EE 254

Electronic Instrumentation

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Lecture Note #06

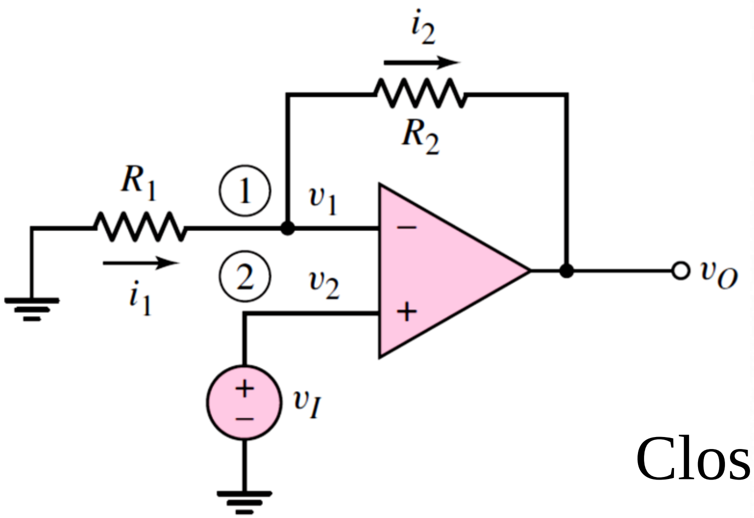
Content (Brief)

2. Op-Amp Applications

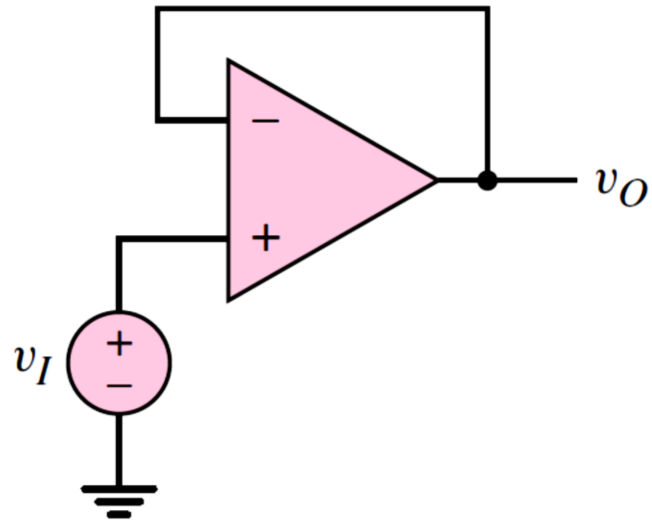
- Linear Applications
  - Inverting amplifiers
  - Noninverting amplifiers
  - Differential amplifiers
  - Summing amplifiers
  - Integrators
  - Differentiators
  - Low/ High pass filters
  - Instrumentational amplifiers
- Nonlinear Applications
  - Precision rectifiers
  - Peak detectors
  - Schmitt-trigger comparator
  - Logarithmic amplifiers

1. **Voltage Follower**
2. **I-V Converter**
3. **V-I Converter**

① Voltage Follower *(Additional Reading)*



$R_1 = \infty$



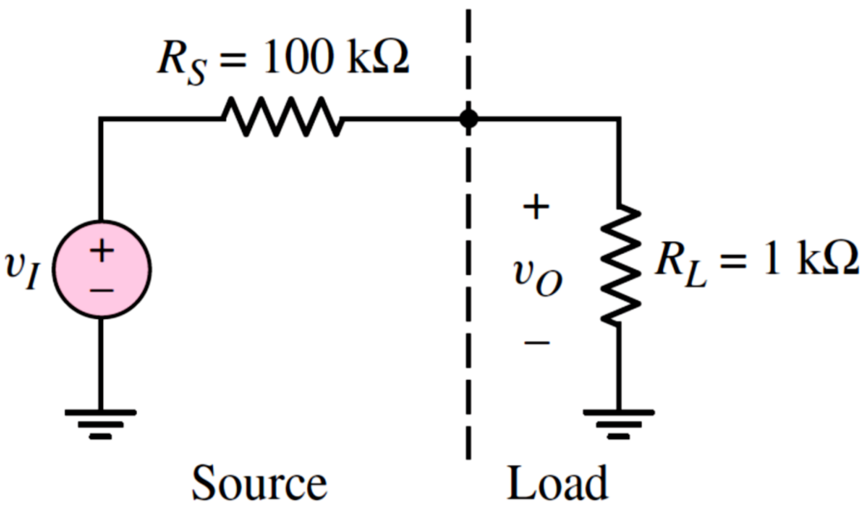
Close-loop gain

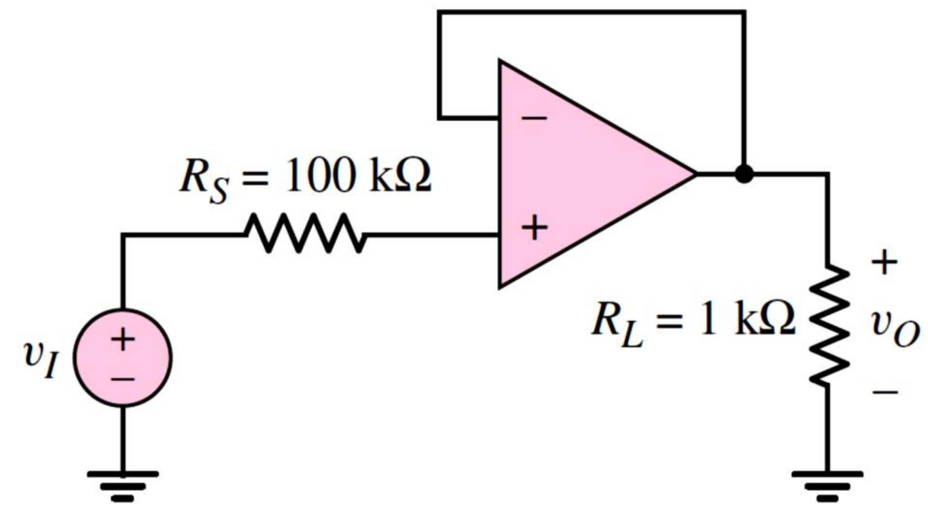
$$A_v = \frac{v_O}{v_I} = 1$$

- The closed-loop gain is independent of resistor $\boldsymbol{R_2}$ (except when $R_2 = \infty$), so we can set $R_2 = 0$ to create a short circuit.
- Other terms used: **impedance transformer or buffer**.
- The input impedance is essentially ∞ and output impedance is 0

① Voltage Follower *(Additional Reading)*

- If for example, the output impedance of a signal source is large, a voltage follower inserted between the source and a load (act as a buffer).
- Hence can prevent **loading effect/ Attenuation**.





$$\frac{v_O}{v_I} = \frac{R_L}{R_L + R_S} = \frac{1}{1+100} \cong 0.01$$

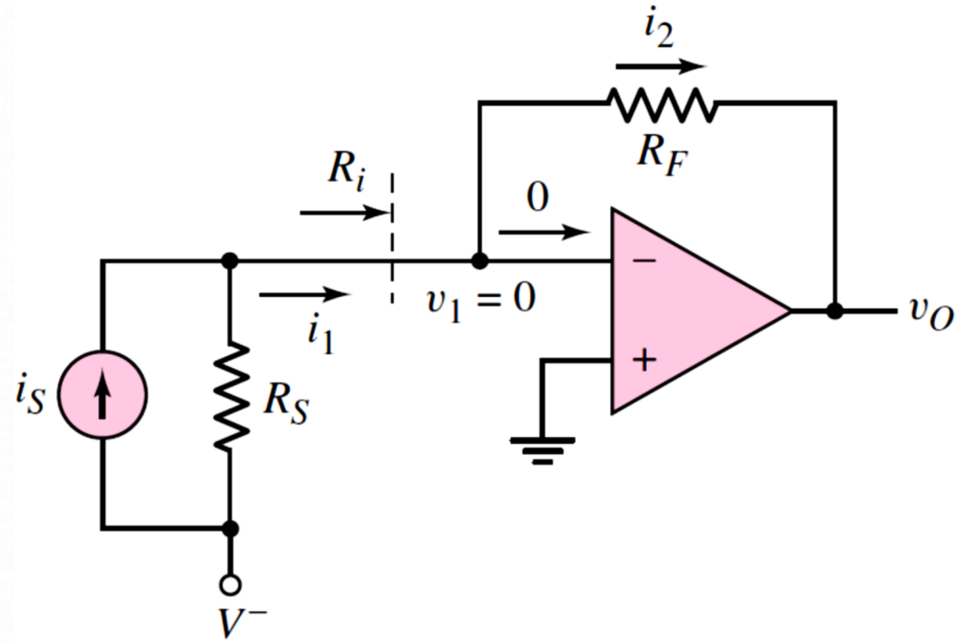
$$v_O \cong v_I$$

Attenuation

Loading effect is eliminated

② Current-to-Voltage Converter *(Additional Reading)*

The input resistance R_i at the virtual ground node is



$$R_i = \frac{v_1}{i_1} \cong 0$$

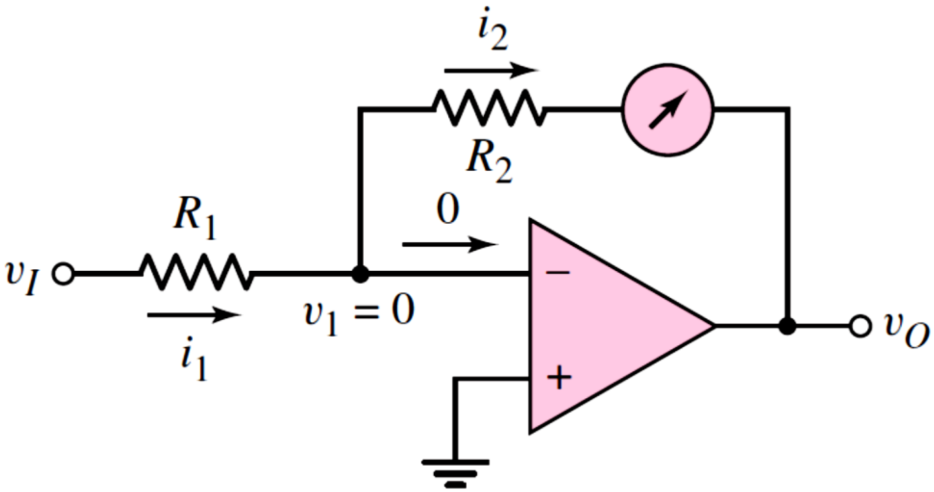
We can assume that $R_S \gg R_i$; therefore

$$i_2 = i_1 = i_S$$

And

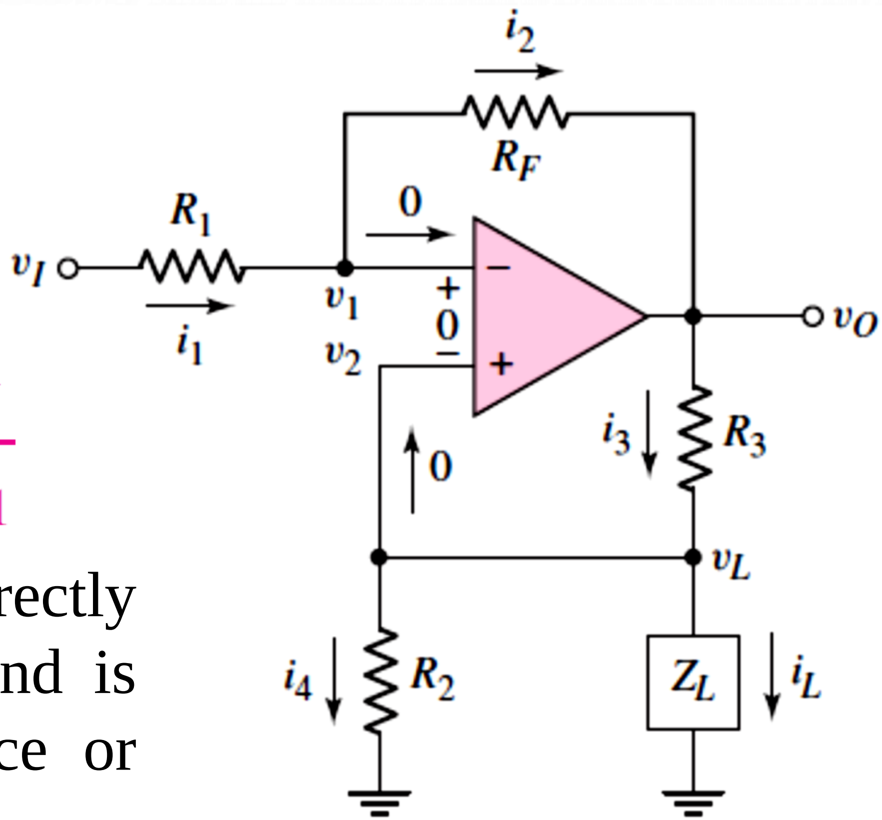
$$v_O = -i_2 R_F = -i_S R_F$$

③ Voltage-to-Current Converter *(Additional Reading)*



Simple voltage-to-current converter

More Practical Voltage-to-current converter

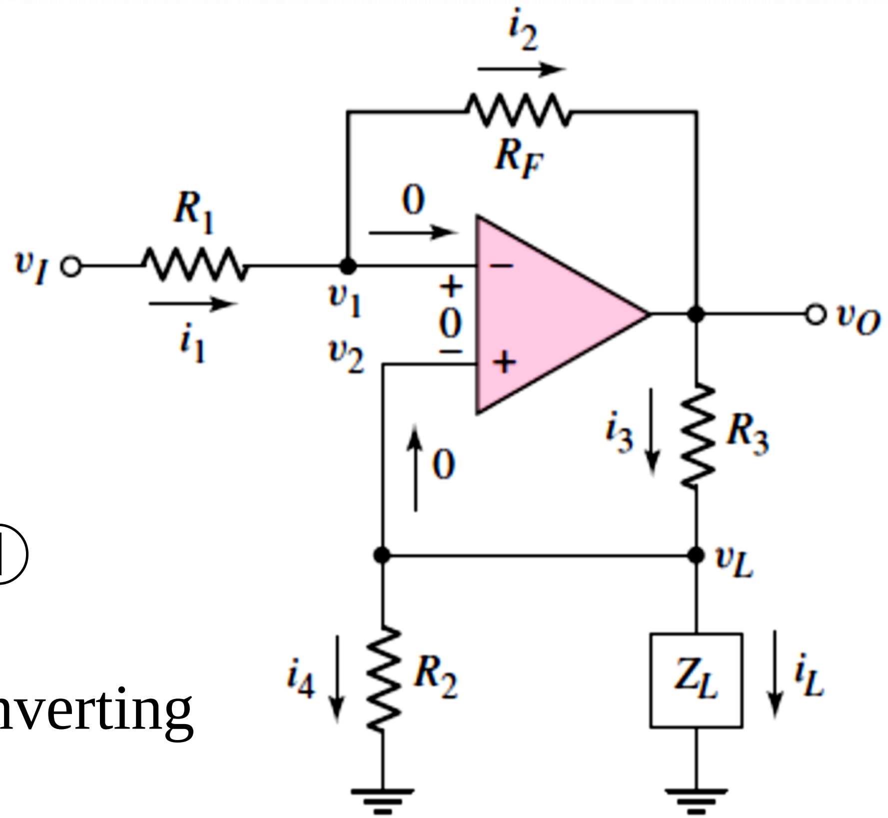


For this circuit;

$$i_2 = i_1 = \frac{v_I}{R_1}$$

Which means that current i_2 is directly proportional to input voltage v_I and is independent of the load impedance or resistance R_2.

③ Voltage-to-Current Converter *(Additional Reading)*



From the virtual short-circuit concept

$$v_1 = v_2$$

Also note that,

$$v_1 = v_2 = v_L = i_L Z_L$$

Equating the currents i_1 and i_2,

$$\frac{v_I - i_L Z_L}{R_1} = \frac{i_L Z_L - v_O}{R_F} \quad \rightarrow ①$$

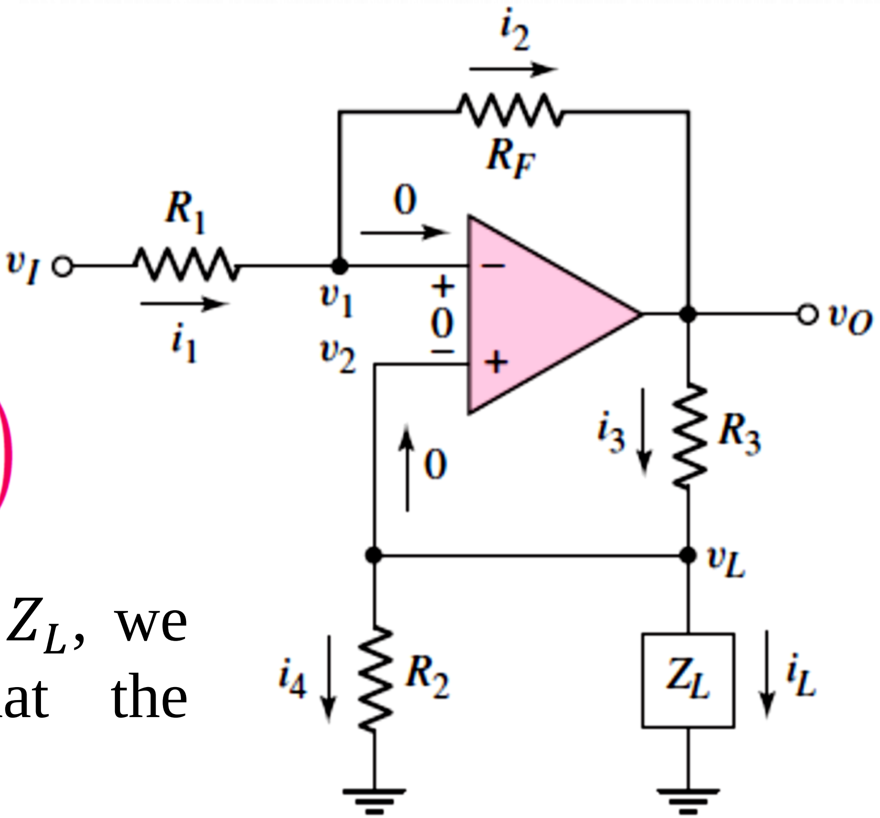
Summing the currents at the noninverting terminal

$$\frac{v_O - i_L Z_L}{R_3} = i_L + \frac{i_L Z_L}{R_2} \quad \rightarrow ②$$

And then, $$\frac{R_F}{R_1} \cdot \frac{(i_L Z_L - v_I)}{R_3} = i_L + \frac{i_L Z_L}{R_2}$$

③ Voltage-to-Current Converter *(Additional Reading)*

$$\frac{R_F}{R_1} \cdot \frac{(i_L Z_L - v_I)}{R_3} = i_L + \frac{i_L Z_L}{R_2}$$



Combining terms in i_L,

$$i_L\left(\frac{R_F Z_L}{R_1 R_3} - 1 - \frac{Z_L}{R_2}\right) = v_I\left(\frac{R_F}{R_1 R_3}\right)$$

In order to make i_L independent of Z_L, we can design the circuit such that the coefficient of Z_L is zero;

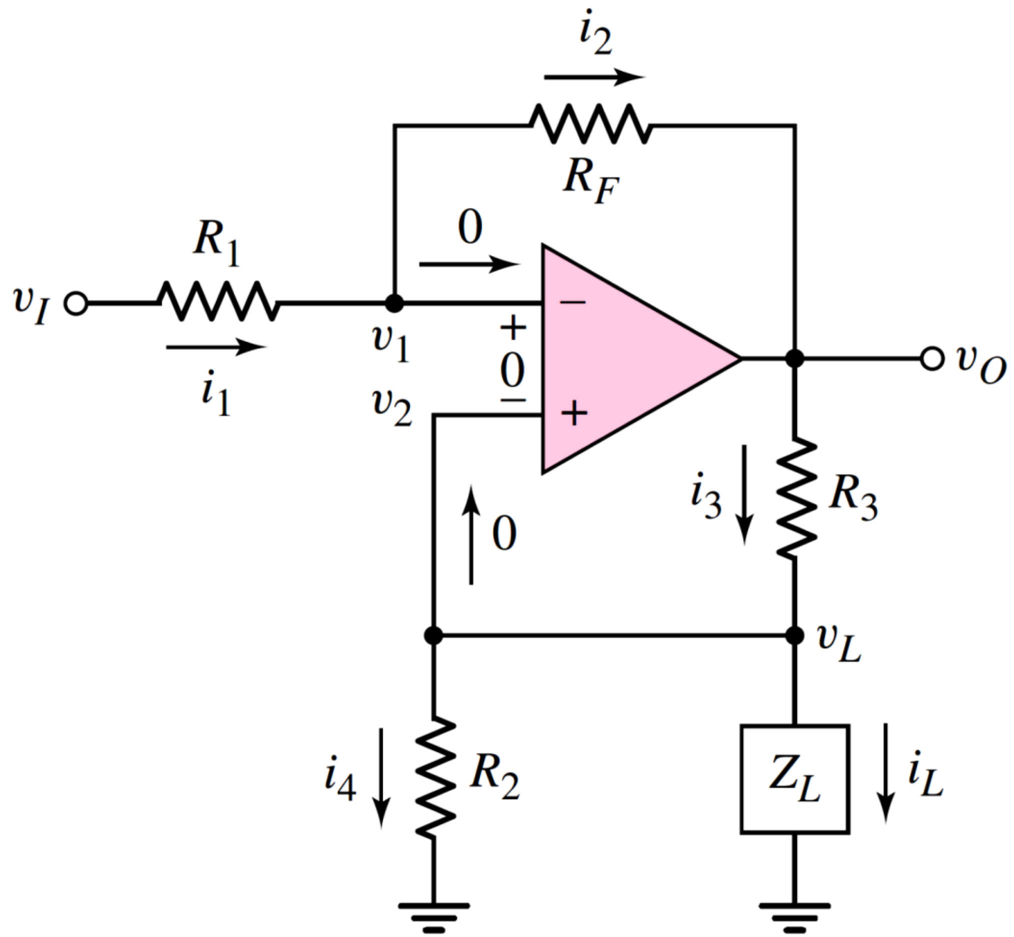
$$\frac{R_F}{R_1 R_3} = \frac{1}{R_2}$$

And then;

$$i_L = -v_I\left(\frac{R_F}{R_1 R_3}\right) = \frac{-v_I}{R_2}$$

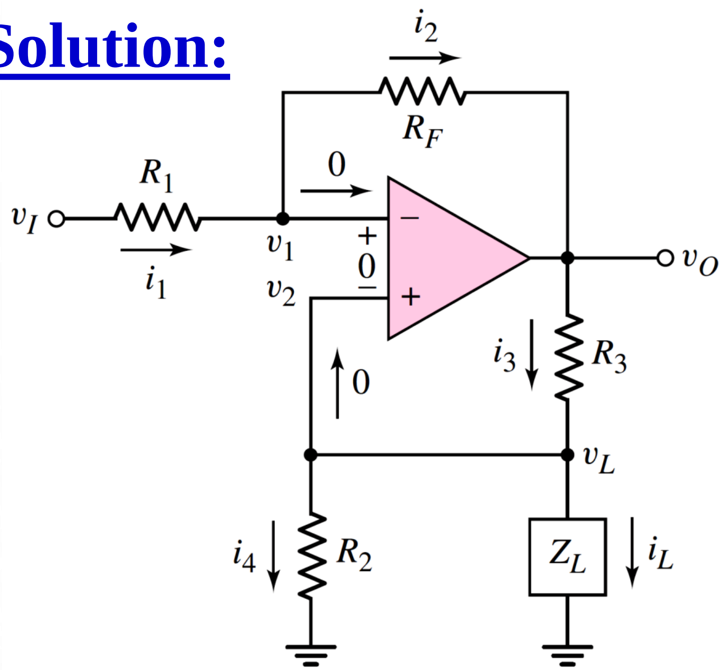
Example 01: Voltage-to-Current Converter

Determine a load current in a voltage-to-current converter. Consider the circuit in the figure. Let $Z_L = 100\Omega$ $R_1 = 10\ k\Omega$, $R_2 = 1\ k\Omega$, $R_3 = 1\ k\Omega$, and $R_F = 10\ k\Omega$. If $v_I = -5\ V$, determine the load current i_L and the output voltage v_O.



Example 01: Voltage-to-Current Converter

Solution:



Given $Z_L = 100\Omega$ $R_1 = 10\ k\Omega$, $R_2 = 1\ k\Omega$, $R_3 = 1\ k\Omega$, and $R_F = 10\ k\Omega$.

If $v_I = -5\ V$, **determine** i_L and v_O

Condition to be satisfied

$$\frac{R_F}{R_1 R_3} = \frac{1}{R_2} \qquad \frac{1}{R_2} = \frac{10}{(10)(1)} = 1$$

The load current $\quad i_L = \frac{-v_I}{R_2} = \frac{-(-5)}{1 \times 10^3} \quad \underline{\underline{= 5\ mA}}$

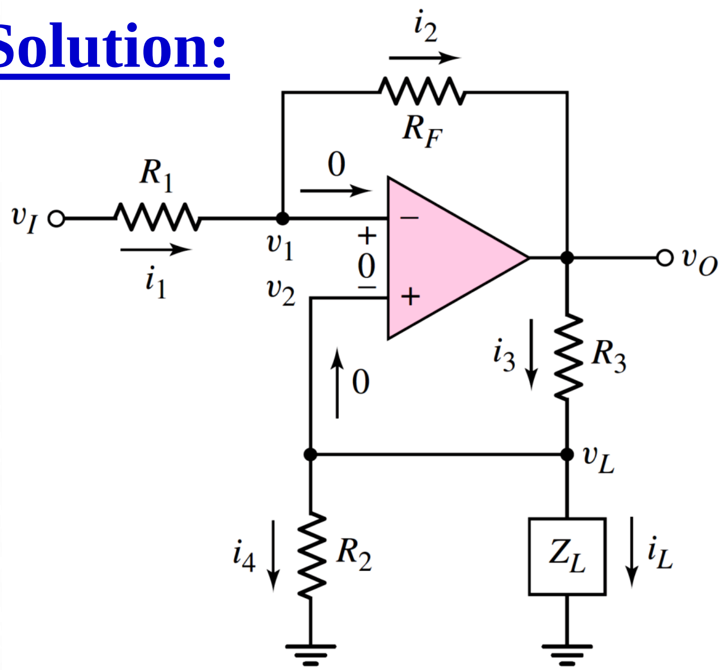
The voltage across the load $\quad v_L = i_L Z_L = (5 \times 10^{-3})(100) = 0.5\ V$

Current i_4 and i_3 $\quad i_4 = \frac{v_L}{R_2} = \frac{0.5}{1} = 0.5\ mA$

$$i_3 = i_4 + i_L = 0.5 + 5 = 5.5\ mA$$

Example 01: Voltage-to-Current Converter

Solution:



The output voltage is then calculated as:

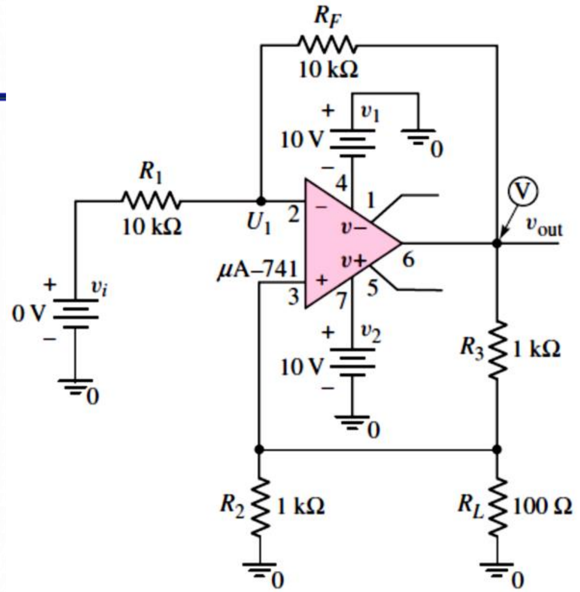
$$v_O = i_3 R_3 + v_L$$

$$= (5.5 \times 10^{-3})(10^3) + 0.5$$

$$\boxed{= 6.0\ V}$$

We could also calculate the current i_1 and i_2 $\quad i_1 = i_2 = -0.55\, mA$

Example 01: V-to-I Converter



Solution:

PSpice Simulation for the input voltage variation between $0V$ to $10V$

Input voltage $0V$ to $-10V$