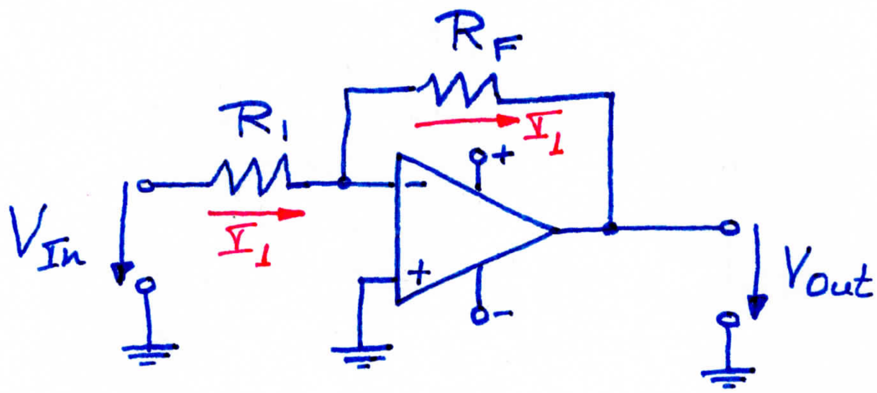
Basic differential amplifier circuit



⊕ Non-inverting input at GND

Ohm: $V_{In} = I_1 R_1$ $\qquad$ $V_{out} = -I_1 R_F$

$\Rightarrow$ 2 eqns. $\Rightarrow$ Eliminate I_1 $\Rightarrow$ $\dfrac{V_{out}}{V_{In}} = \dfrac{-R_F}{R_1}$

$$\Rightarrow \quad \boxed{A = \frac{V_{out}}{V_{In}} = -\frac{R_F}{R_1}}$$

$\hookrightarrow$ Amplification or Gain

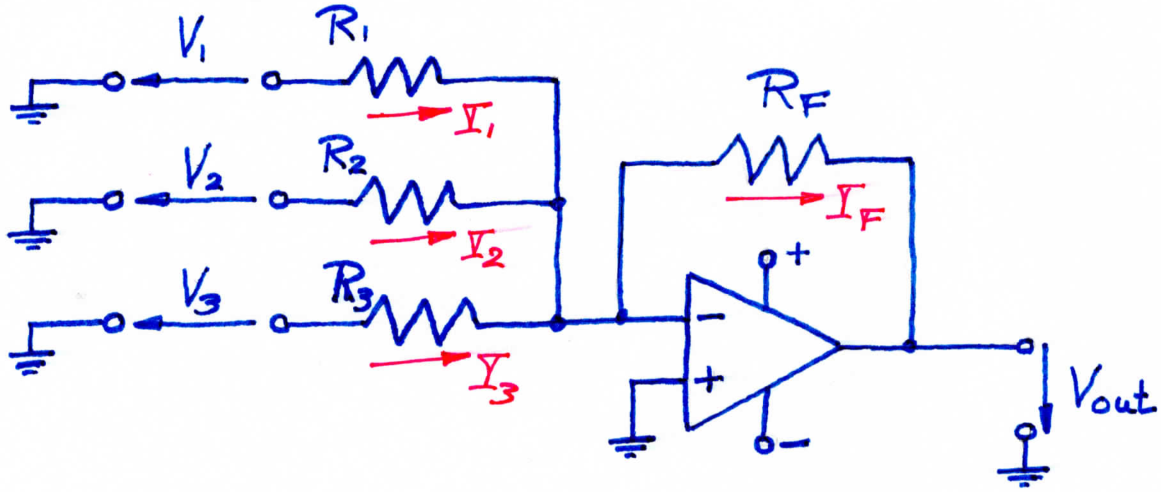
$\Rightarrow$ Amplification is largely controlled by the feedback resistor R_F

Feedback resistor R_F: Is feedback positive or negative? $\Rightarrow$ Negative feedback. Why?

What would happen if we had positive feedback? $\Rightarrow$ "Runaway"

For positive feedback $\Rightarrow$ $V_{out} = +V_{cc}$

Summation circuit



Non-inverting input ⊕ connected to GND.

Inverting input ⊖ is "virtual GND". Why?

$V_1 = I_1 R_1$ $\qquad V_2 = I_2 R_2$ $\qquad V_3 = I_3 R_3$

$I_F = I_1 + I_2 + I_3$ — KCL $\qquad V_{out} = -I_F R_F$ — KVL

$$\Rightarrow \quad V_{out} = -R_F\,(I_1 + I_2 + I_3) = -R_F\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

Consider the following case:

$R_1 = R_2 = R_3 = R$

$$\Rightarrow \quad \boxed{V_{out} = -\frac{R_F}{R}(V_1 + V_2 + V_3)}$$

→ Summation circuit

Consider the following case

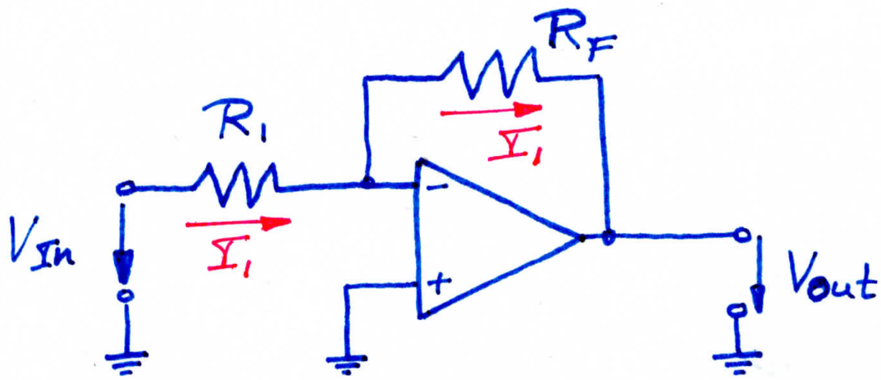
$$R_1 = R_F \qquad R_2 = \frac{1}{2} R_F \qquad R_3 = 2R_F$$

$$\Rightarrow V_{out} = -R_F \left(\frac{V_1}{R_F} + \frac{V_2}{\frac{1}{2}R_F} + \frac{V_3}{2R_F} \right)$$

$$= -\left(V_1 + 2V_2 + \frac{1}{2}V_3 \right)$$

$\Rightarrow$ Weighted summation

Inverter circuit



$V_{In} = I_1 R_1$ $\qquad\qquad$ $V_{out} = -I_1 R_F$

Eliminate I_1 from the two equations.

$$\Rightarrow \quad V_{out} = -\frac{R_F}{R_1} V_{In}$$

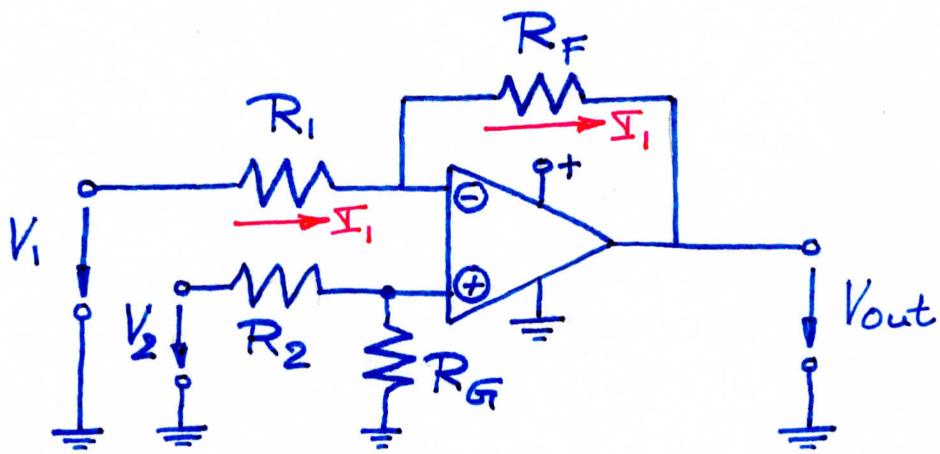
Consider the following case:

$R_F = R_1$

$$\Rightarrow \quad \boxed{V_{out} = -V_{In}}$$

$\Rightarrow$ Inverter

Subtraction circuit



We can write: $V_\oplus = V_\ominus$ (Why ?)

$$V_\oplus = V_2 \frac{R_G}{R_2 + R_G} = V_\ominus \qquad (1) \text{ (voltage divider)}$$

$$V_1 = I_1 R_1 + V_\ominus \qquad (2)$$

$$V_{out} = - I_1 R_F + V_\ominus \qquad (3)$$

$\Rightarrow$ 3 equations. 3 unknowns V_{out}, $V_\ominus$, I

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* **1ST step**: eliminate I_1 from Eqns. (2) & (3)

Eqn. (3): $I_1 = - \dfrac{V_{out} - V_\ominus}{R_F}$ $\Rightarrow$ Insert into Eqn. 2

$$V_1 = \left(- \frac{V_{out} - V_\ominus}{R_F} \right) R_1 + V_\ominus \qquad (4)$$

* **2ND step**: eliminate $V_\ominus$ from Eqns. (1) & (4)

Eqn. (4): $V_1 = - \dfrac{R_1}{R_F} V_{out} + \dfrac{R_1}{R_F} V_2 \dfrac{R_G}{R_2 + R_G} + V_2 \dfrac{R_G}{R_2 + R_G}$

$$-\frac{R_F}{R_1}V_1 = V_{out} - V_2\frac{R_G}{R_2+R_G} - V_2\frac{R_F}{R_1}\frac{R_G}{R_2+R_G}$$

$$V_{out} = -\frac{R_F}{R_1}V_1 + V_2\left(\frac{R_G}{R_2+R_G} + \frac{R_F}{R_1}\frac{R_G}{R_2+R_G}\right)$$

$$= -V_1\frac{R_F}{R_1} + V_2\left(\frac{R_G}{R_2+R_G}\right)\left(1+\frac{R_F}{R_1}\right)$$

$$\Rightarrow \boxed{V_{out} = -V_1\frac{R_F}{R_1} + V_2\left(\frac{R_G}{R_2+R_G}\right)\left(\frac{R_1+R_F}{R_1}\right)}$$

Consider the following special case:

$$R_1 = R_2 = R_G = R_F$$

$$\Rightarrow V_{out} = -V_1 + V_2 = V_2 - V_1$$

$\Rightarrow$ Voltage subtraction

> Note: An alternative way to solve the present problem is to employ the superposition theorem.
> V_1 and V_2 are inputs.
> $$V_{out} = f(V_1) + f(V_2)$$

Consider the following special case:

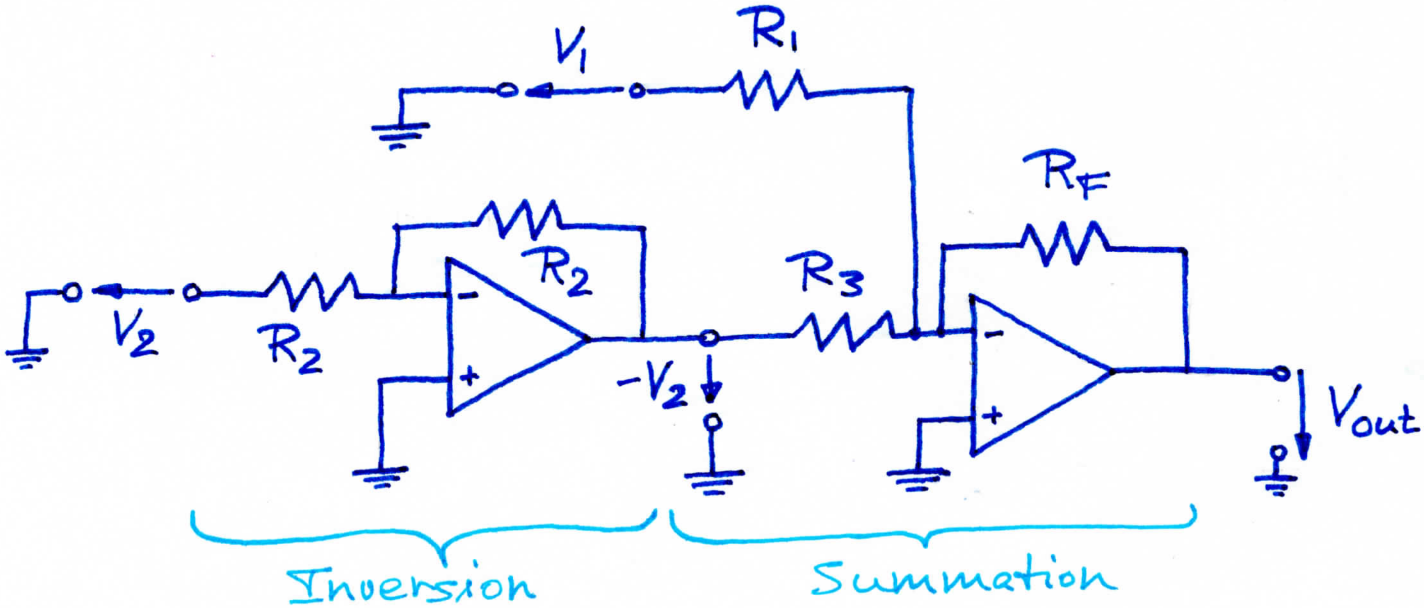
$$R_1 = R_F \quad \text{and} \quad R_2 = 9\,R_G$$

$$\Rightarrow \quad V_{out} = -V_1 + V_2 \left(\frac{R_G}{9R_G + R_G}\right) \frac{2}{1}$$

$$= -V_1 + V_2 \frac{1}{5} = \frac{1}{5} V_2 - V_1$$

$\Rightarrow$ Weighted voltage subtraction

Subtraction implemented by inversion-followed-by-summation circuit



Output of inverting differential amplifier

$$V_{out,\,inverter} = -\frac{R_2}{R_2} V_2 = -V_2$$

Output of summation differential amplifier

$$V_{out} = -R_F\left(\frac{V_1}{R_1} + \frac{-V_2}{R_3}\right) \quad \text{(shown previously)}$$

$$= -\frac{R_F}{R_1} V_1 + \frac{R_F}{R_3} V_2$$

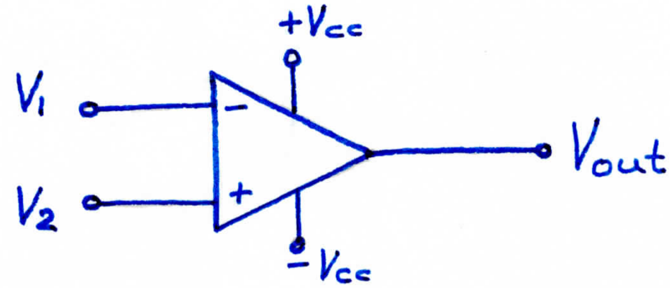
$\Rightarrow$ Weighted subtraction

Consider the following special case:

$$R_1 = R_3 = R_F \quad \Rightarrow \quad V_{out} = V_2 - V_1$$

$\Rightarrow$ Subtraction

Comparator circuit

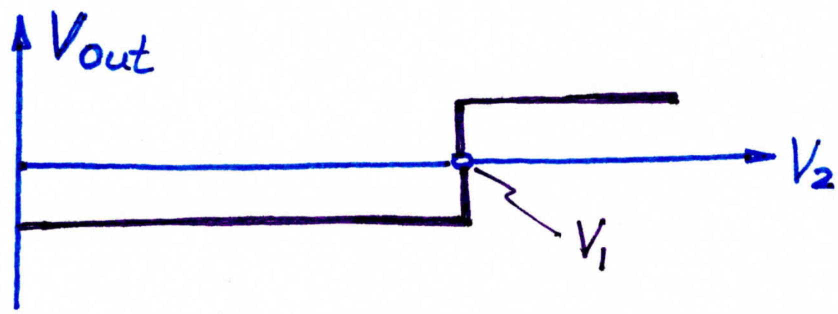


All voltages are with respect to GND

No feedback $\Rightarrow R_F = \infty \Rightarrow$ Amplification $= \infty$

If $V_1 > V_2 \Rightarrow V_{out} = -V_{cc}$

If $V_1 < V_2 \Rightarrow V_{out} = +V_{cc}$



$\Rightarrow$ Comparator functionality