C5-Supplementary Information

Practice Problem 5.2

Repeat Example 5.1 using the ideal op amp model.

Answer: -2, 200 μA.

Example 5.1

A 741 op amp has an open-loop voltage gain of 2×10^5, input resistance of 2 MΩ, and output resistance of 50 Ω. The op amp is used in the circuit of Fig. 5.6(a). Find the closed-loop gain v_o/v_s. Determine current i when $v_s = 2$ V.

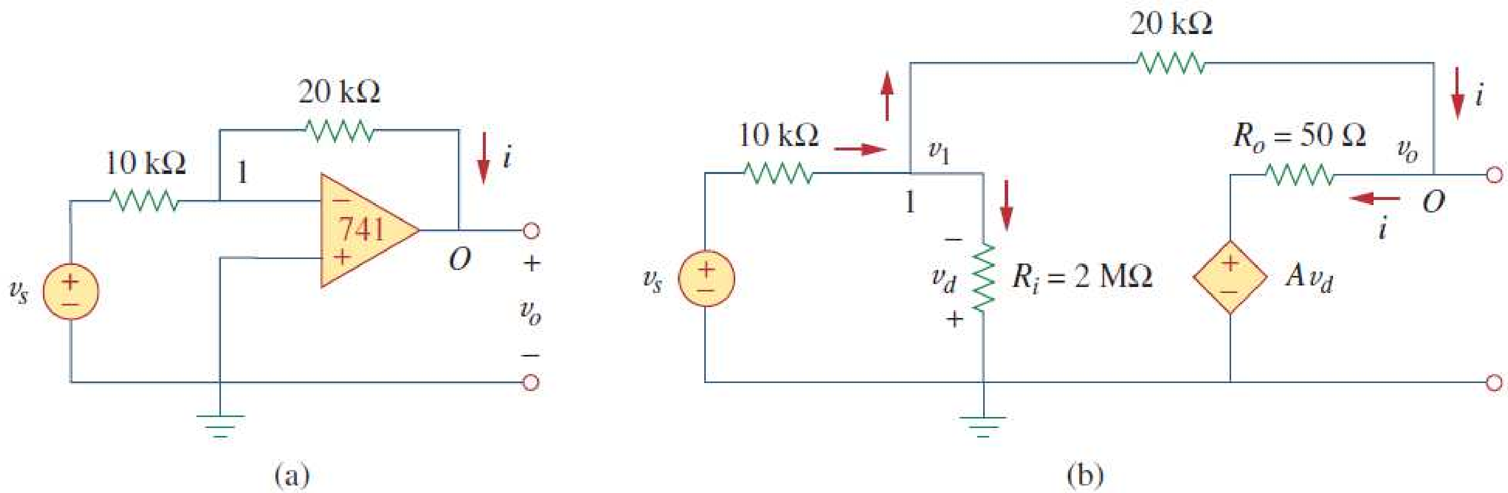

Figure 5.6
For Example 5.1: (a) original circuit, (b) the equivalent circuit.

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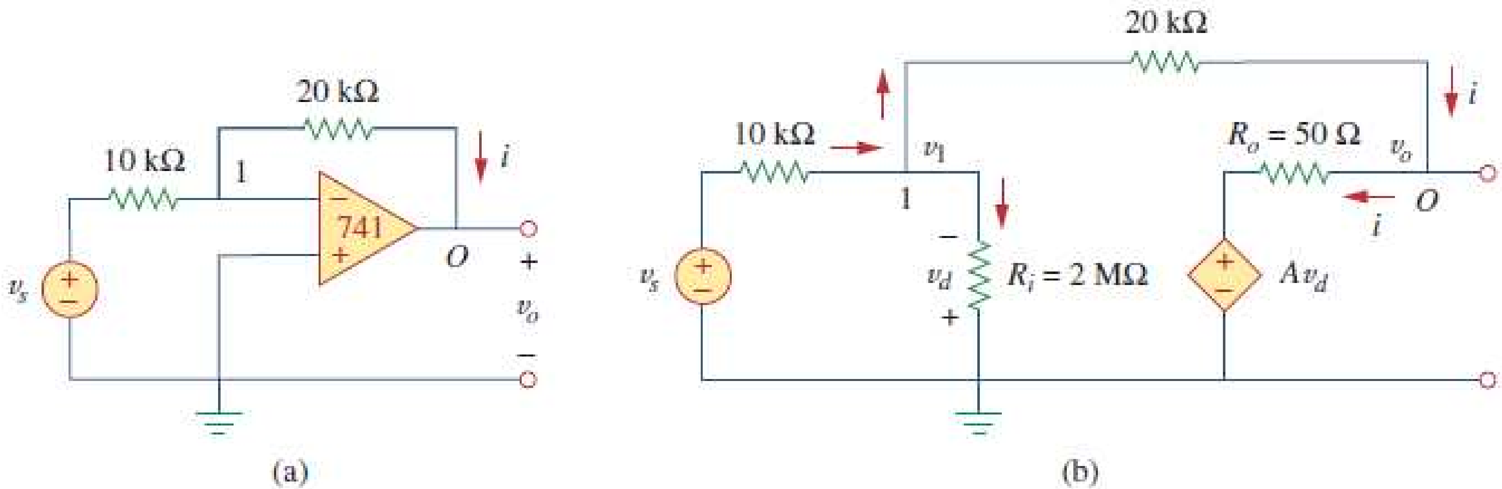
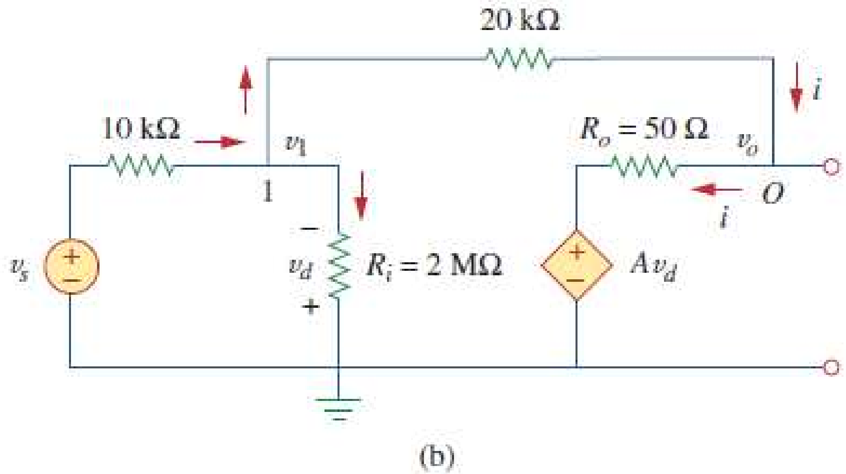


Figure 5.6
For Example 5.1: (a) original circuit, (b) the equivalent circuit.

A real op amp

- 1. The equivalent circuit



- 2. KCL@node 1

$$\frac{v_s - v_1}{10 \times 10^3} = \frac{v_1}{2000 \times 10^3} + \frac{v_1 - v_o}{20 \times 10^3}$$

$$200v_s = 301v_1 - 100v_o$$

$$2v_s \simeq 3v_1 - v_o \quad \Rightarrow \quad v_1 = \frac{2v_s + v_o}{3} \qquad \textbf{(5.1.1)}$$

- 3. KCL@node O

$$\frac{v_1 - v_o}{20 \times 10^3} = \frac{v_o - Av_d}{50}$$

$v_d = -v_1$ and $A = 200{,}000$

$$v_1 - v_o = 400(v_o + 200{,}000v_1) \qquad \textbf{(5.1.2)}$$

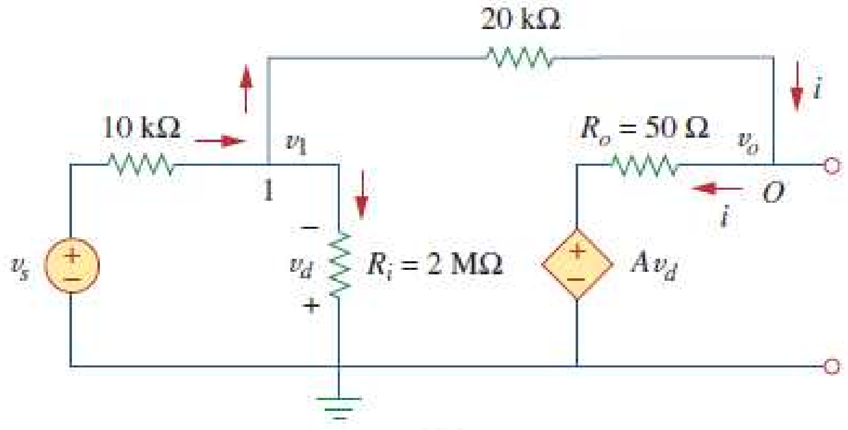
- 4.
  - 3 unknowns (v_s, v_1, v_o); need to get relation between v_s and v_o → eliminate v1
  - Substitute Eq. (5.1.2) into Eq. (5.1.1)

$$0 = 26{,}667{,}067 v_o + 53{,}333{,}333 v_s \quad \Rightarrow \quad \frac{v_o}{v_s} = -1.9999699$$

$$\boxed{\text{This is closed-loop gain, because the 20-k feedback resistor closes the loop between the output and input terminals.}}$$

- 5.
  - When v_s=2V, v_o=–3.9999398V.
  - From Eq. (5.1.1), we obtain v_1=20.066667 μV.
  - Thus, $i = \dfrac{v_1 - v_o}{20 \times 10^3} = 0.19999 \text{ mA}$

- Question: What if there is no feedback loop?



(b)

- <u>Answer</u>:
  - $v_1 = v_s \times (2/0.01+2)$
  - E.g., for v_s=2V, $v_1 \cong$2V,

    $|v_o|=|Av_d|>>|Vcc|$, in saturation region

    The feedback loop is helpful to operate an op amp in linear region.

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Practice Problem 5.2

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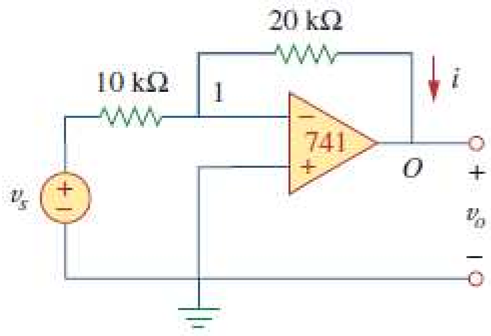

(a)

V_1=0V

(v_s–0)/10k=(0–Vo)/20k

V_o/V_s=–2

For V_s=2V, V_o=–4V

i=(0+4)/20k=200μA

Comparisons

	Real op amp	Ideal op amp
Gain v_o/v_s	-1.9999699	-2
v_1	20.066667 μV	0 V
v_o	–3.9999398V μV	–4V
i	199.999 μA	200 μA
i_{Ro} (i through R_o)	199.999 μA	200 μA
v_d=0-v_1	–20.066667 μV	0V
Av_d	–4.0133 V	$v_o - i_{Ro} \times R_o = -4V \neq 0$ *

* cannot be calculated by $A \times v_d$ since $\infty \times 0$ is not defined.