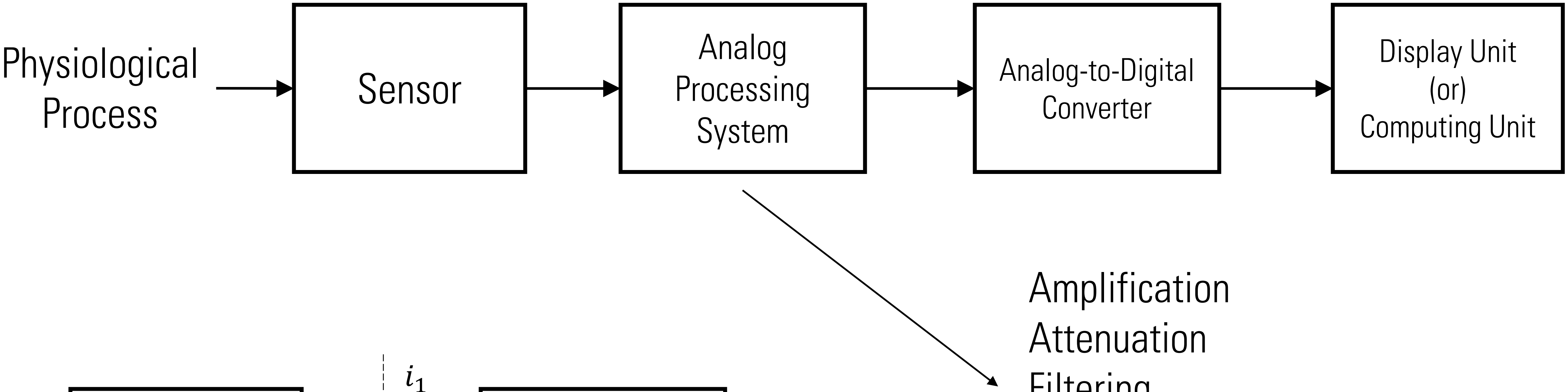
Transducers & Instrumentation

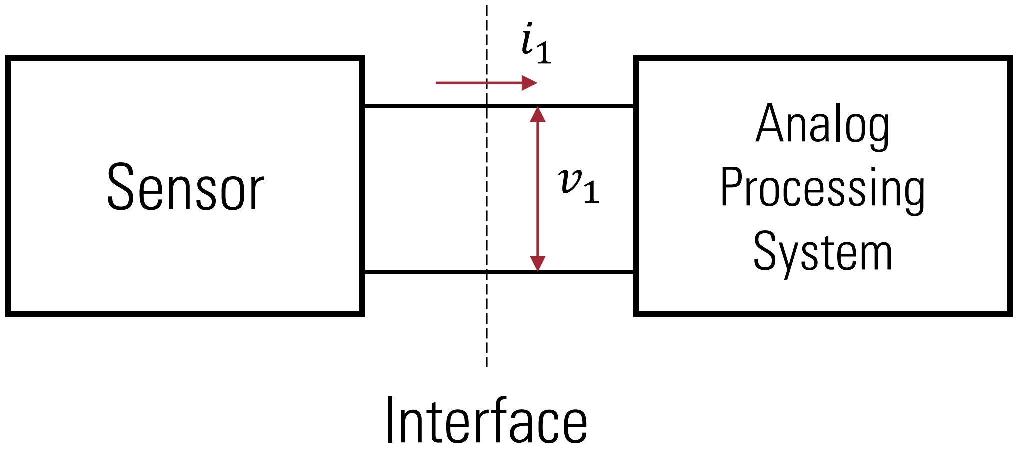
Module 02

(Basic Instrumentation)

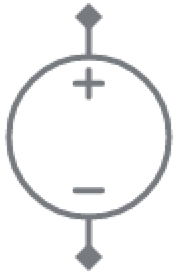
A typical measurement system



Amplification
Attenuation
Filtering
Signal conversion
.
.
.



Basic (linear) Electrical Circuits



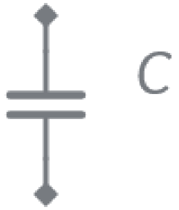
$$i(t) = \frac{v(t)}{R}$$

$$i(t) = C\frac{dv(t)}{dt}$$

$$i(t) = \frac{1}{L}\int_{-\infty}^{t} v(l) \cdot dl$$

Linear Electrical Circuits – Frequency Domain Characteristics

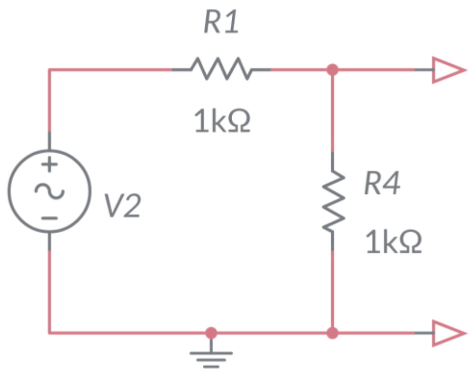
$$i(t) = \frac{v(t)}{R} \qquad I(\omega) = \frac{V(\omega)}{R}$$

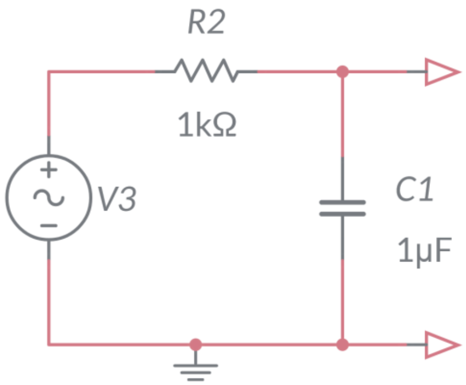


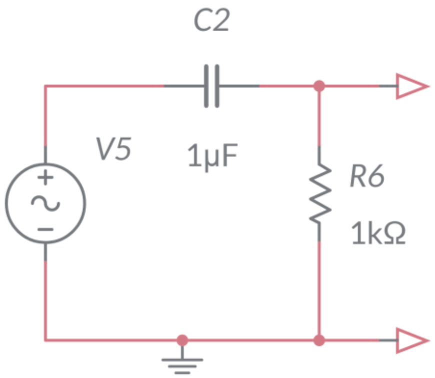
$$i(t) = C\frac{dv(t)}{dt} \qquad I(\omega) = j\omega C \cdot V(\omega)$$

$$i(t) = \frac{1}{L}\int_{-\infty}^{t} v(l) \cdot dl \qquad I(\omega) = \frac{1}{j\omega L}V(\omega)$$

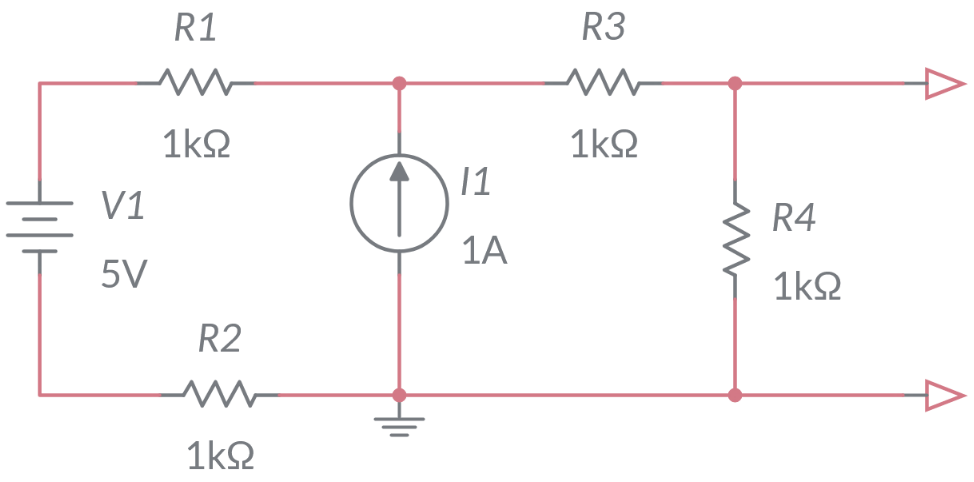
Behaviour of some simple linear circuits

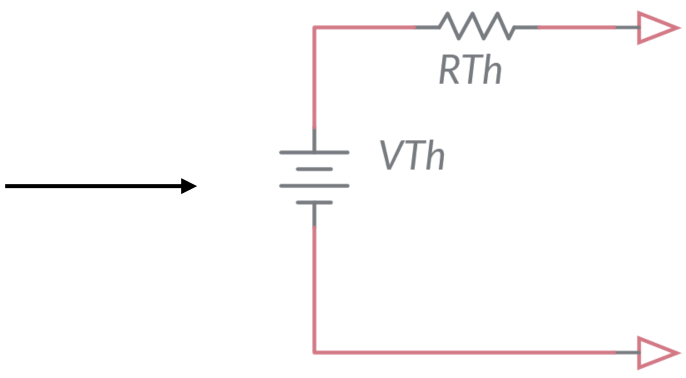






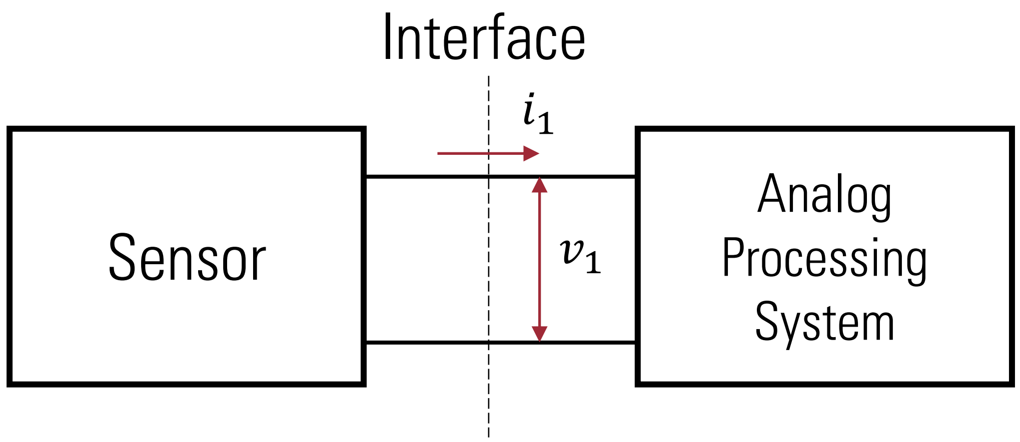
Equivalent circuit

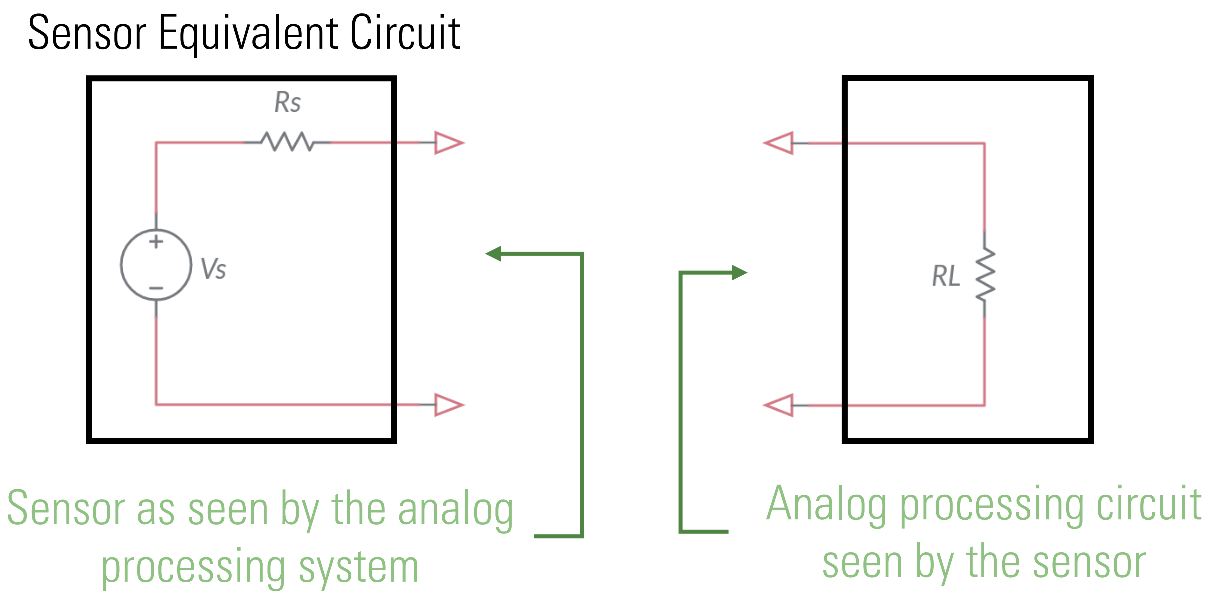




Thevenin Equivalent Circuit

Analog processing of sensor output

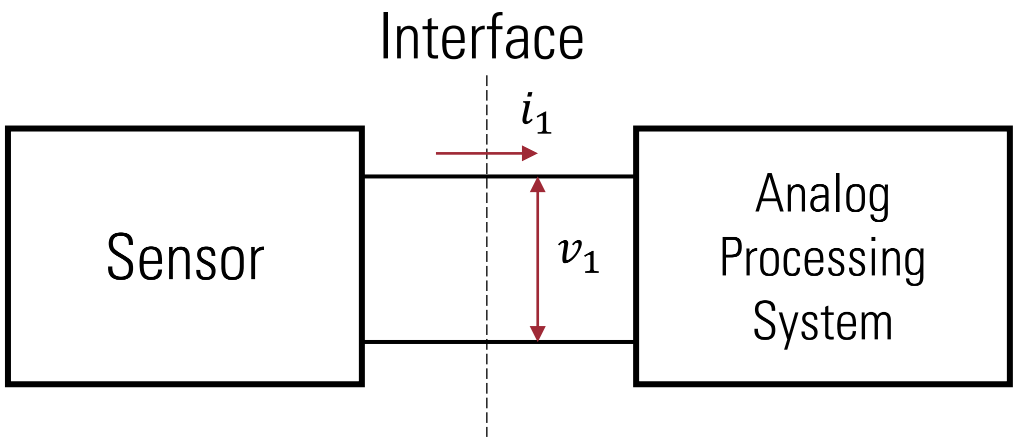


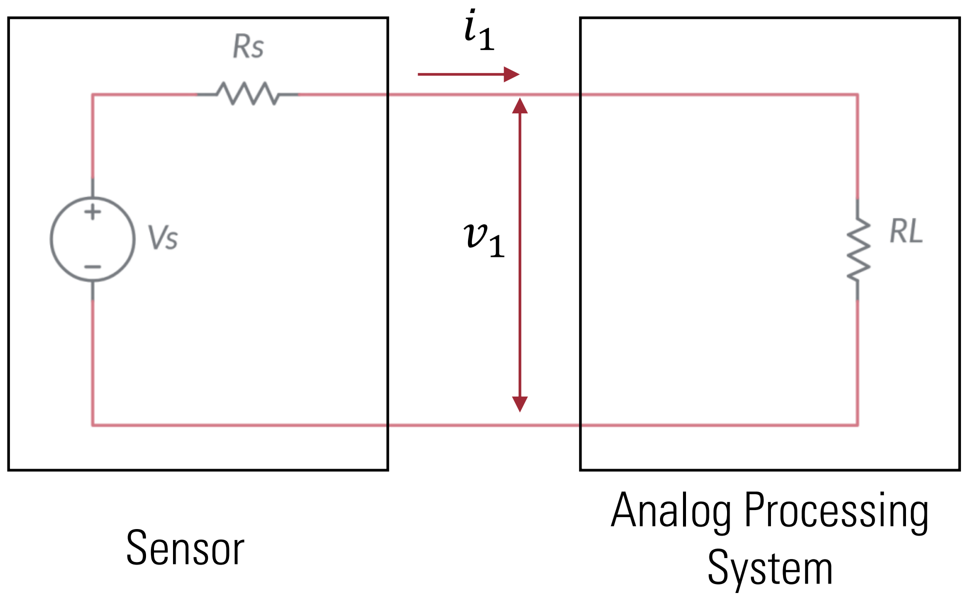


Output Impedance

Input Impedance

Analog processing of sensor output



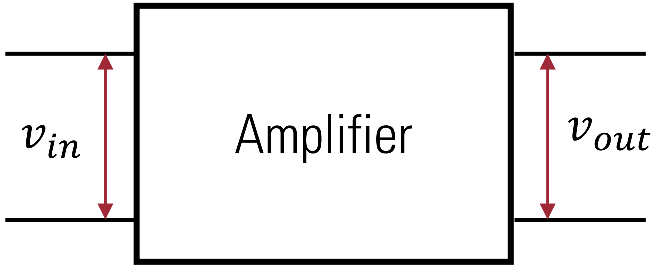


Loading occurs because of the finite input and non-zero output impedance

$$v_1 = \frac{R_L}{R_S+R_L} v_S \implies v_1 < v_S$$

How can we reduce loading?

Analog processing: Amplifier

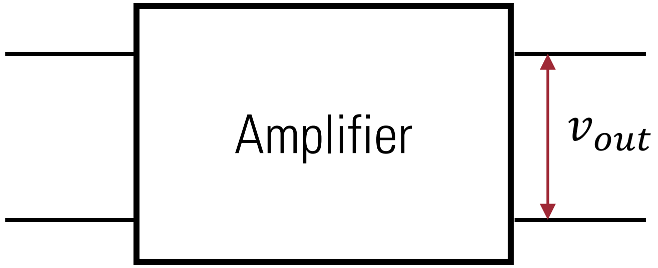


$$v_{out} = G \cdot v_{in}$$

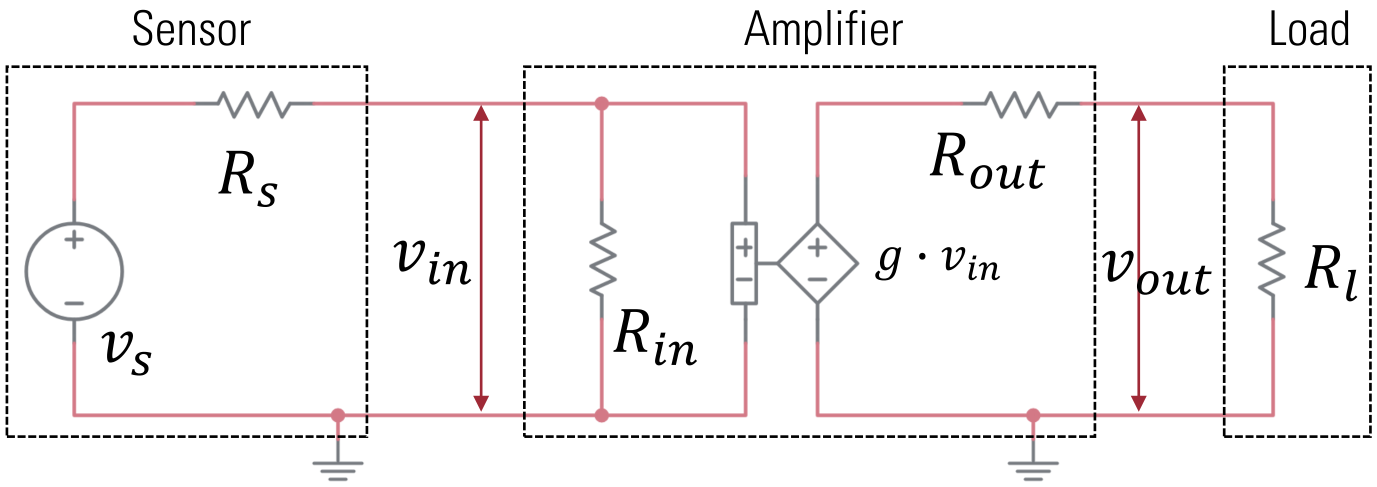
$$G_{dB} = 20 \cdot \log\left(\frac{v_{out}}{v_{in}}\right)$$

Frequency Response of amplifier

Analog processing: Amplifier



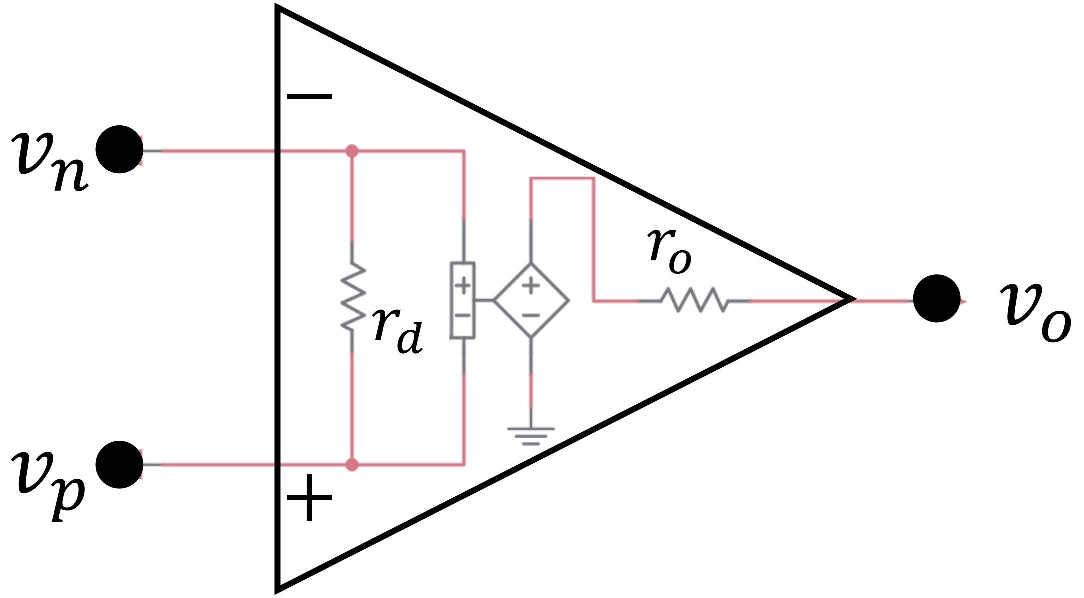
Loading in real amplifiers



Operational Amplifier

- Practical, low-cost, commonly available integrated circuit – Operational Amplifier (op-amp).
- An voltage amplifier with extremely high gain g.
- Has very high input impedance r_d and low output impedance r_o.

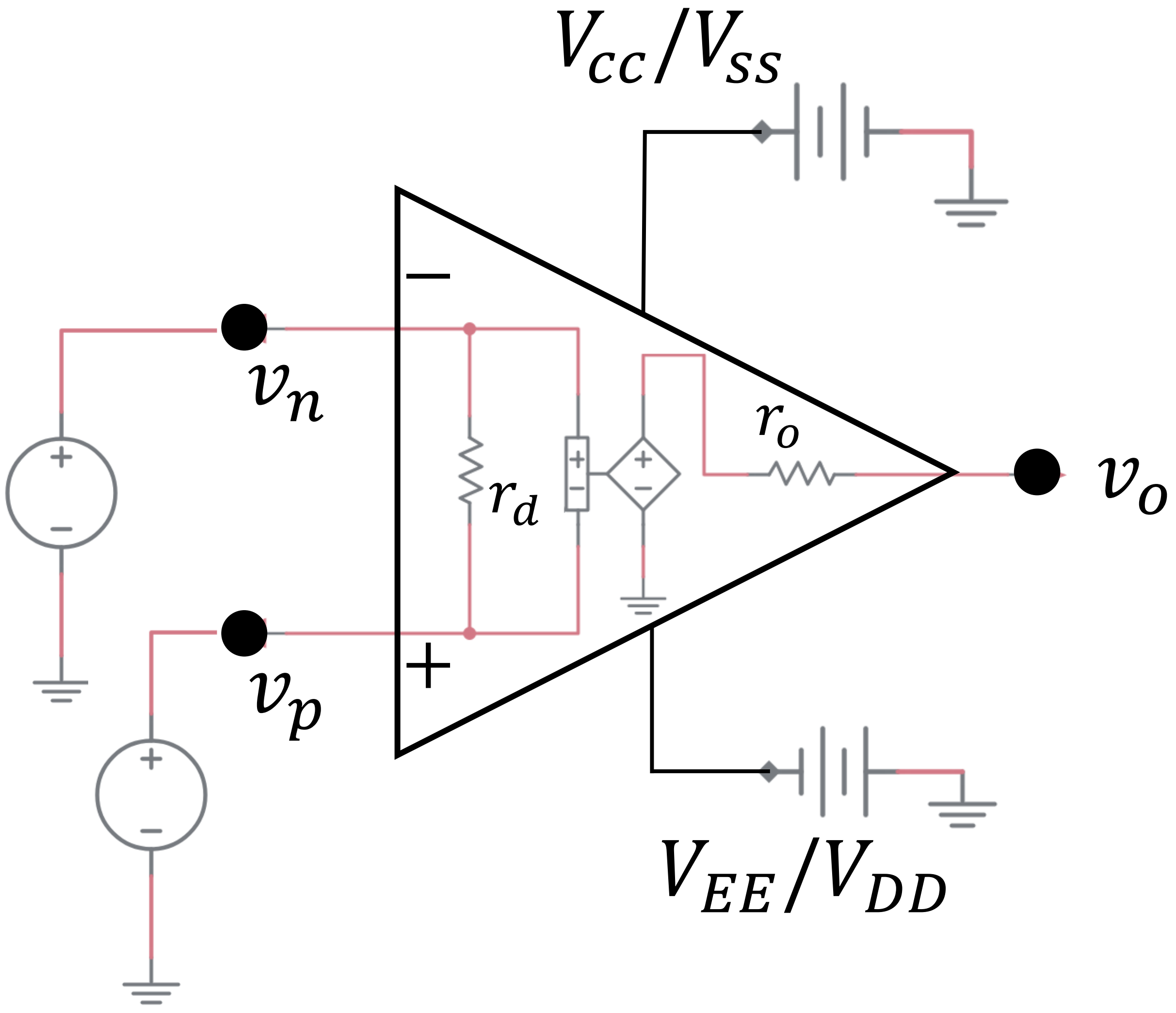
$$v_o = g \cdot v_d = g \cdot (v_p - v_n)$$



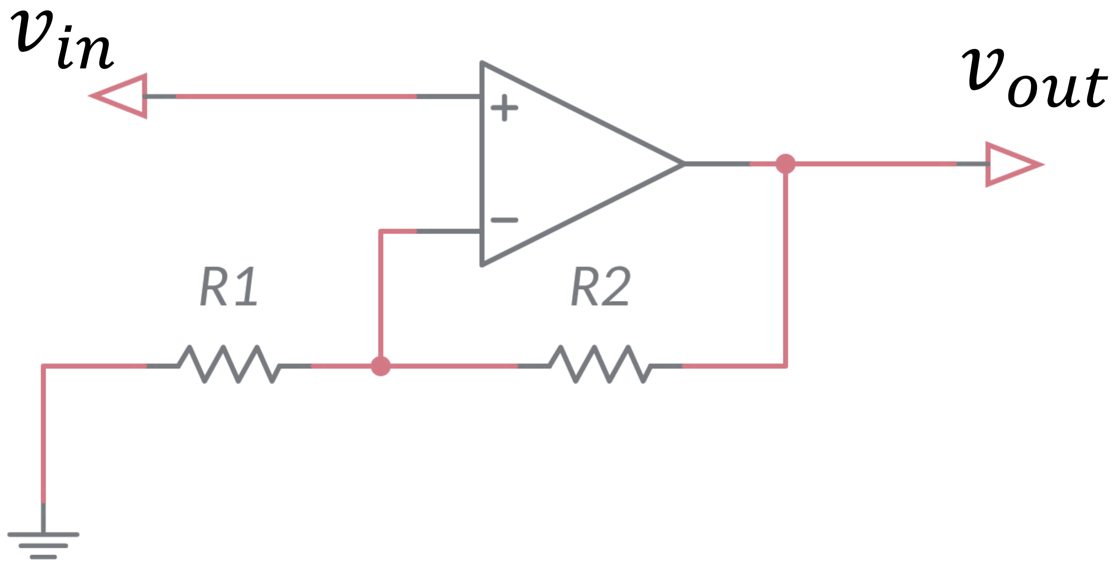
Ideal Op-amp

$$r_d = \infty$$
$$r_o = 0$$
$$g = \infty$$

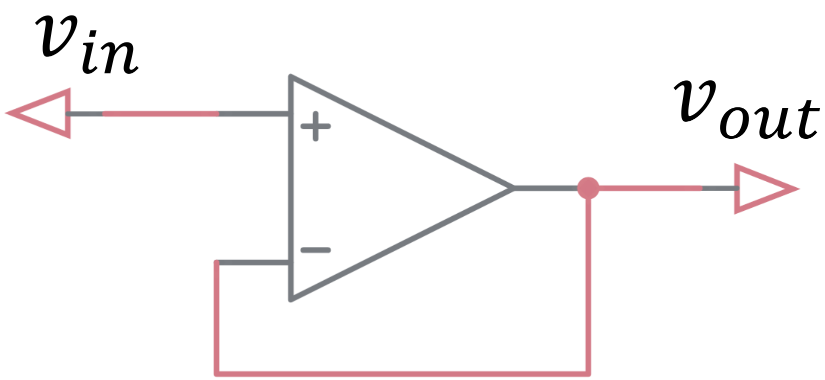
Operational Amplifier



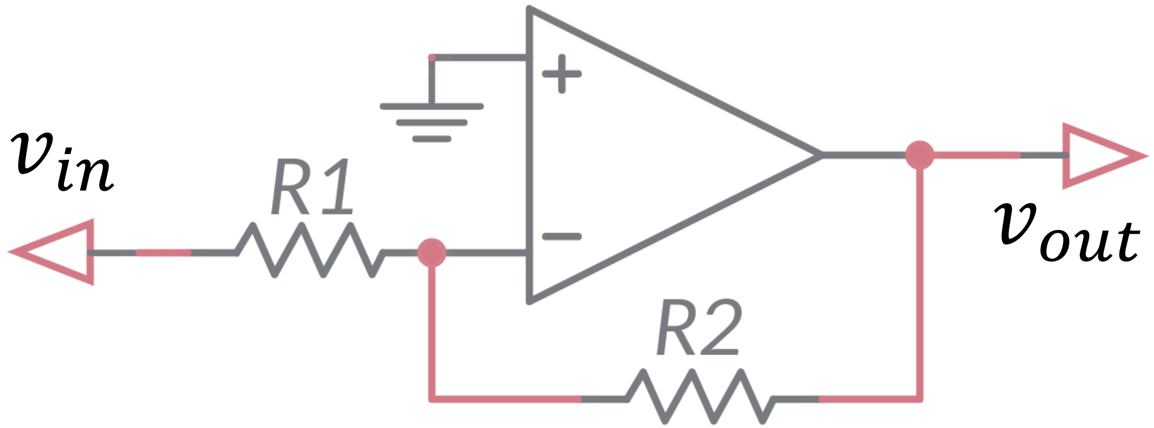
Non-Inverting Amplifier



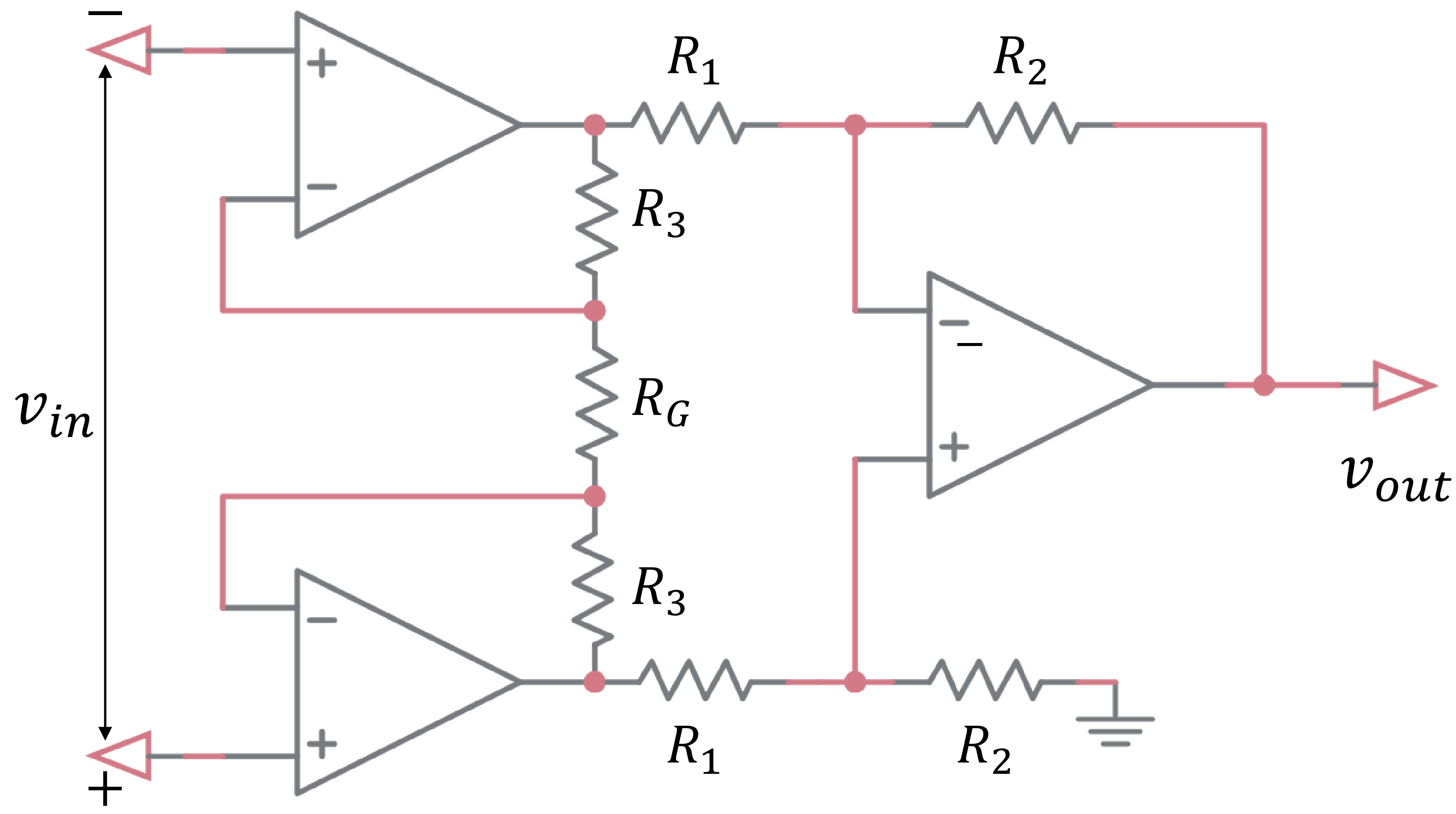
Voltage follower



Inverting Amplifier



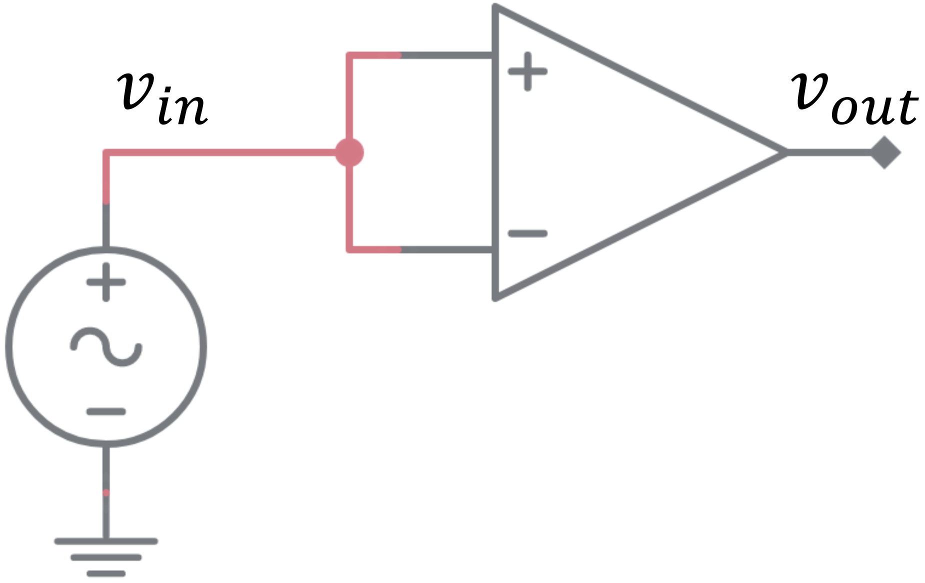
Three OpAmp Instrumentation Amplifier



$$v_{out} = \left(1 + 2\frac{R_3}{R_G}\right)\left(\frac{R_2}{R_1}\right)v_{in}$$

Common Mode Rejection

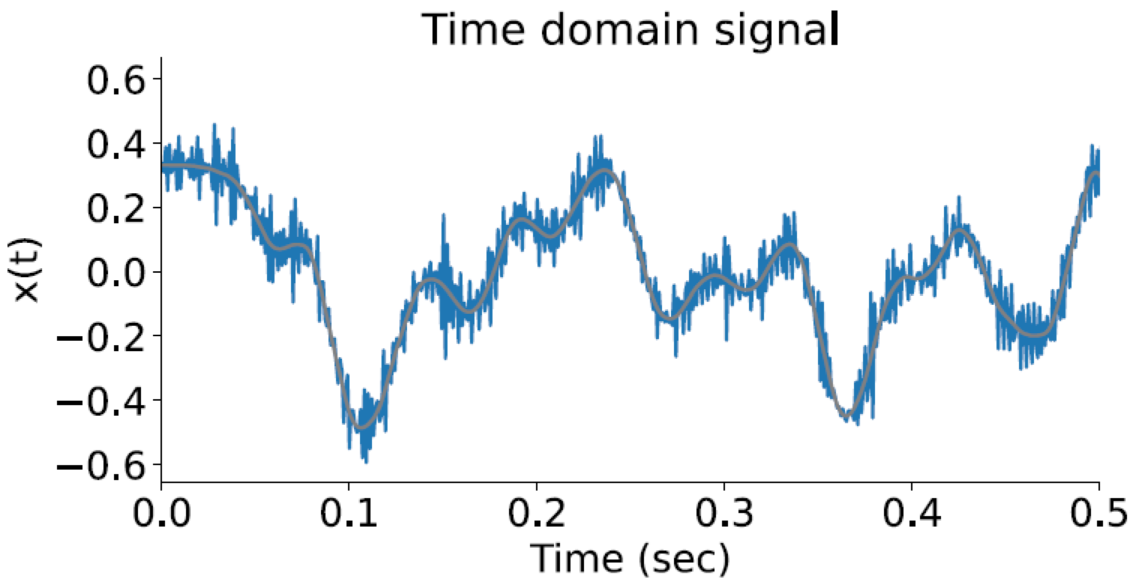
- The ability of an op-amp to reject a common signal that appears at both its input terminals.

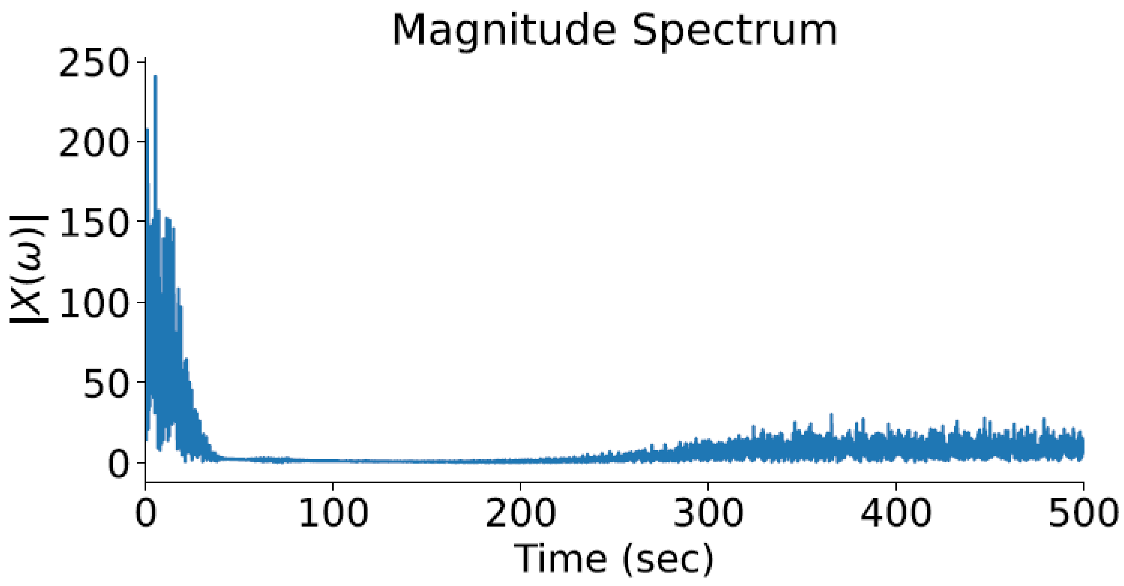


$$CMRR = 20\log_{10}\left(\frac{g}{v_{out}/v_{in}}\right)$$

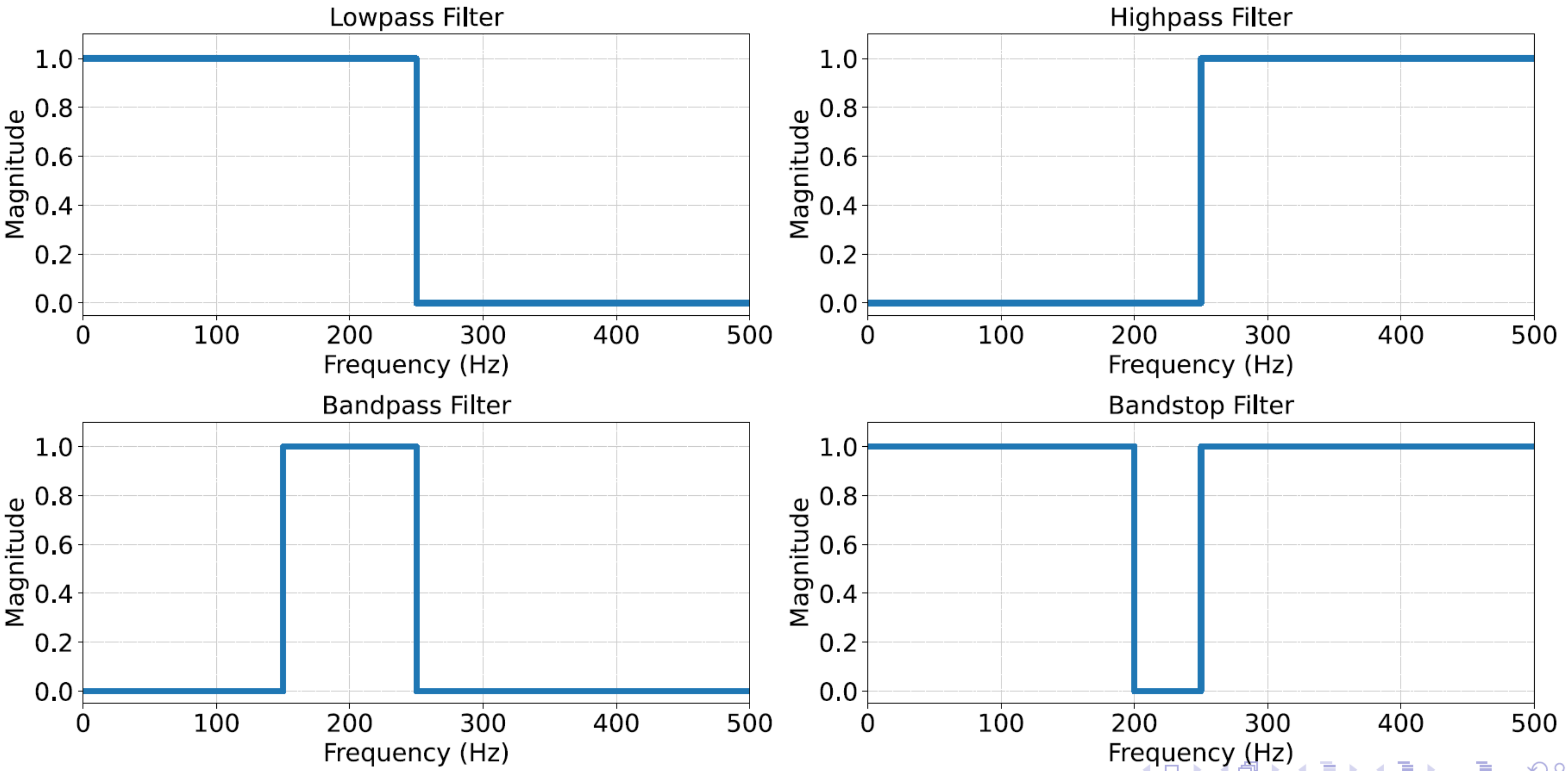
Frequency selective filters

- LTI system can be used for implementing frequency selective filters, i.e. to modify the amplitude and phase of sinusoidal signals without affecting their frequency.



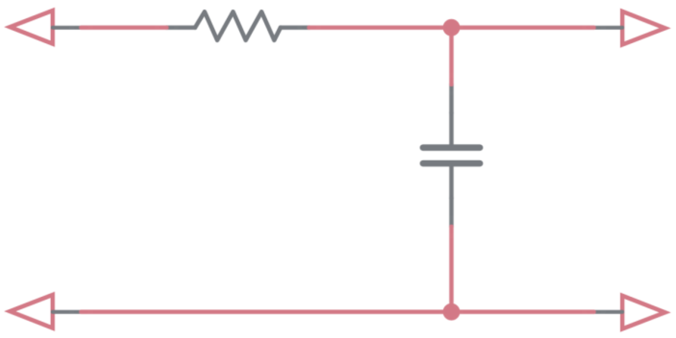


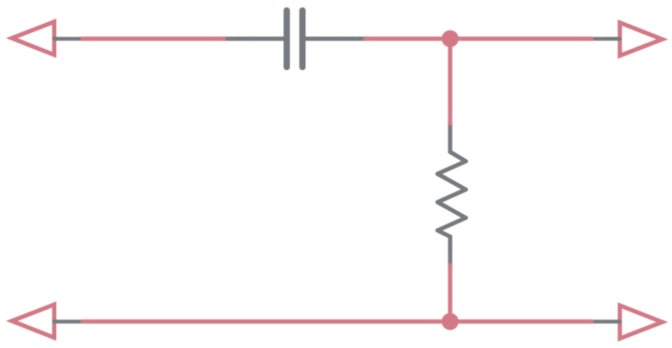
Frequency selective filters



Passive filters

- Passive filters are made from passive elements – resistors, capacitors, and inductors.

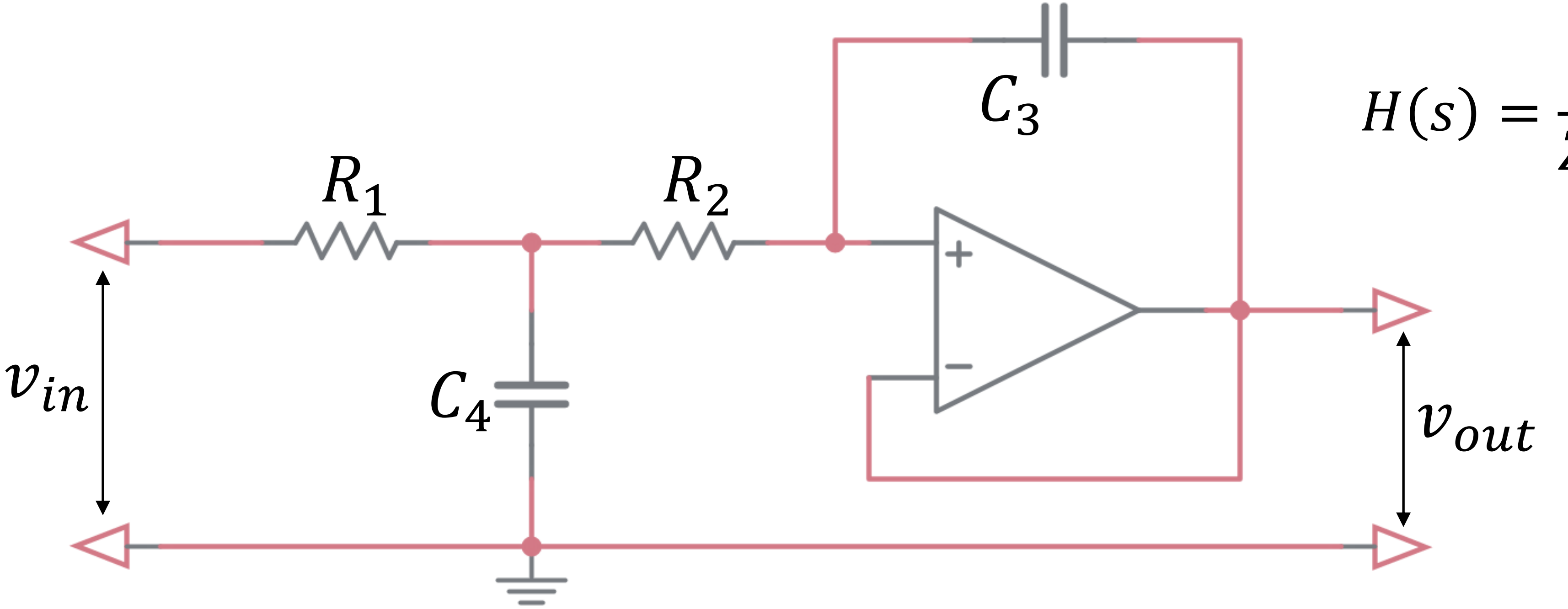




Active filters

- Active filter use active elements, e.g. op-amp.
    - Avoid attenuation introduced by the filter in the passband.
    - Provide interstage isolations.
    - Can implement filters without inductors.

Active Lowpass Filter

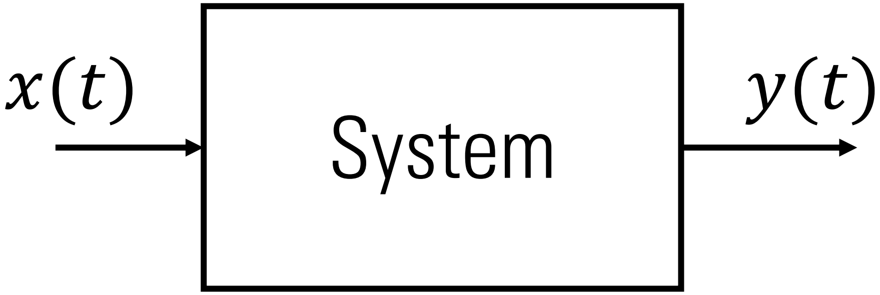


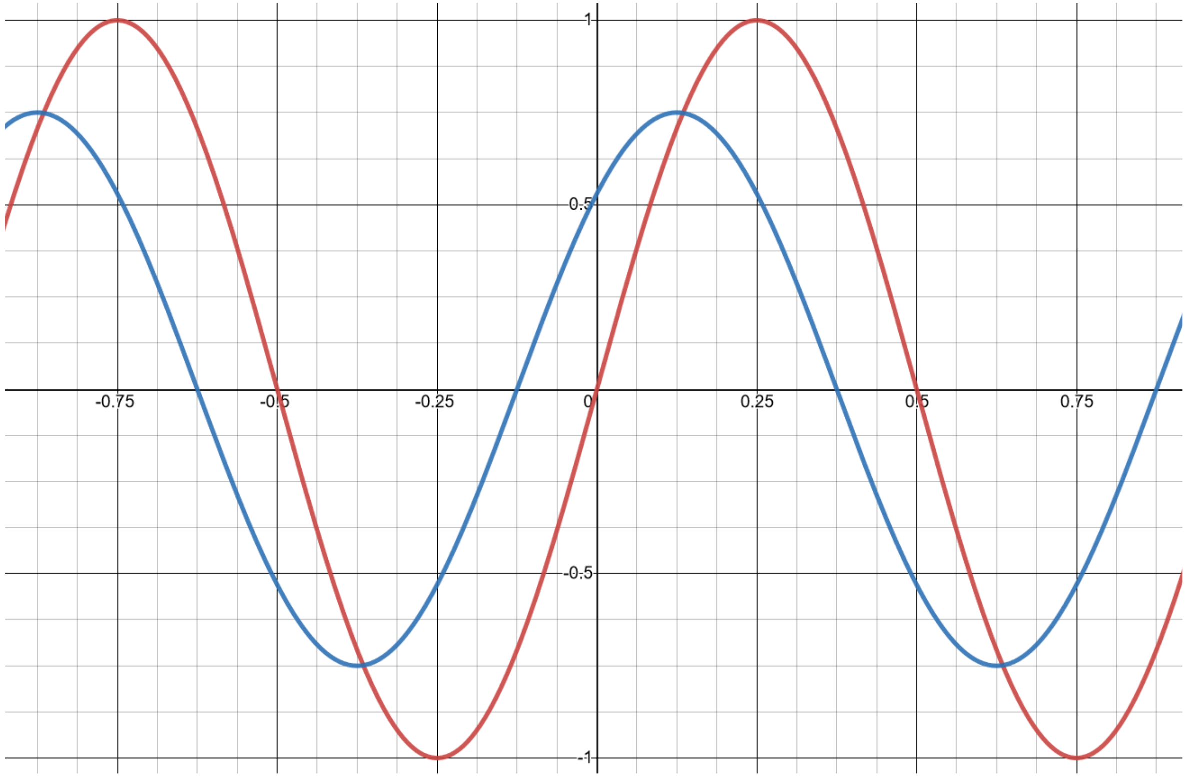
$$H(s) = \frac{Z_3 Z_4}{Z_1 Z_2 + Z_3(Z_1 + Z_2) + Z_3 Z_4}$$

$$Z_1 = R_1 \qquad Z_3 = \frac{1}{sC_3}$$

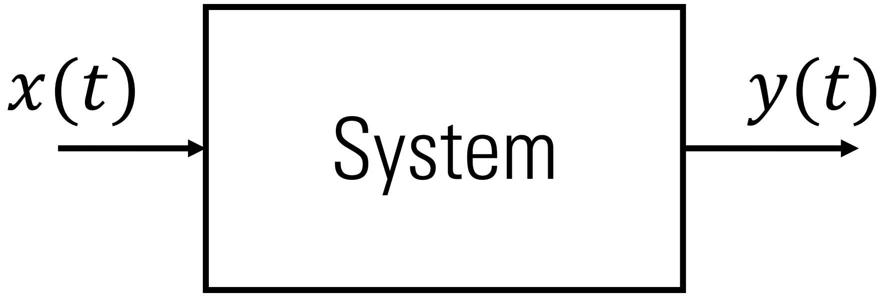
$$Z_2 = R_2 \qquad Z_4 = \frac{1}{sC_4}$$

Determining the frequency response of a system





Determining the frequency response of a system



$$H(j\omega) = \frac{Y(j\omega)}{X(j\omega)}$$