Example 4-13  Find the input-output relationship for the circuit below.

Break circuit into two parts: (1) $K_S$, the proportionality constant of the source circuit

(2) $K_{Amp}$, the gain of the non-inverting amplifier

Since the output resistance of the non-inverting amplifier is zero, the load $R_L$ has no effect on $V_o$.

We know the closed loop gain of the amplifier to be

$$K_{Amp} = \frac{V_o}{V_p} = \frac{R_3 + R_4}{R_4}$$

The input current $i_p$ to the amplifier is zero, so

$$V_p = \frac{R_2}{R_{1} + R_2} V_s \text{ by voltage divider.}$$

The overall circuit gain is given as

$$K_{Circuit} = K_S K_{Amp}$$

$$K_{Circuit} = \left[ \frac{R_2}{R_{1} + R_2} \right] \left[ \frac{R_3 + R_4}{R_4} \right]$$
Voltage Follower

Consider the above circuit where there is a direct connection from the output back to the input.

By inspection \( V_p = V_N \), \( V_o = V_N \), and \( V_p = V_S \).

Substituting \( V_o = V_S \).

Since the output exactly follows the input this circuit is called a voltage follower.

This circuit is also called a buffer because it isolates the source and load circuits. Without this circuit you would have

\[ V_o = \frac{R_L}{R_L + R_S} V_S \]

There would be a voltage divider relationship between the input and output circuits.
Example 4-34 Find the input-output relationship for this circuit.

\[ V_o = -K \cdot V_T = -\frac{R_4}{R_T + R_3} \cdot V_T = -\frac{R_4}{R_1 R_2 + R_3} \cdot V_T \]

Thevenize this source.

\[ V_0 = -\frac{\frac{R_4 (R_1 + R_2)}{R_1 R_2 + R_1 R_3 + R_2 R_3}}{V_5} \]

In terms of the original \( V_s \)

\[ V_o = -\frac{R_4}{R_1 R_2 + R_1 R_3 + R_2 R_3} \cdot \frac{R_2}{R_1 + R_2} \cdot V_5 = -\frac{R_2 R_4}{R_1 R_2 + R_1 R_3 + R_2 R_3} \cdot V_5 \]

\[ \text{K}_\text{circuit} \]
Exercise 4-11

Sketch the transfer characteristic of the OP AMP circuit shown below for $-10 < V_s < 10$ volts.

This is an inverting amplifier where $K = -\frac{33k}{10k} = -3.3$

The amplifier has the transfer shown below.

Amplifier output saturates at $\pm 15$ volts corresponding to inputs given by:

$\pm 15 = K V_s = -3.3 V_s$

$V_s = \pm 4.54$ volts.
The summing amplifier

By inspection \( i_N = 0 \) and \( v_A = v_N = v_P = 0 \)

Using KCL @ node A.

\[
\sum_{i=0}^{+m} i_1 + i_2 - i_N + i_F = 0
\]

\[
\frac{v_1}{R_1} + \frac{v_2}{R_2} - 0 + \frac{v_2}{R_F} = 0
\]

\[
\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_0}{R_F} = 0
\]

\[
v_o = -\frac{R_F}{R_1} v_1 - \frac{R_F}{R_2} v_2
\]

\[
v_o = k_1 v_1 + k_2 v_2
\]

In the case that \( R_1 = R_2 = R \) this reduces

\[
v_o = -\frac{R_F}{R} (v_1 + v_2)
\]

This is called a summation amplifier.
The differential amplifier or subtractor.

\[ i_1 = \frac{v_1 - v_p}{R_1} \quad i_2 = \frac{v_o - v_p}{R_2} \]

Since \( i_p = 0 \)  
\[ v_p = \frac{R_4}{R_3 + R_4} \cdot v_2 \]
which is the voltage at (A)

Using KCL at A  
\[ \sum_{i=1}^{m} i = 0 \quad i_1 + i_2 = 0 \]

\[ \frac{v_1 - v_p}{R_1} = -\frac{v_o - v_p}{R_2} \]

\[ \frac{v_1 - \frac{R_4}{R_3 + R_4} \cdot v_2}{R_1} = \frac{R_4}{R_3 + R_4} \cdot \frac{v_2 - v_o}{R_2} \]

\[ \frac{R_2}{R_1} \cdot v_1 - \frac{R_4 R_2}{R_1 (R_3 + R_4)} \cdot v_2 = \frac{R_4}{R_3 + R_4} \cdot v_2 - v_o \]

\[ v_o = -\frac{R_2}{R_1} \cdot v_1 + \left[ \frac{R_4 R_2}{R_1 (R_3 + R_4)} + \frac{R_4}{R_2 + R_4} \right] \cdot v_2 \]

\[ v_o = -\frac{R_2}{R_1} \cdot v_1 + \left( \frac{R_4}{R_3 + R_4} \right) \left( \frac{R_2 + R_1}{R_1} \right) \cdot v_2 \]

\[ v_o = -k_1 v_1 + k_2 v_2 \]

When \( \frac{R_3}{R_1} = \frac{R_4}{R_2} \) this reduces to  
\[ v_o = \frac{R_2}{R_1} \cdot (v_2 - v_1) \]

a subtractor.