Characteristics of an Ideal Op-Amp

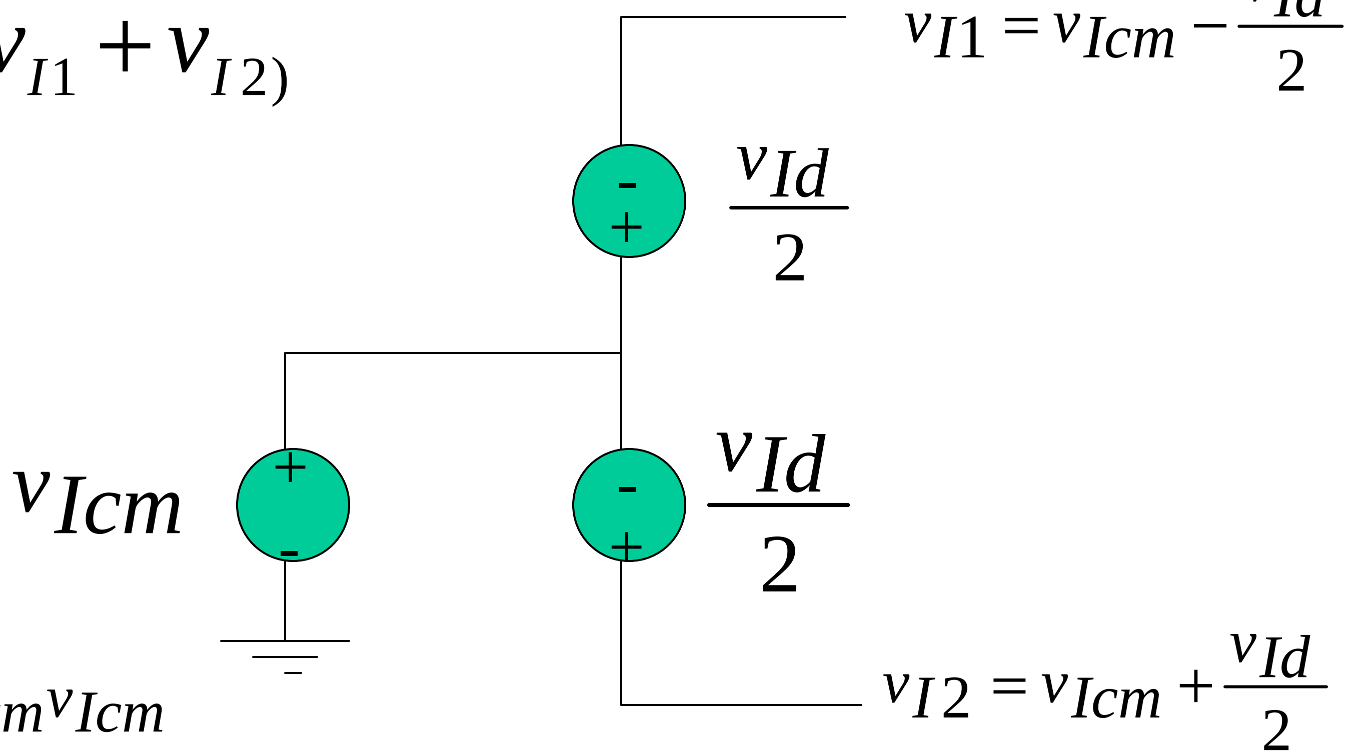
- Infinite input impedance
- Zero output impedance
- Zero common-mode gain, or, infinite common-mode rejection
- Infinite open-loop gain A
- Infinite bandwidth.

Difference Amplifier

- A difference amplifier is one that responds to the difference between the two signals applied at its input and ideally rejects signals that are common to the two inputs.

$$v_{Id} = v_{I2} - v_{I1}$$

$$v_{Icm} = \frac{1}{2}(v_{I1} + v_{I2})$$



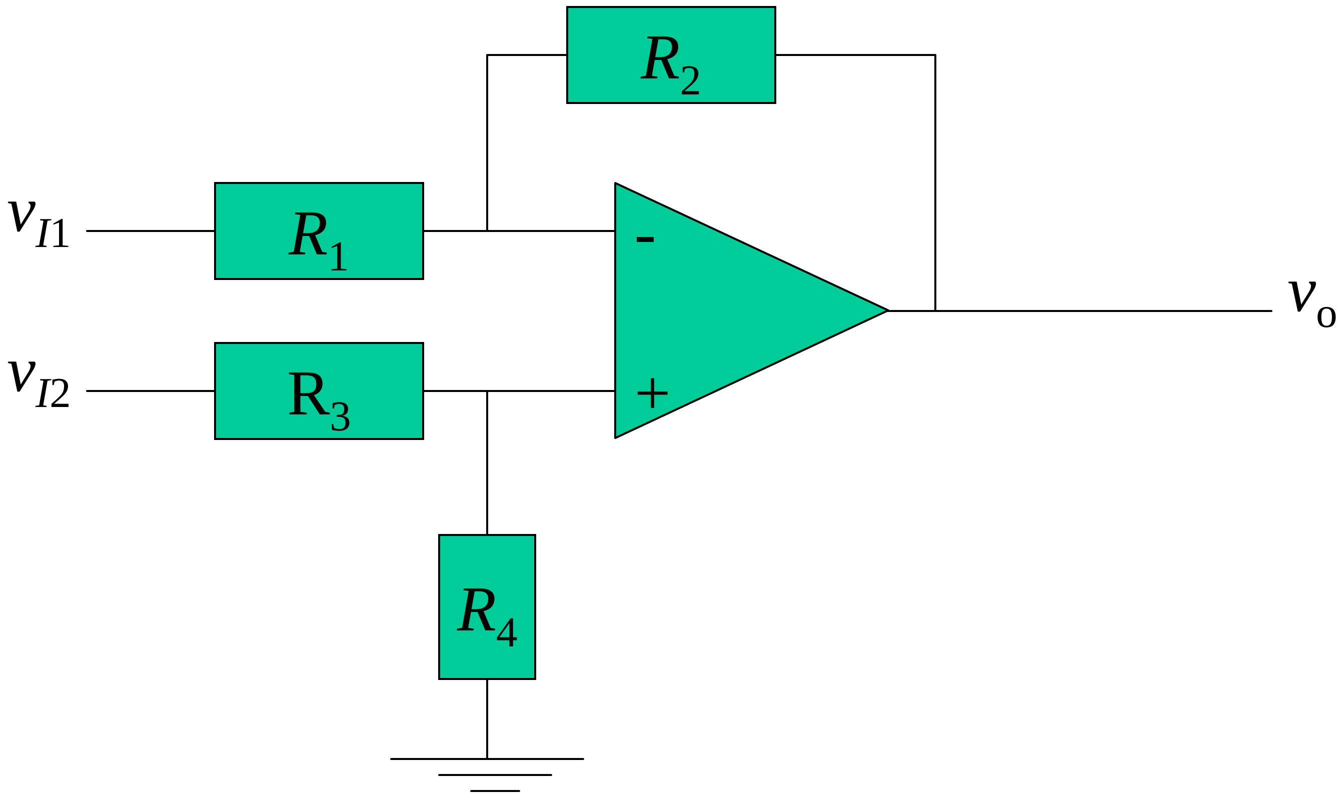
$$v_O = A_d v_{Id} + A_{cm} v_{Icm}$$

$$\text{CMRR} = 20 \log \frac{|A_d|}{|A_{cm}|}$$

More Characteristics of Op-Amp

- Since the ideal op-amp responds only to the difference between the two input signals, the ideal op-amp maintains a zero output signal when the two input signals are equal.
- When the two input signals are unequal, there is what is called a common-mode input signal.
- For the ideal op-amp, the common-mode output signal is zero. This characteristic is referred to as common-mode rejection.
- Another characteristic, because op-amp is biased by both positive and negative power supplies, most op-amps are direct coupled devices (no coupling capacitors are required on the input). Accordingly, the two input voltages can be DC.
- Because the OP is composed of transistors biased in the active region by the DC power supply, the output voltage is limited.

Difference Amplifier

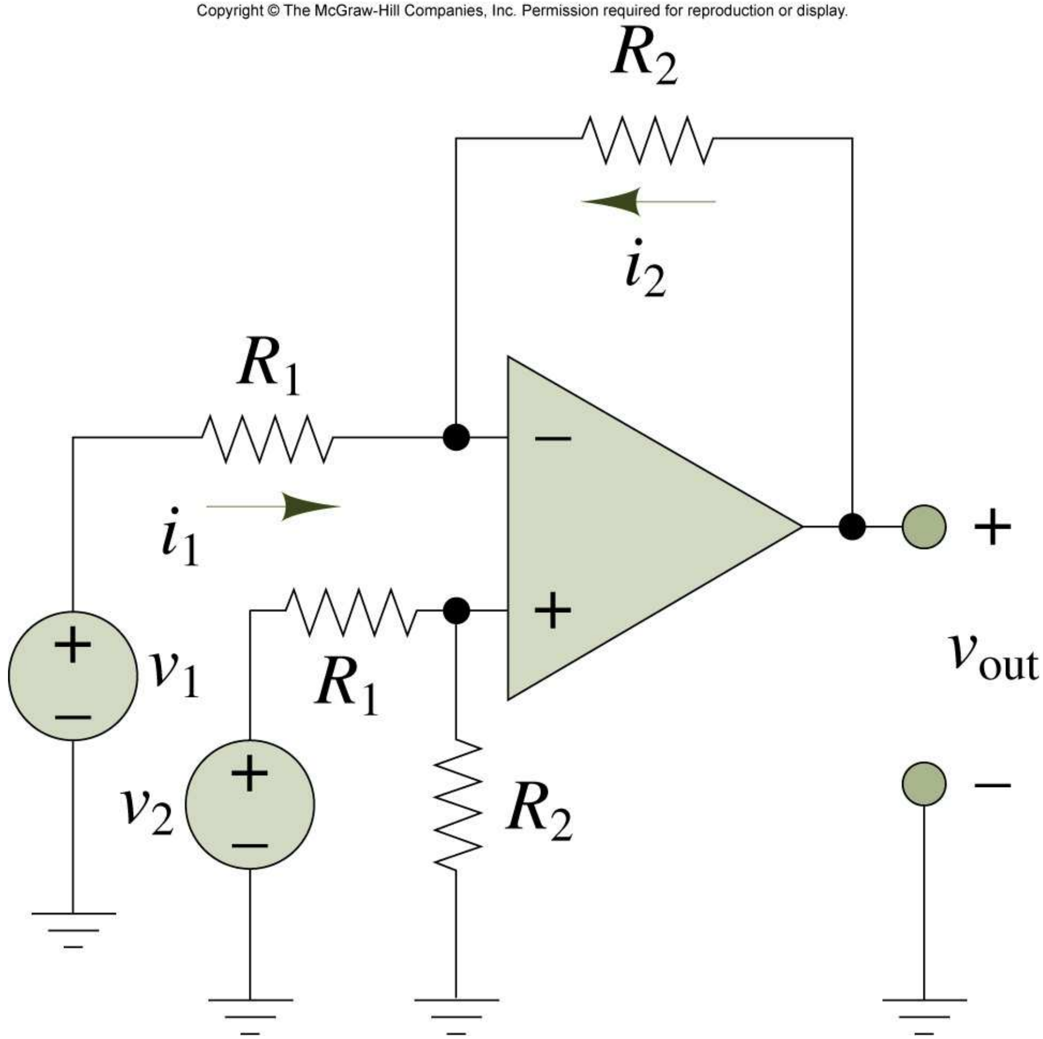


A Single Difference or Differential Amplifier

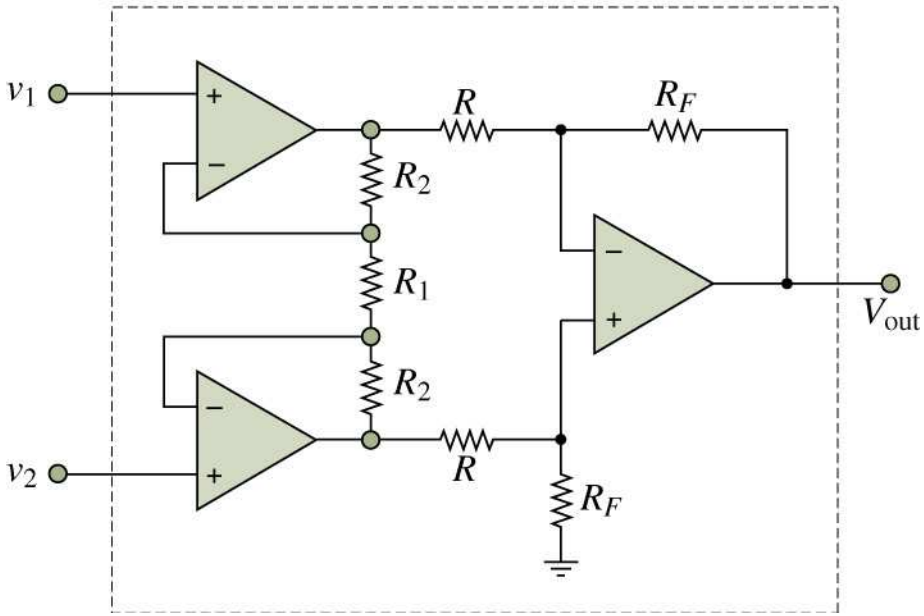
$$v_{out} = \frac{R_2}{R_1}(v_2 - v_1)$$

$$v_{out} = \frac{R_2}{R_1} v_{Id}$$

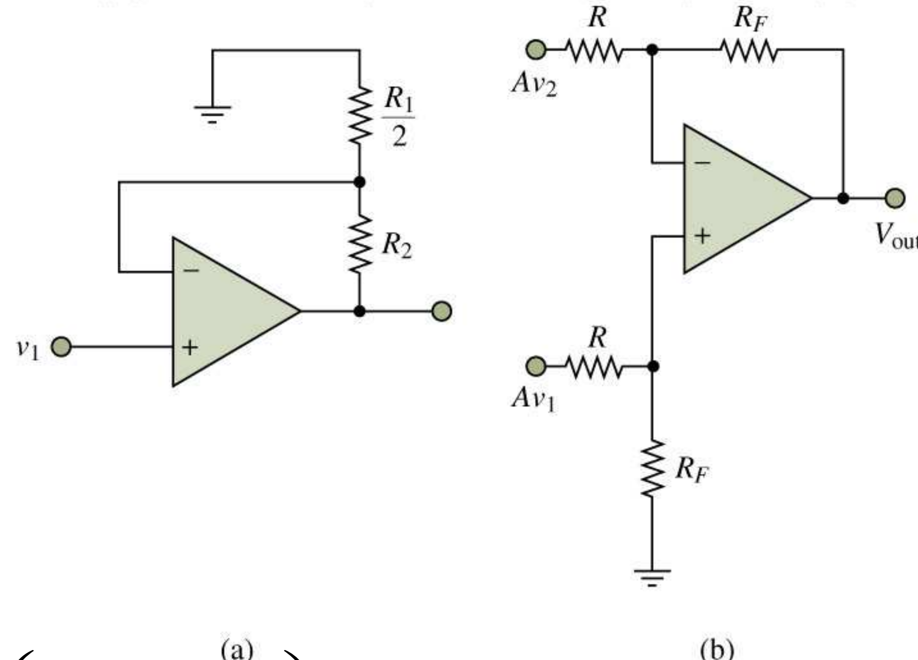
$$A_d = \frac{R_2}{R_1}$$



Instrumentation Amplifier



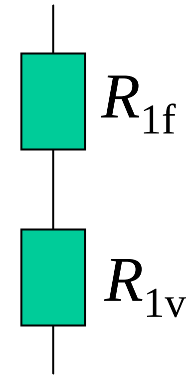
Input (a) and output (b) stages of Instrumentation amplifier



$$A_V = \frac{v_{out}}{v_1 - v_2} = \frac{R_F}{R}\left(1 + \frac{2R_2}{R_1}\right)$$

Design Example: Determine the range required for resistor R_1 in the instrumentation amplifier to realize a differential gain adjustable from 5 to 500. Assume $R_F = 2R$, so that the difference amplifier gain is 2.

- Assume R_1 is a combination of a fixed resistor R_{1f} and a variable resistor R_{1v}. Assume R_{1v} = 100 kΩ



$$A_V = \frac{v_{out}}{v_1 - v_2} = \frac{R_F}{R}\left(1 + \frac{2R_2}{R_1}\right)$$

$$500 = 2\left(1 + \frac{2R_2}{R_{1f}}\right) \text{ and the minimum differential gain is}$$

$$5 = 2\left(1 + \frac{2R_2}{R_{1f} + 100}\right) \text{ and from the maximum gain expression}$$

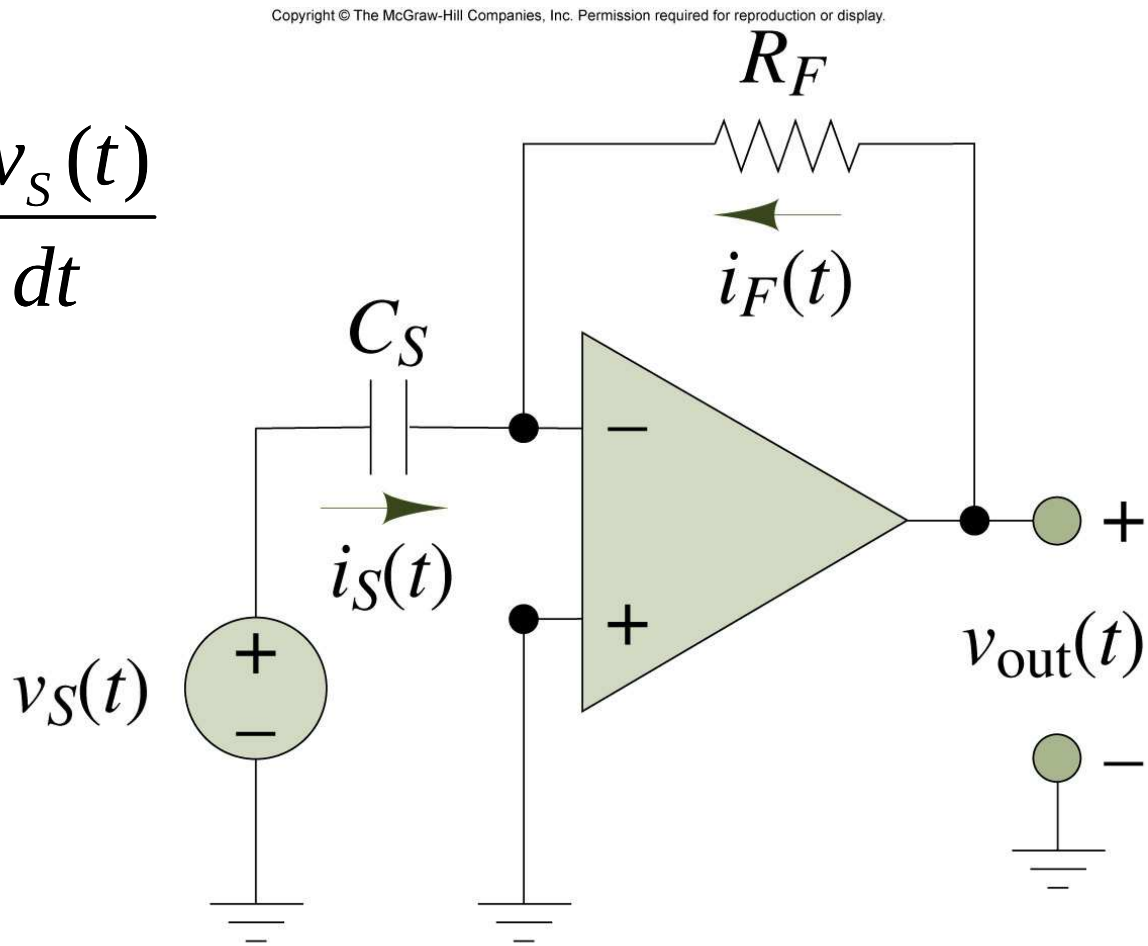
$$2R_2 = 249R_{1f}$$

$$1.5 = \frac{2R_2}{R_{1f} + 100} = \frac{249R_{1f}}{R_{1f} + 100}$$

$$R_{1f} = 0.606 \text{ k}\Omega \text{ and } R_2 = 75.5 \text{ k}\Omega$$

Op-amp Differentiator

$$v_{out}(t) = -R_F C_S \frac{dv_S(t)}{dt}$$



Large Signal Operation of Op Amp

- Like other amplifiers, op amps operate linearly over a limited range of output voltages.
- Another limitation of the operation of op amps is that their output current is limited to a specified maximum. For example, the op amp 741 is specified to have a maximum output current of ±20 mA.
- Read Example 2.5.
- Another phenomenon that can cause nonlinear distortion when large output signals are present is that of slew-rate limiting. This means there is a specific maximum rate of change possible at the output of a real op amp. This maximum is known as the slew rate (SR) of the op amp and is defined as

$$\mathrm{SR} = \left.\frac{dv_O}{dt}\right|_{\max}$$

Design Example. Design a difference amplifier with a specified gain and minimum differential input resistance. Design the circuit such that the differential gain is 30 and the minimum differential input resistance is R_i = 50 kΩ

$$R_i = 2R_1 = 50\ \text{k}\Omega$$

$$R_1 = R_3 = 25\ \text{k}\Omega$$

Since the differential gain is $\dfrac{R_2}{R_1} = 30$,

we must have $R_2 = R_4 = 750\ \text{k}\Omega$

Design Example: Calculate the common-mode rejection ratio of a differential amplifier. Consider the difference amplifier shown in page 2. Let R_2/R_1 = 10 and R_4/R_3 = 11. Determine CMRR (dB)

$$vo = vo1 + vo2$$

$$v_o = (1+\frac{R_2}{R_1})\left(\frac{\frac{R_4}{R_3}}{1+\frac{R_4}{R_3}}\right)v_{I2} - (\frac{R2}{R1})v_{I1}$$

$$v_o = (1+10)(\frac{11}{1+11})v_{I2} - (10)v_{I1} = 10.0833v_{I2} - 10v_{I1}$$

$$v_d = v_{I2} - v_{I1}; v_{cm} = \frac{v_{I1}+v_{I2}}{2}; v_{I1} = v_{cm} - \frac{v_d}{2}; v2 = v_{cm} + \frac{v_d}{2}$$

$$vo = 10.0833(v_{cm} + \frac{v_d}{2}) - 10(v_{cm} - \frac{v_d}{2})$$

$$v_o = 10.042v_d + 0.0833v_{cm}; v_o = A_d v_d + A_{cm}v_{cm}$$

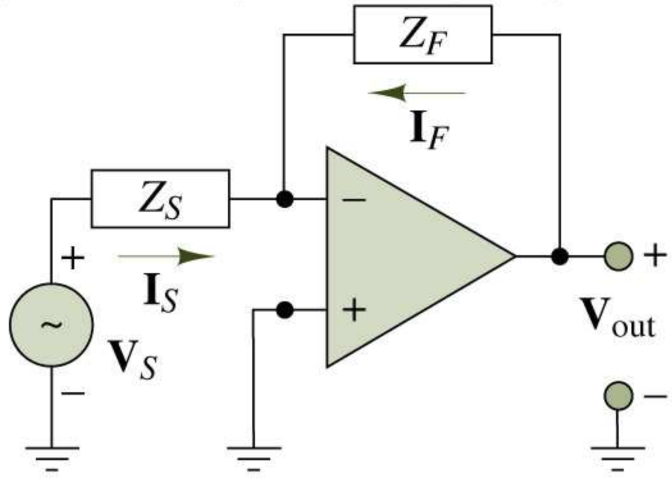
$$A_d = 10.042; A_{cm} = 0.0833$$

$$\text{CMRR(dB)} = 20\log_{10}\left(\frac{10.042}{0.0833}\right) = 41.6\,\text{dB}$$

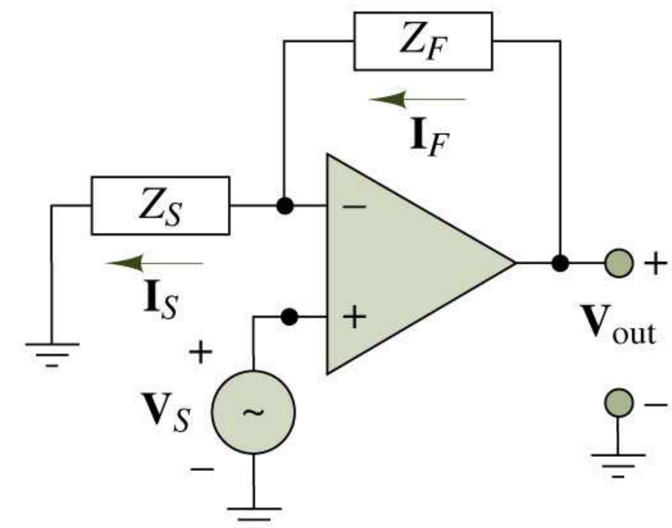
Op-amp Circuits Employing Complex Impedances

$$\frac{V_{out}}{V_S}(j\omega) = -\frac{Z_F}{Z_S}$$

$$\frac{V_{out}}{V_S}(j\omega) = 1 + \frac{Z_F}{Z_S}$$

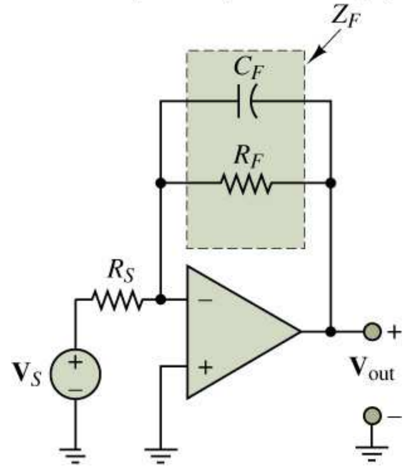


Inverting

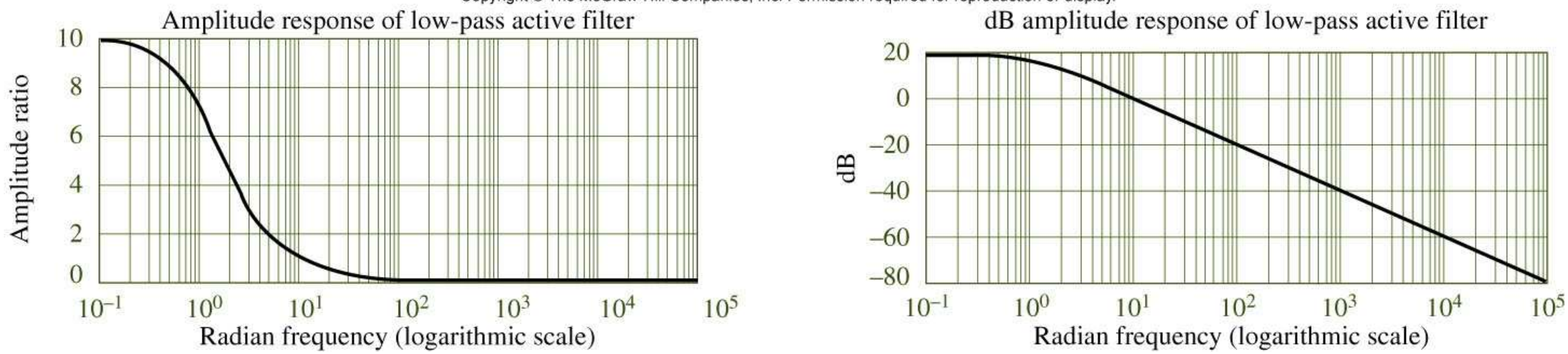


Noninverting

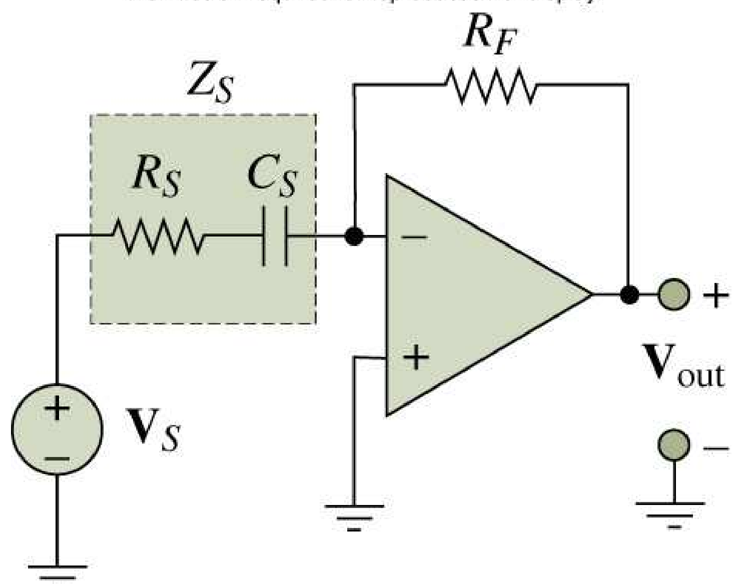
Active Low-Pass Filter



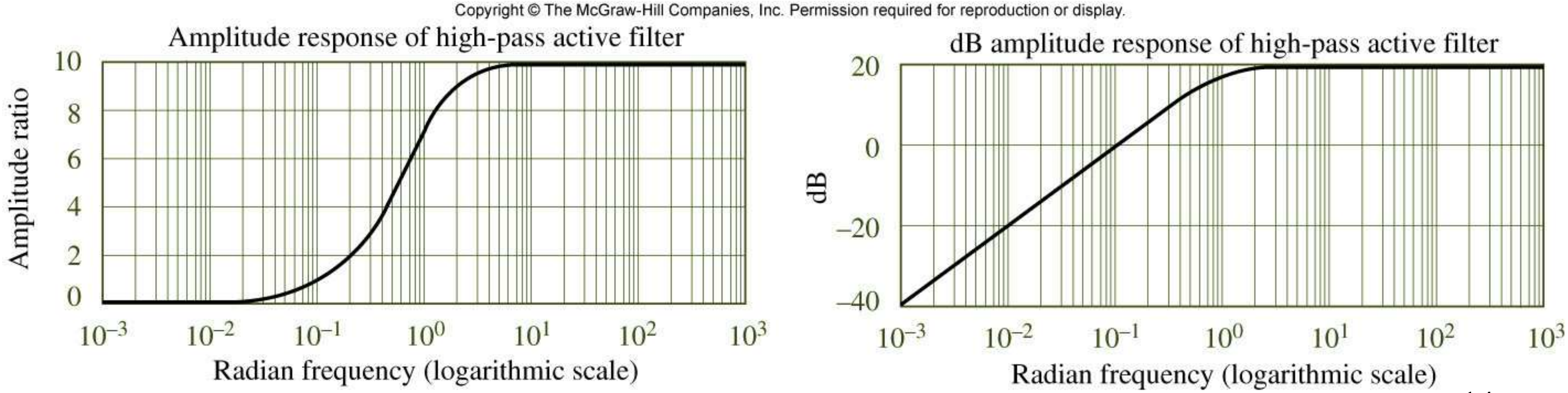
Normalized Response of Active Low-pass Filter



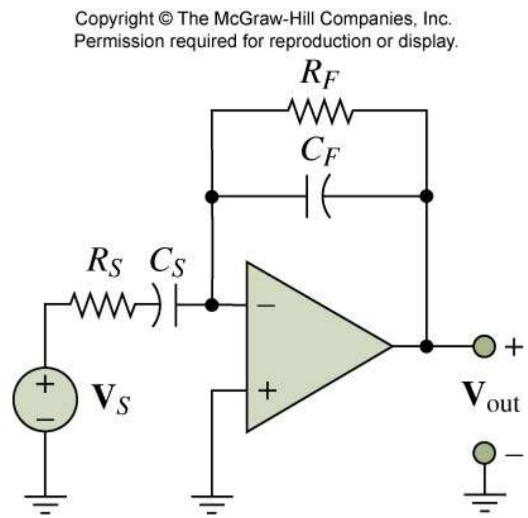
Active High-Pass Filter



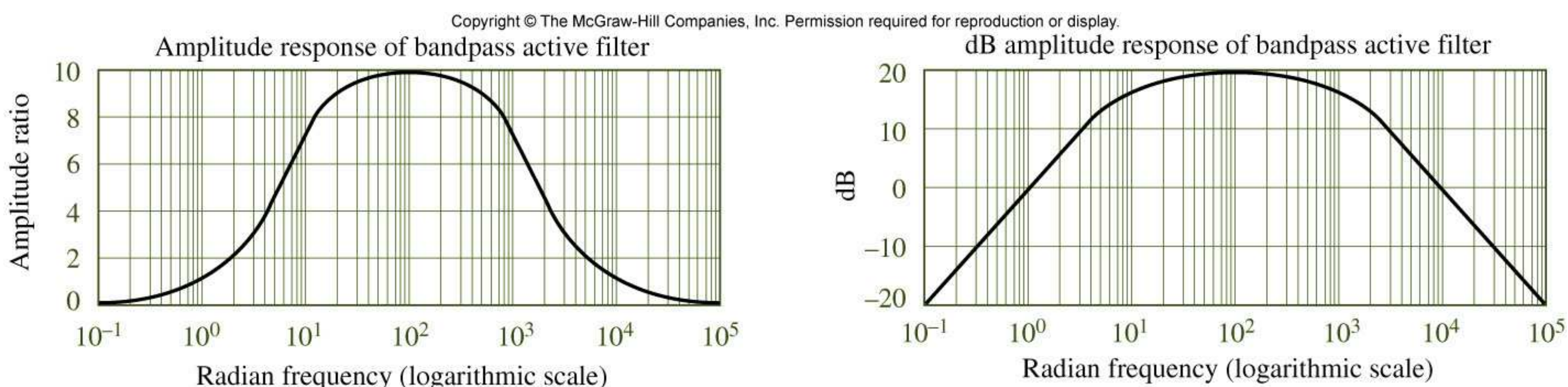
Normalized Response of Active High-pass Filter



Active Band-Pass Filter

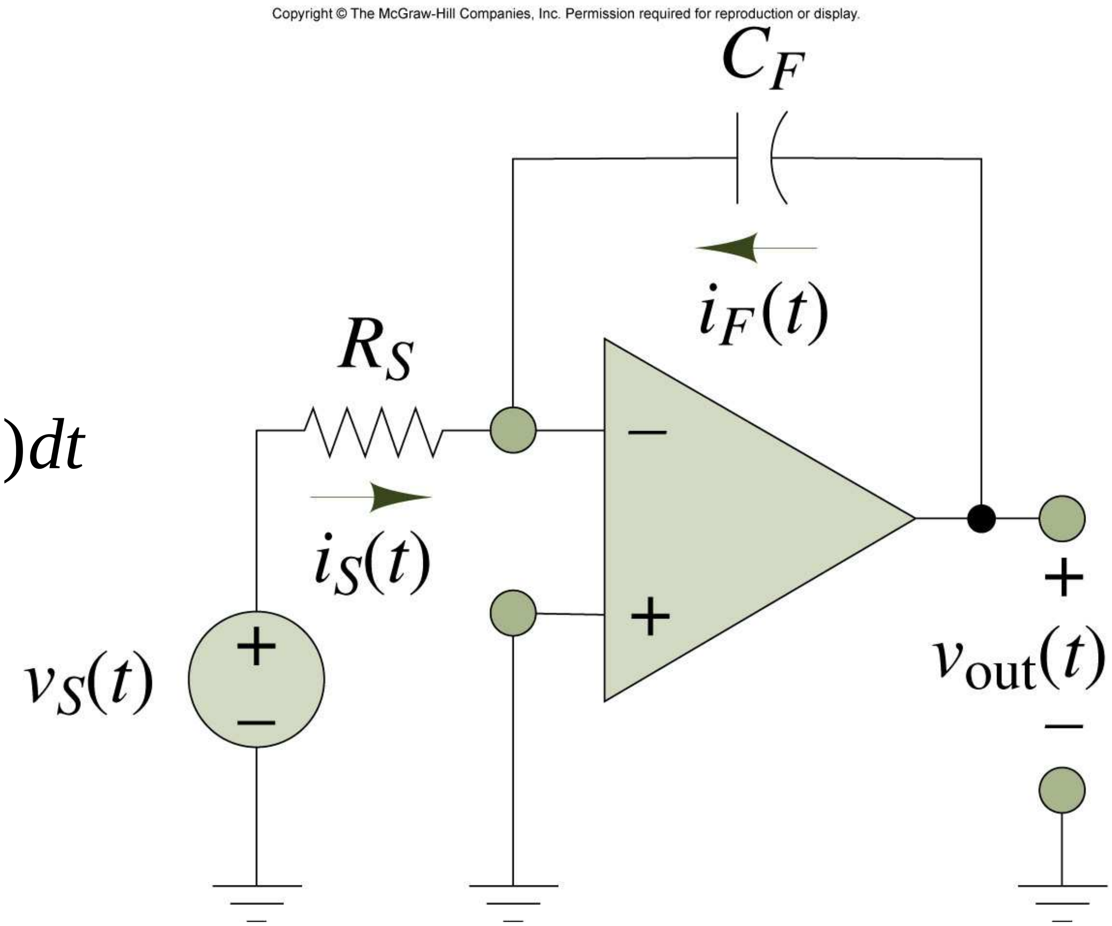


Normalized Amplitude Response of Active Band-pass Filter



Op-amp Integrator

$$v_{out}(t) = -\frac{1}{R_S C_F}\int_{-\infty}^{t} v_S(t)dt$$



Op-amp Differentiator

$$v_{out}(t) = -R_F C_S \frac{dv_S(t)}{dt}$$