Microelectronics
Circuit Analysis and Design

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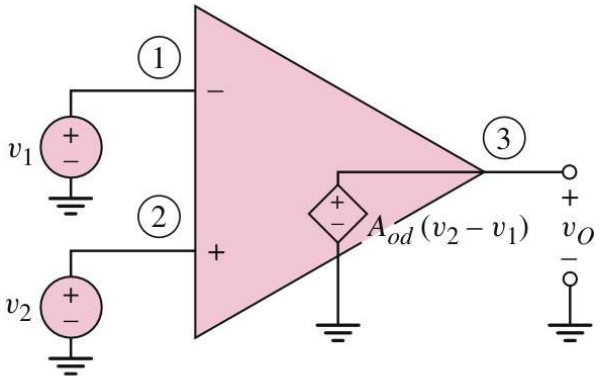
Chapter 9

Ideal Operational Amplifiers and Op-Amp Circuits

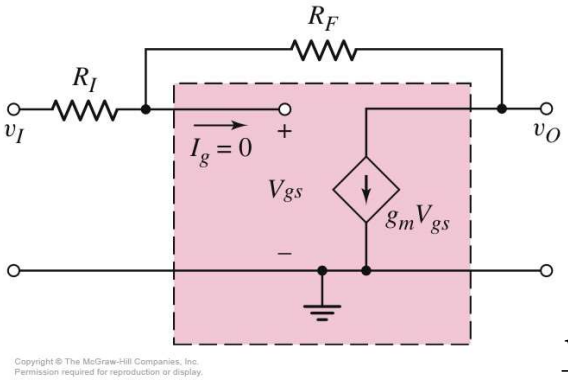
In this chapter, we will:

- Develop the parameters and characteristics of the ideal operational amplifier, and determine the analysis method of ideal op-amp circuits.
  - inverting operational amplifier
  - summing operational amplifier
  - noninverting operational amplifier
- Analyze several ideal op-amp circuits including the difference amplifier and the instrumentation amplifier.
- Design several ideal op-amp circuits with given design specifications.

Ideal Op-Amp Equivalent Circuit

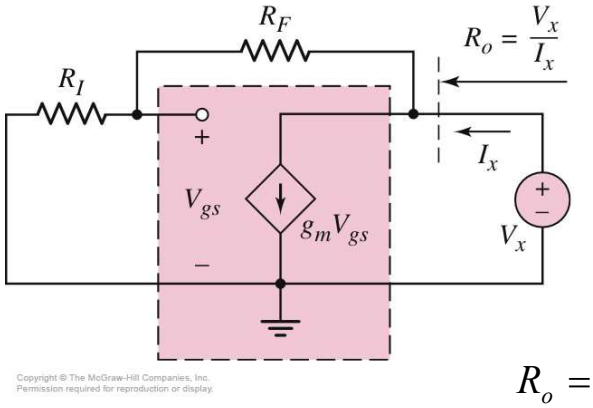


Small-Signal Equivalent Circuit: MOSFET with Input and Output Feedback



$$\frac{v_O}{v_I} = -\frac{R_F}{R_I}$$

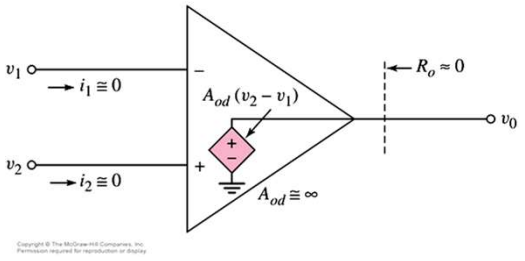
Output Impedance : MOSFET with Input and Output Feedback



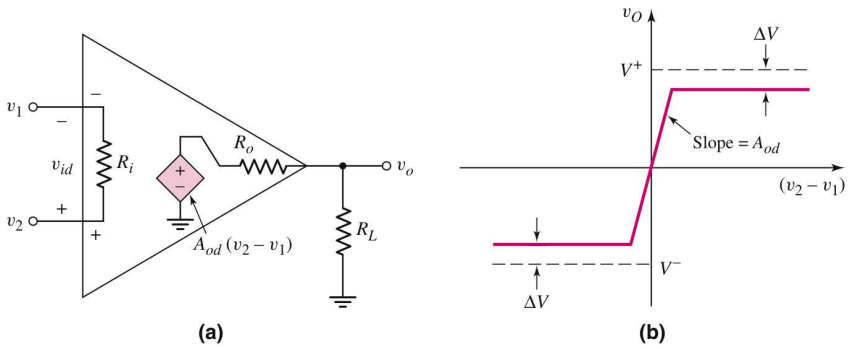
$$R_o = \frac{R_I + R_F}{1 + g_m R_I}$$

Ideal Op-Amp Characteristics

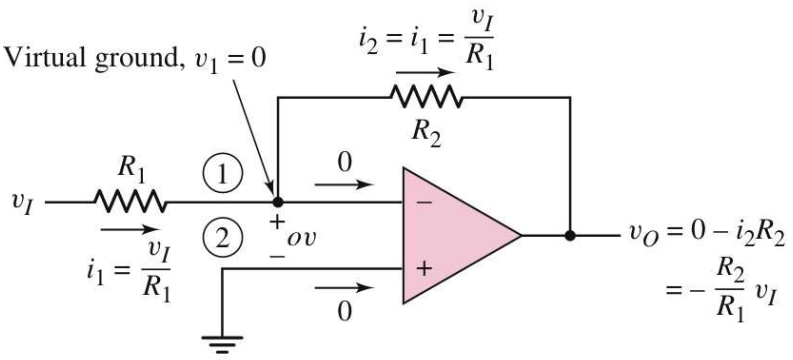
1. Internal differential gain A_{od} is infinite.
2. Differential input voltage (v_2-v_1) is zero.
3. Effective input resistance is infinite.
4. Output resistance is zero, so output voltage is connected directly to dependent voltage source.



Equivalent Circuit of Op-Amp



Inverting Op-Amp

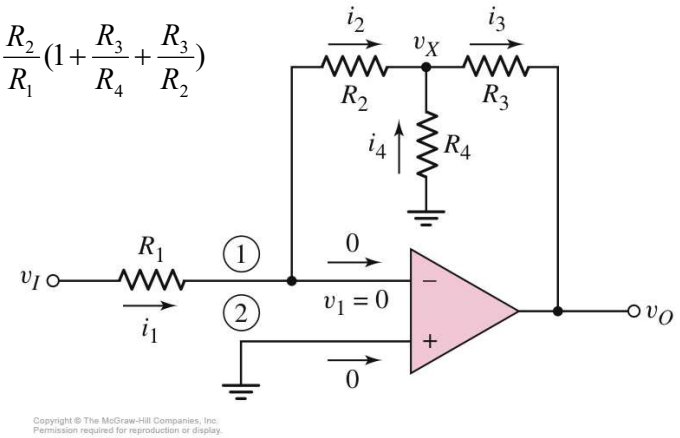


Problem-Solving Technique: Ideal Op-Amp Circuits

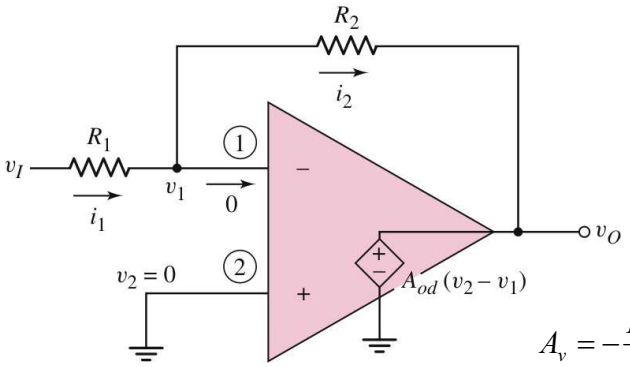
1. If noninverting terminal is grounded, then inverting terminal is virtual ground.
   a. Sum currents at node assuming no current enters Op Amp.
2. If noninverting terminal is not grounded, then inverting terminal voltage is equal to that of the noninverting terminal.
   a. Sum currents at node assuming no current enters Op Amp.
3. Output voltage is determined from either Step 1 or 2.

Inverting Op-Amp with T-Network

$$A_v = -\frac{R_2}{R_1}\left(1+\frac{R_3}{R_4}+\frac{R_3}{R_2}\right)$$

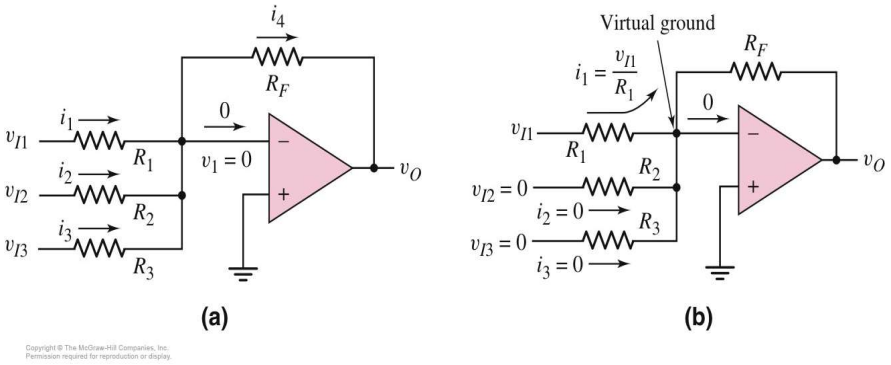


Inverting Op-Amp with Finite Differential-Mode Gain



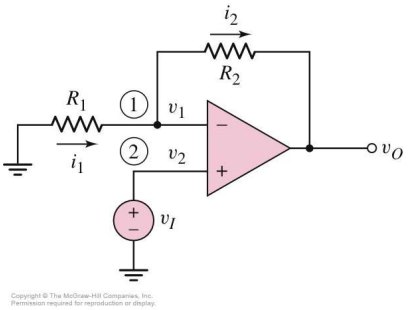
$$A_v = -\frac{R_2}{R_1}\frac{1}{[1+\frac{1}{A_{od}}(1+\frac{R_2}{R_1})]}$$

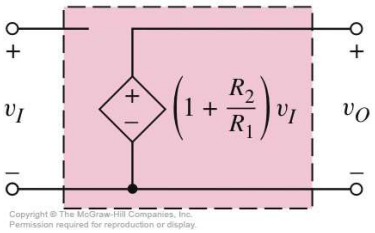
Summing Op-Amp



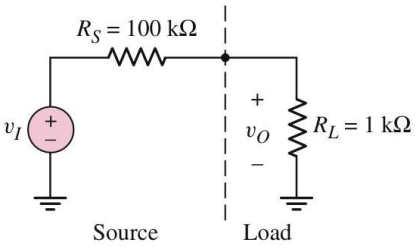
$$v_O = -(\frac{R_F}{R_1}v_{I1} + \frac{R_F}{R_2}v_{I2} + \frac{R_F}{R_3}v_{I3})$$

Noninverting Op-Amp

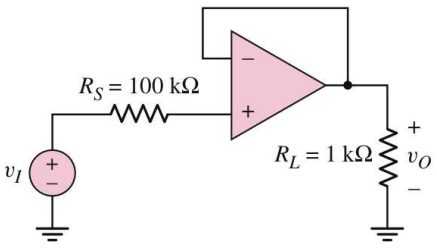




Voltage Follower



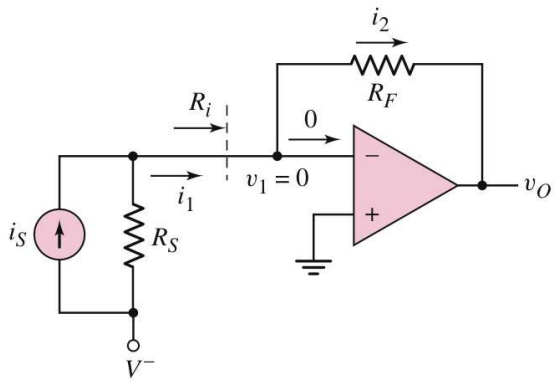
(a)



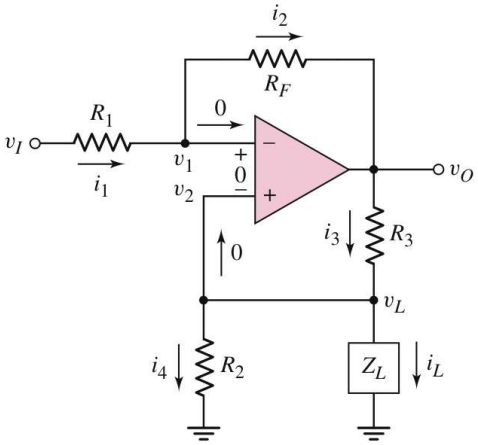
(b)

$$\frac{v_O}{v_I} = \frac{R_L}{R_L + R_S}$$

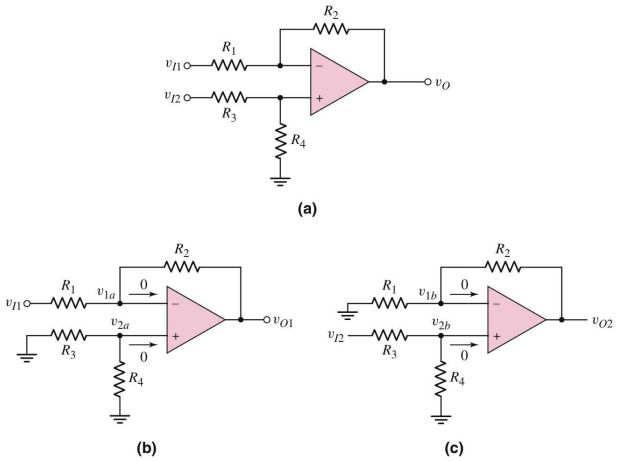
Current-to-Voltage Converter



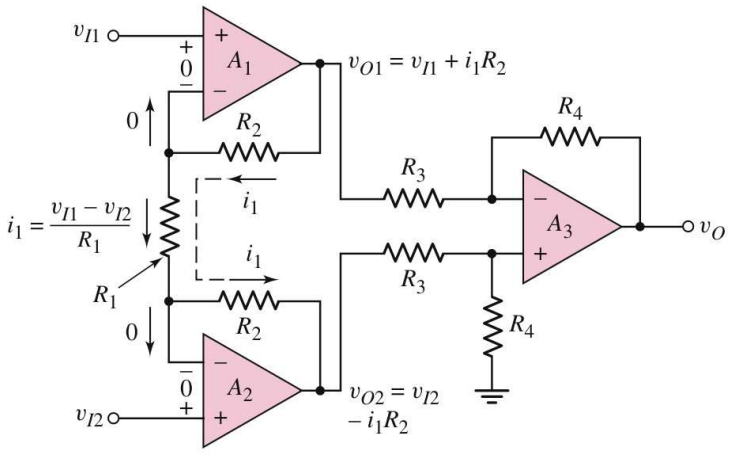
Voltage-to-Current Converter



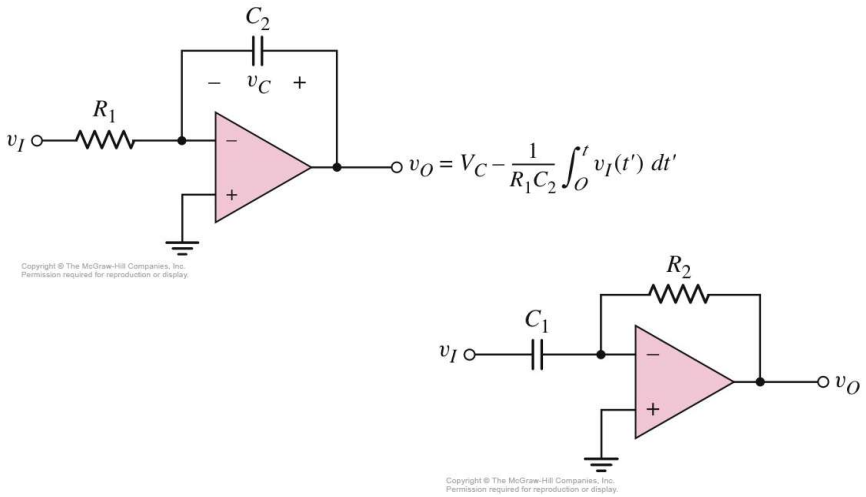
Op-Amp Difference Amplifier



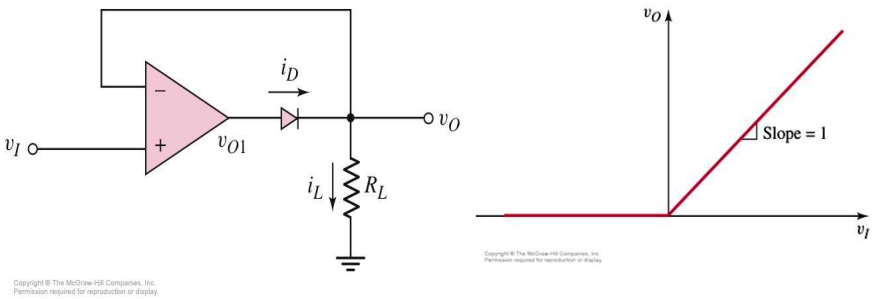
Instrumentation Amplifier



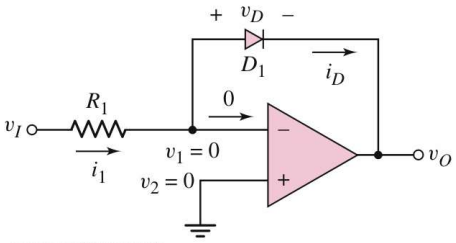
Op-Amp Integrator and Differentiator



Precision Half-Wave Rectifier

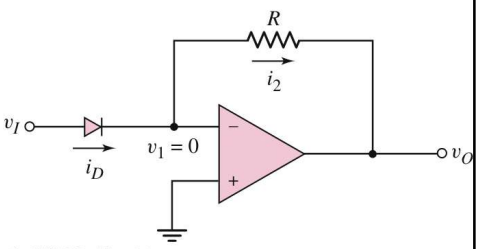


Log and Antilog Amplifiers



Log Amplifier

Antilog Amplifier



Op-Amp Voltage Reference Circuit