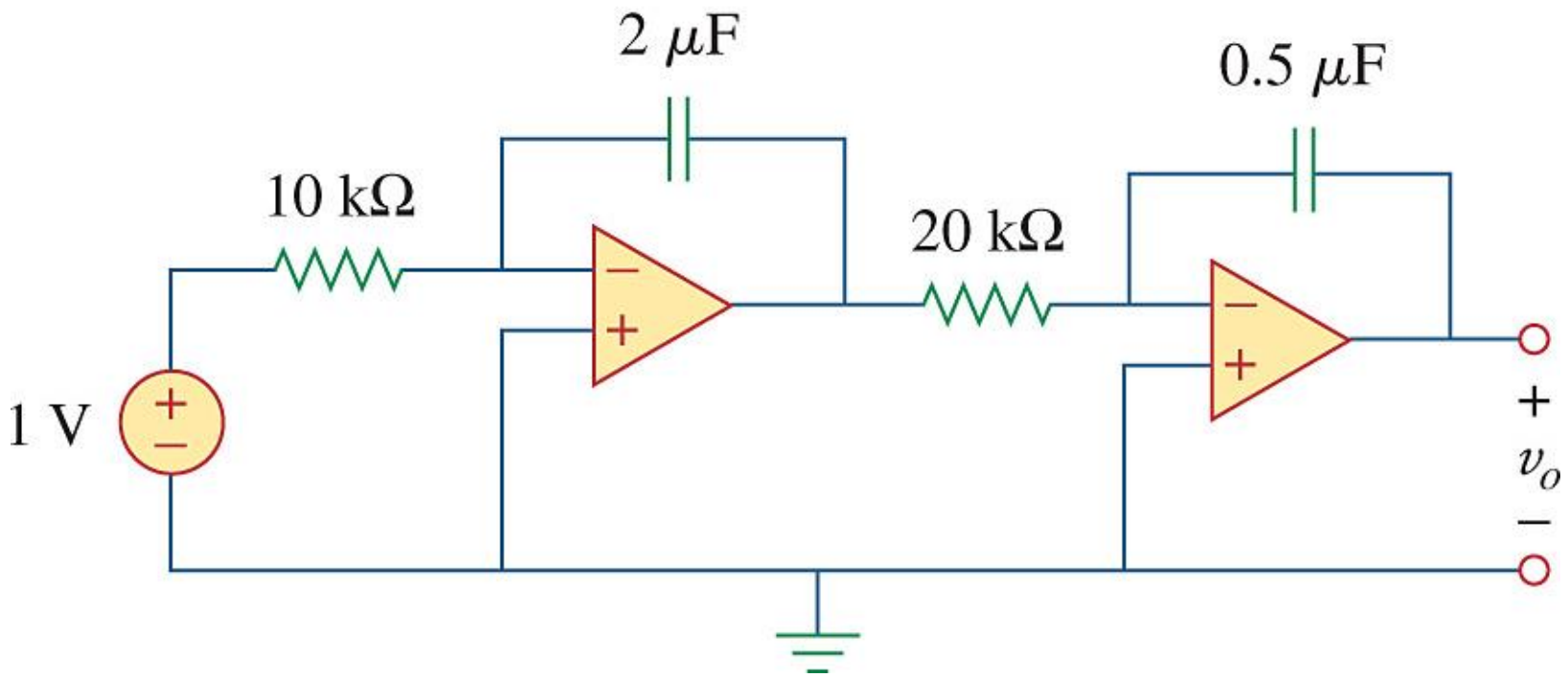
$$v_o(t) = -\frac{1}{RC}\int_0^t v_i(\tau)d\tau + v_C(0)$$



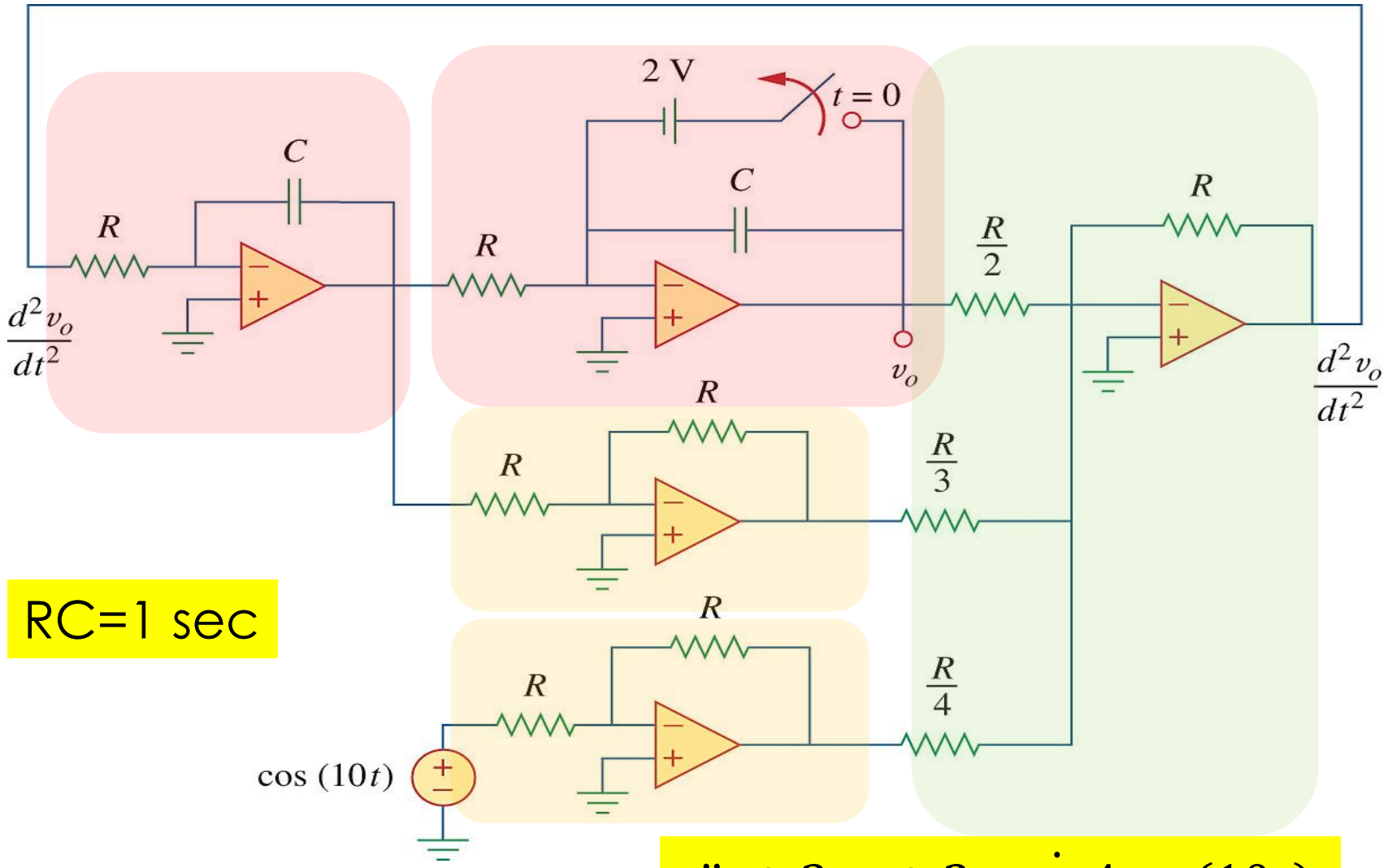
What does this circuit do?
How is Vo related to Vi?

Example

What does the output waveform look like?



Solving Differential Equation Using Opamp Circuit

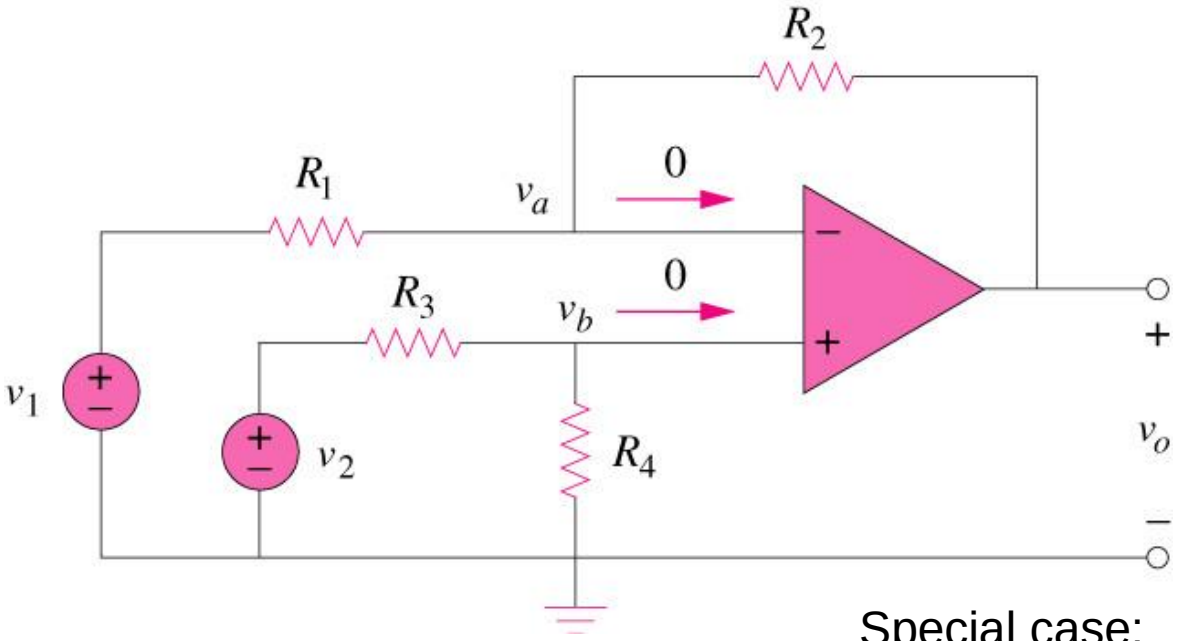


RC=1 sec

$$\ddot{v_0} + 3v_0 + 2v_0 \doteq 4\cos(10t)$$

Difference Amplifier

- Difference amplifier is a device that amplifies the difference between two inputs but rejects any signals common to the two inputs.

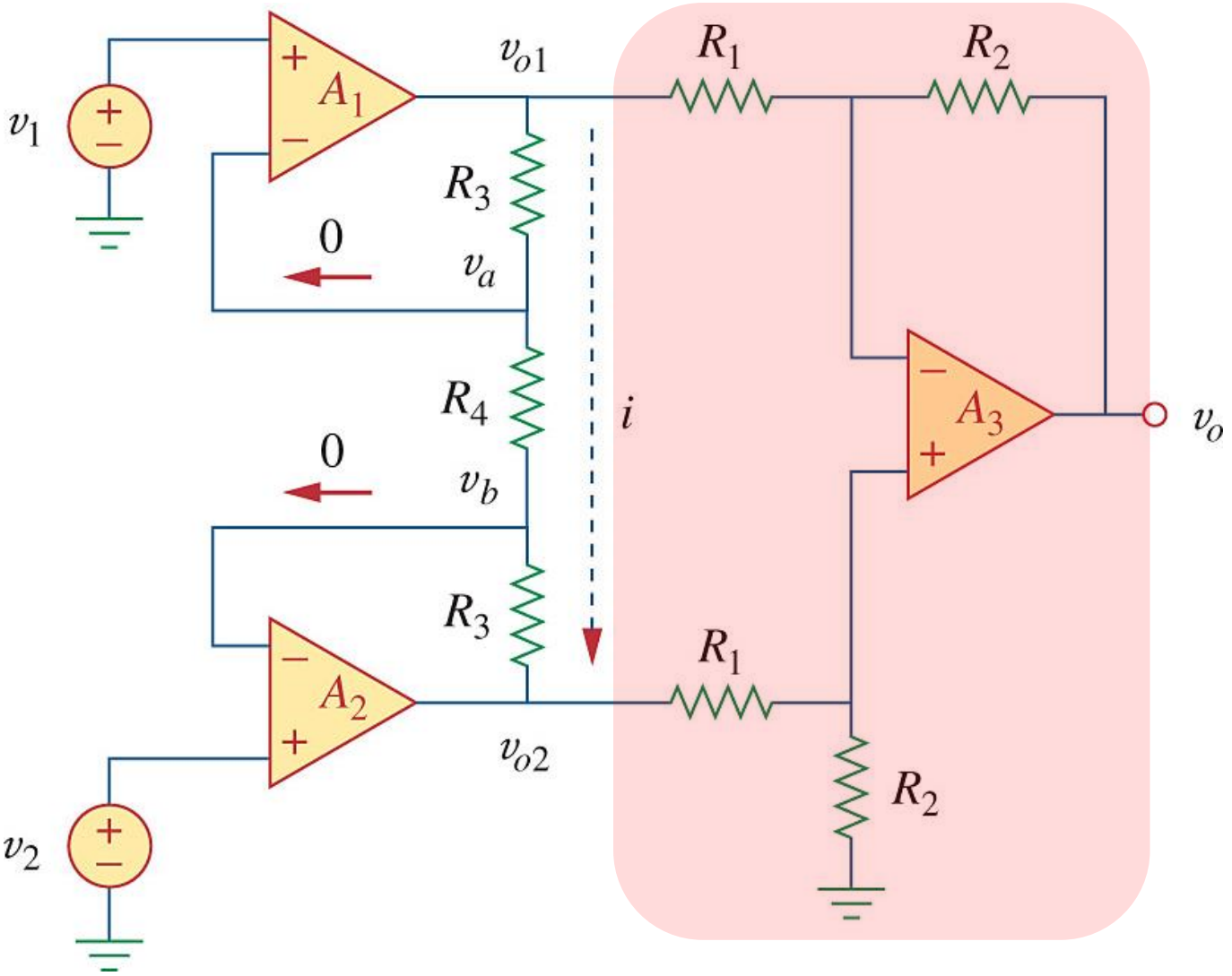


Special case:

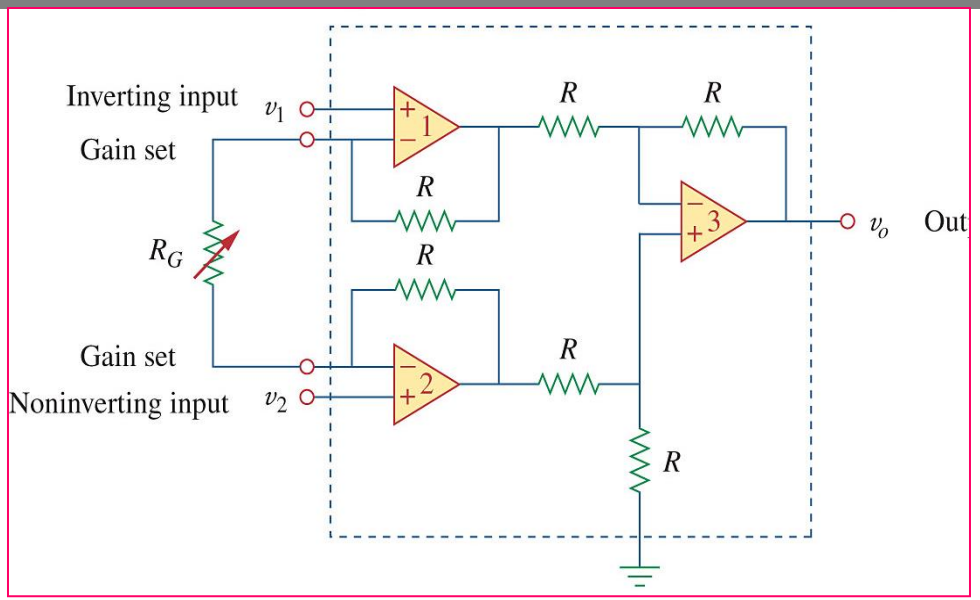
$$v_0 = \frac{1 + R_2/R_1}{1 + R_3/R_4} v_2 - \frac{R_2}{R_1} v_1$$

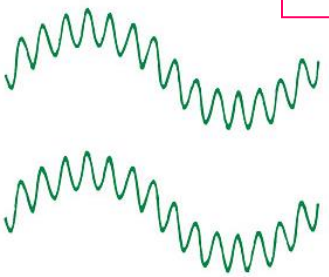
$$R_1 = R_2 \ \ and \ R_3 = R_4$$
$$v_0 = v_2 - v_1$$

Instrumentation Amplifier

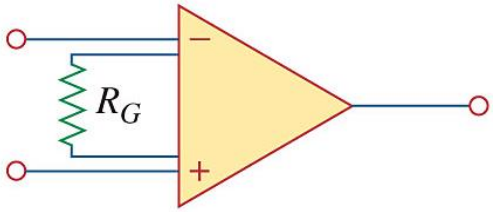


Instrumentation Amplifier Application

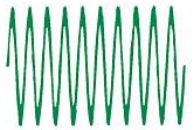




Small differential signals riding on larger common-mode signals



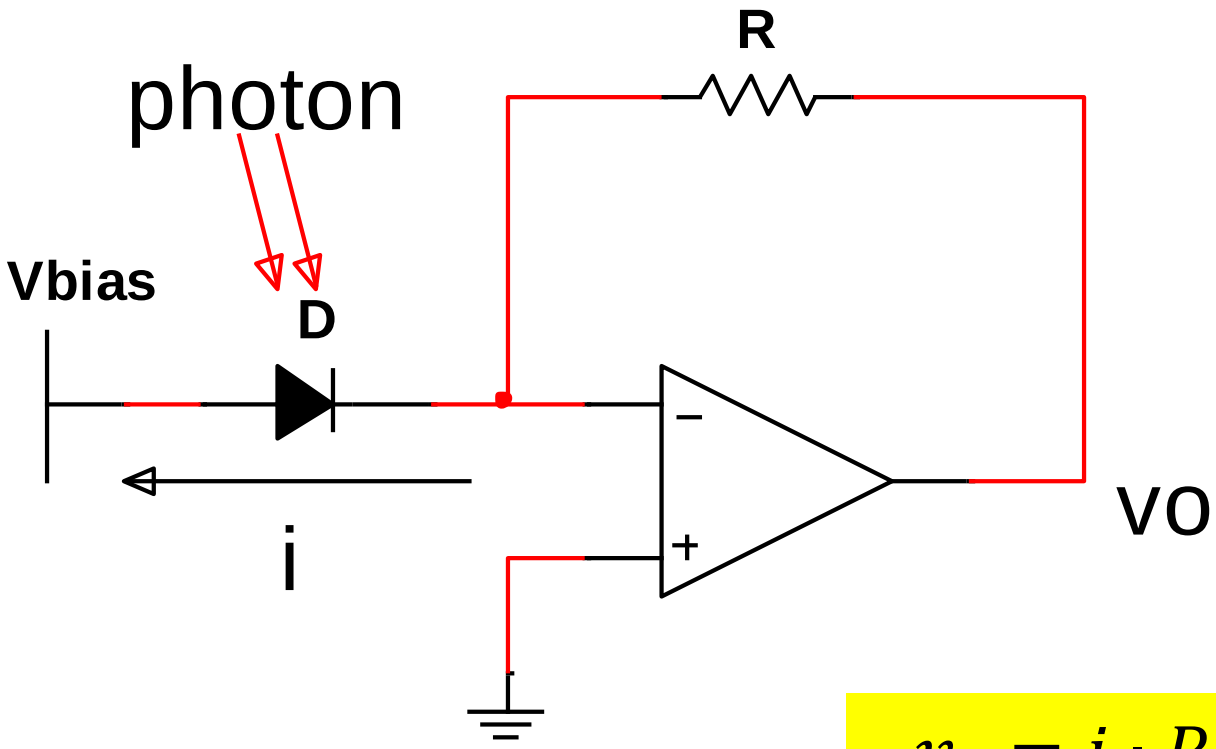
Instrumentation amplifier



Amplified differential signal, No common-mode signal

(1) Only amplify difference
(2) Infinite Input resistance
& zero Output resistance

Transimpedance amplifier for photodiode



$$v_0 = i \cdot R$$

- Much easier to measure voltage than current
- Provide large amplification

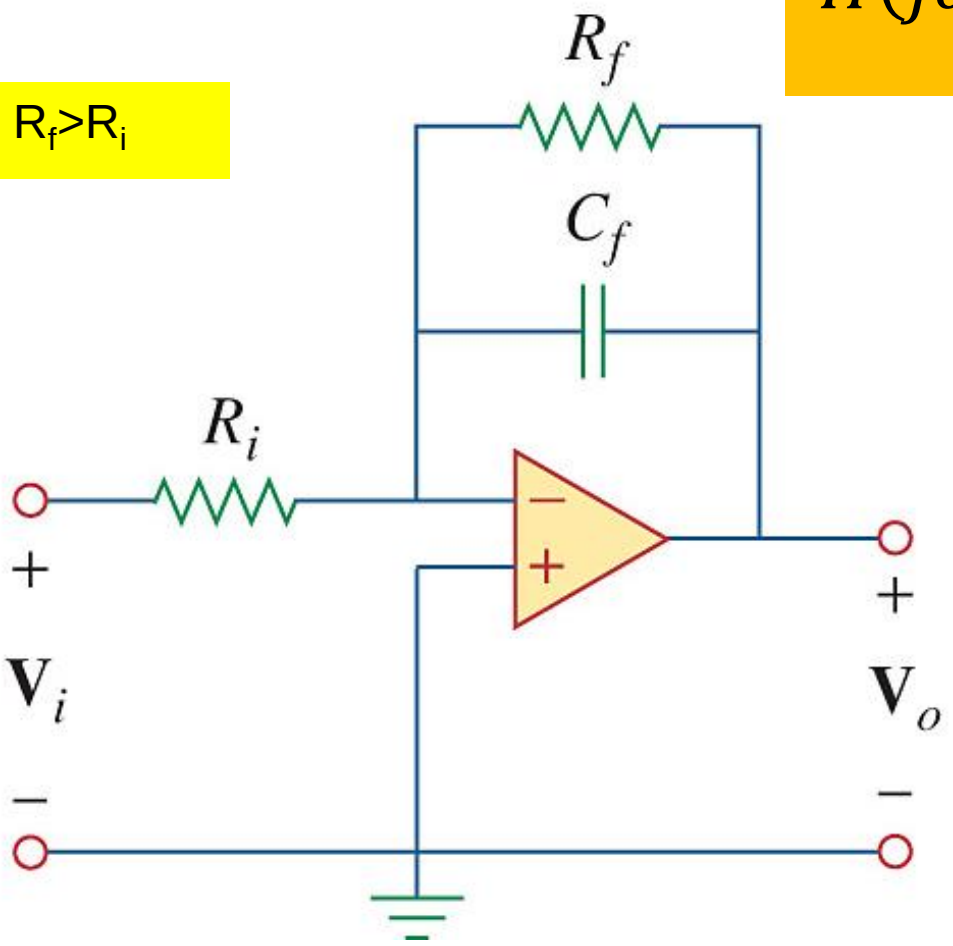
Active filter

- RC and OpAmp (<1MHz, bulky inductor in RLC filters)
- 1st order filters
  - Low pass
  - High pass
  - Inverting
  - Non-inverting
- 2nd order low pass filter

Active Filter Example

$$H(j\omega) = -\frac{R_f/R_i}{1 + j\omega R_f C_f}$$

Say $R_f > R_i$

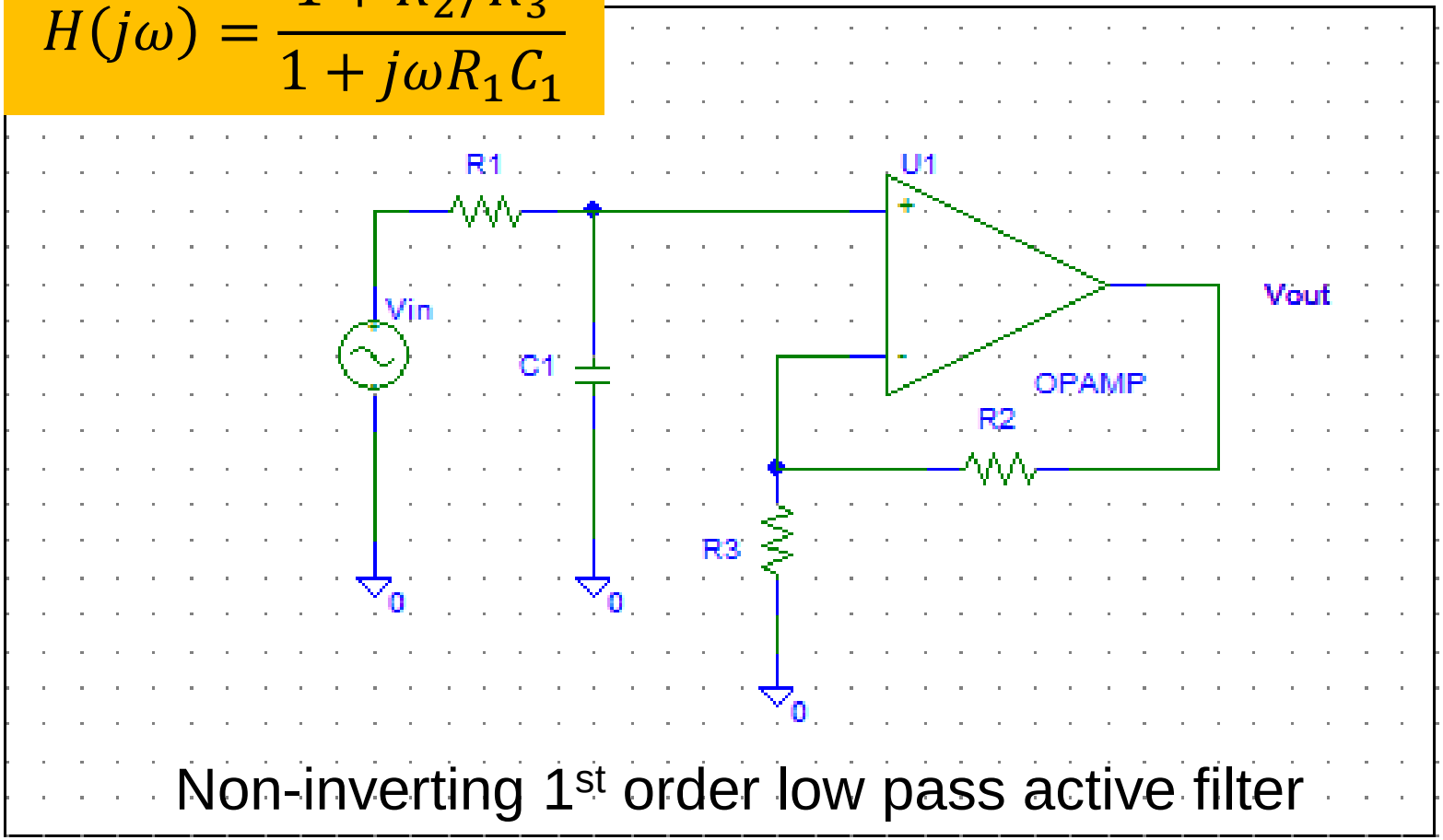


Low pass filter

Sketch Bode Plot

Active Filter Example

$$H(j\omega) = \frac{1 + R_2/R_3}{1 + j\omega R_1 C_1}$$

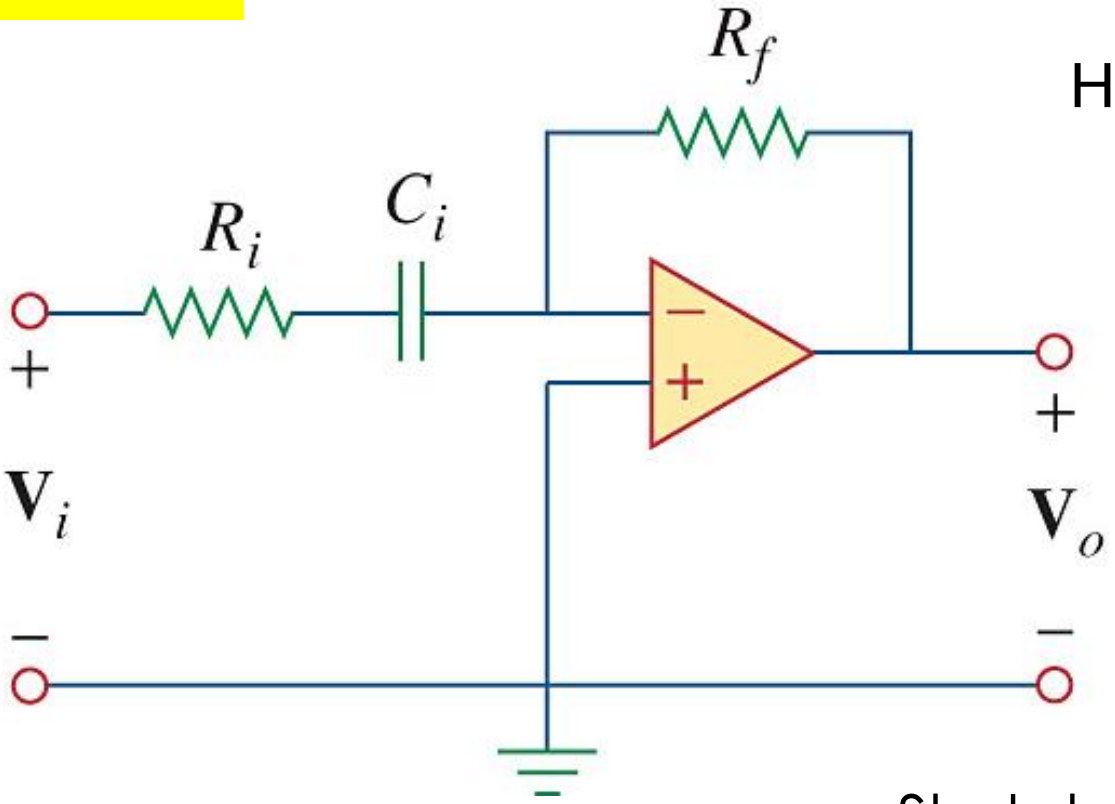


Non-inverting 1st order low pass active filter

Active Filter Example

$$H(j\omega) = -\frac{j\omega R_f C_i}{1 + j\omega R_i C_i}$$

Say $R_f > R_i$

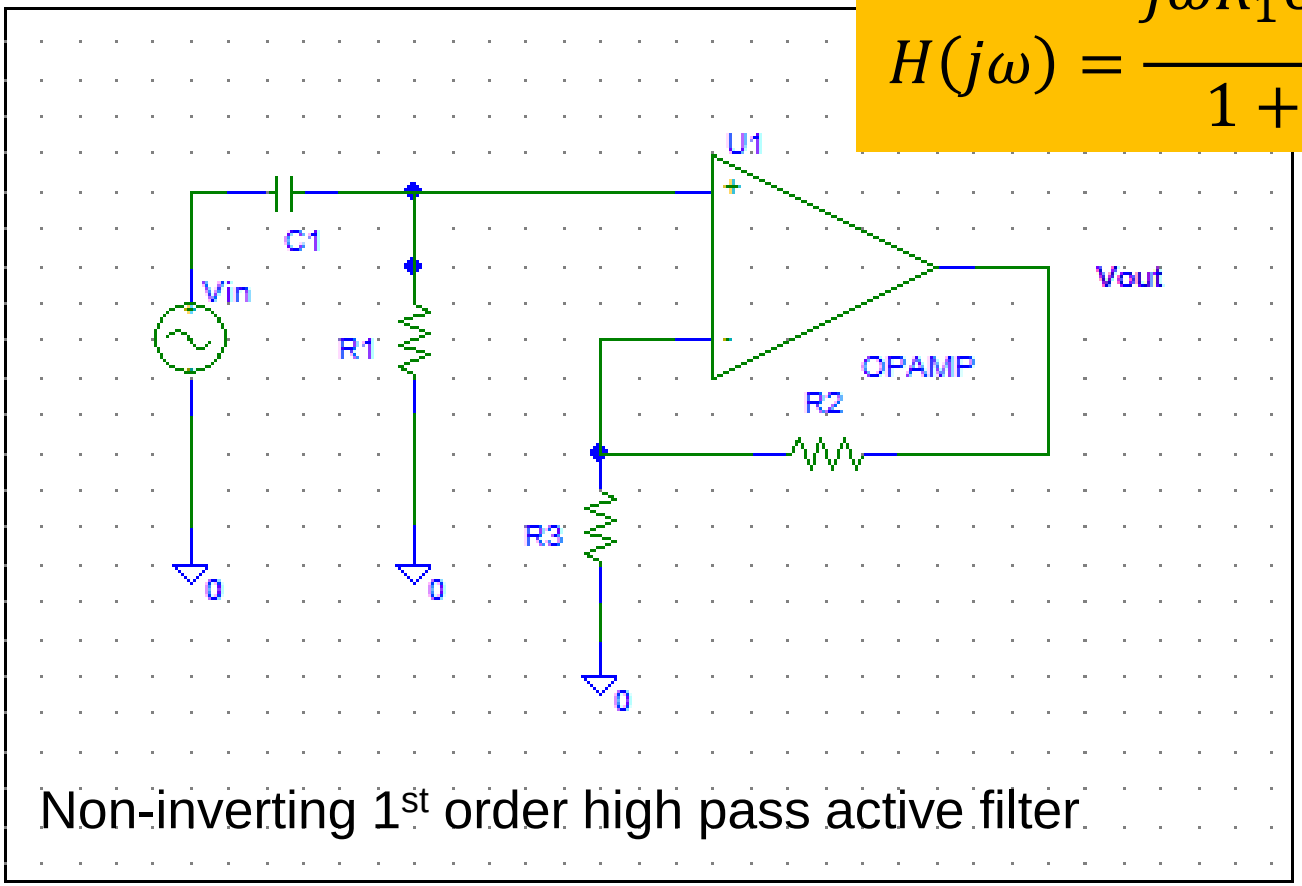


High pass filter

Sketch Bode Plot

Active Filter Example

$$H(j\omega) = \frac{j\omega R_1 C_1 (1 + \frac{R_2}{R_3})}{1 + j\omega R_1 C_1}$$

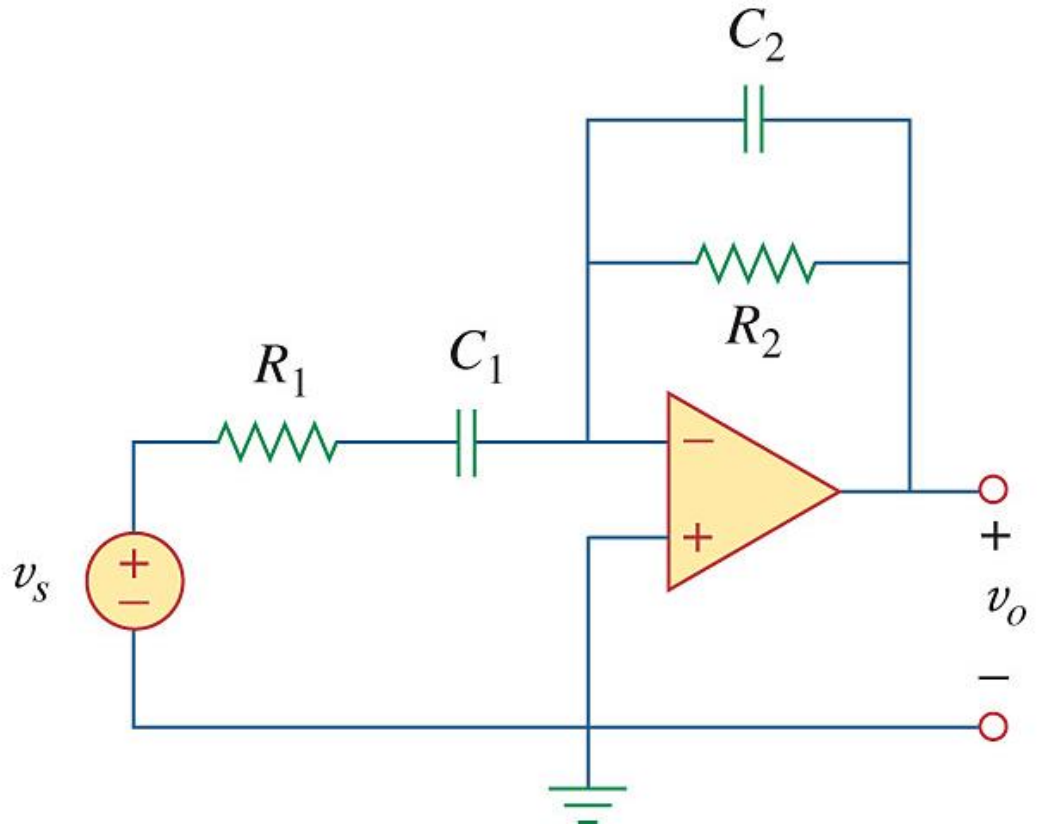


Non-inverting 1st order high pass active filter

Active Filter Example

Say $R_2 > R_1$

$$H(j\omega) = \frac{-j\omega R_2 C_1}{(1 + j\omega R_1 C_1)(1 + j\omega R_2 C_2)}$$

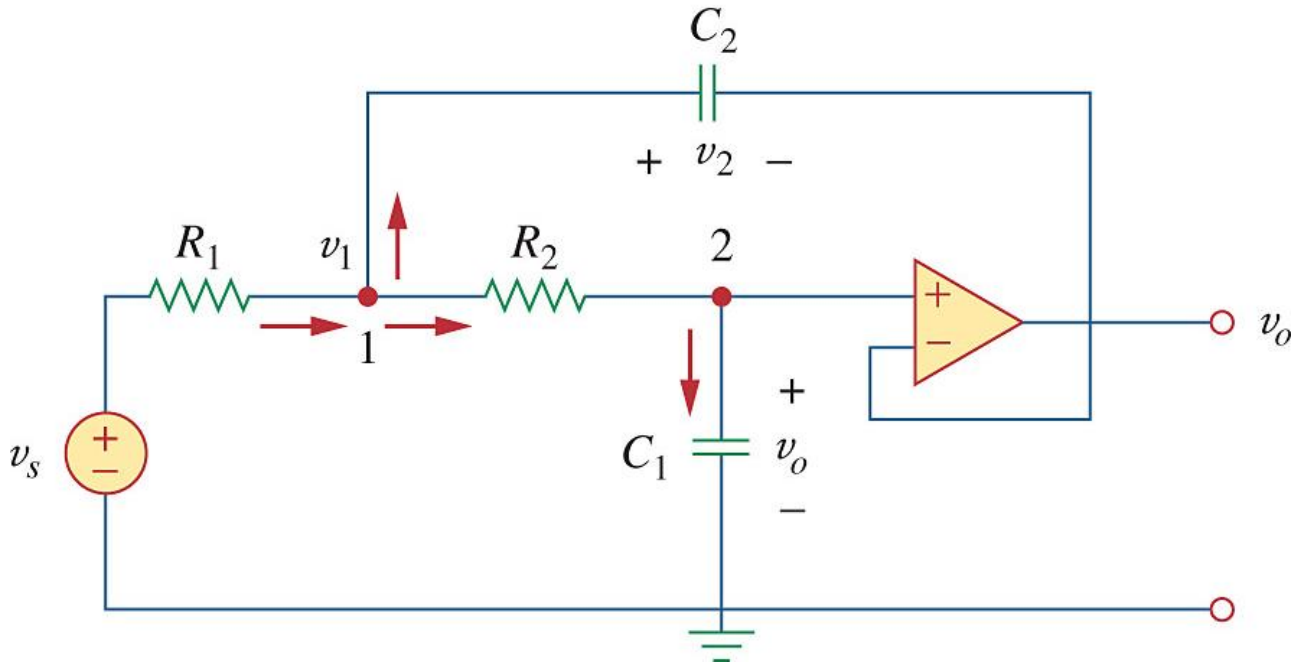


Bandpass filter

Sketch Bode Plot

2nd order Active Filter
Sallen-Key Low Pass Filter

Find frequency response function of unity-gain Sallen Key Topology



$$H(j\omega) = \frac{1}{1 + j\omega(R_1+R_2)C_1 - \omega^2 R_1 R_2 C_1 C_2}$$