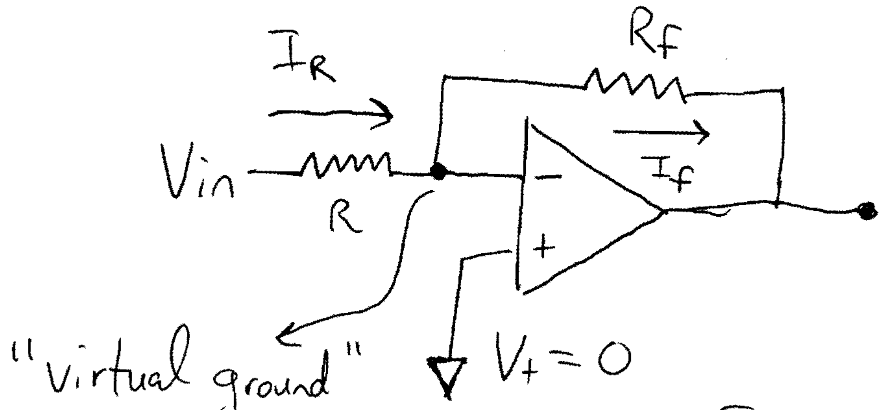
# Inverting Op-Amp :




$$\boxed{V_{out} = -\frac{R_f}{R} V_{in}}$$

Conservation of current yields

$$I_R = I_F \quad , \text{ or}$$

$$\boxed{\frac{V_{in} - V_-}{R} = \frac{V_- - V_{out}}{R_f}}$$

Note that $V_+ =$ ground and that $G$ is very large thus $\underbrace{V_- = V_+ = 0}_{\text{"virtual ground"}}$

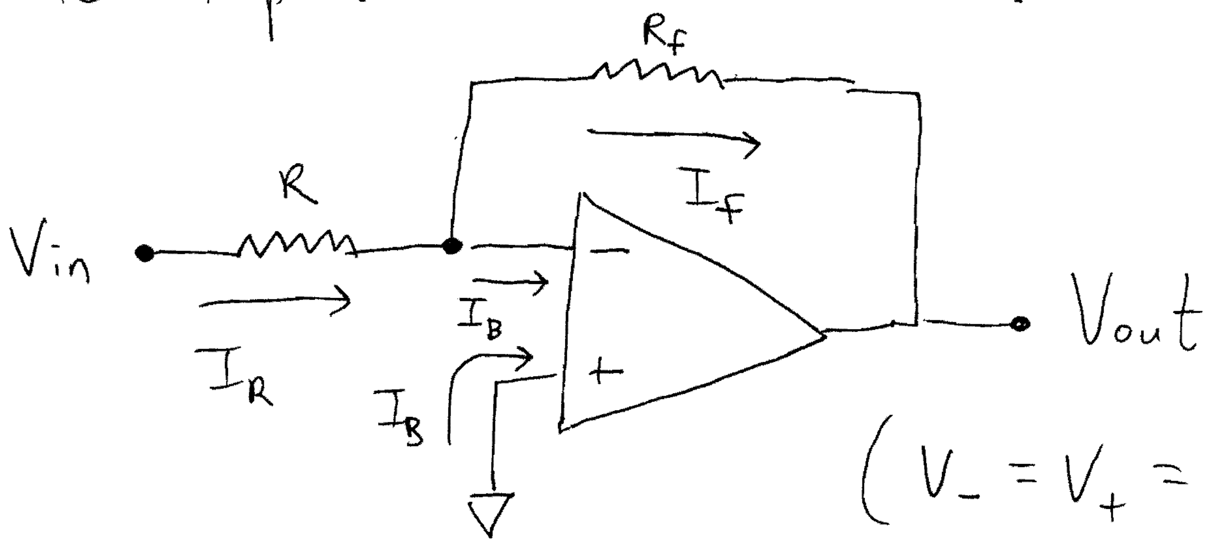
so $V_{out} \neq \pm V_{cc}$.

$$\frac{V_{in}}{R} = \frac{-V_{out}}{R_f} \qquad (\text{when } V_- = 0)$$

$$\Rightarrow \boxed{V_{out} = -\frac{R_f}{R} V_{in}}$$

# Input Bias Current:

On the last page $I_R = I_f$, but this is <u>not</u> true in reality due to input bias current.




$(V_- = V_+ = 0)$

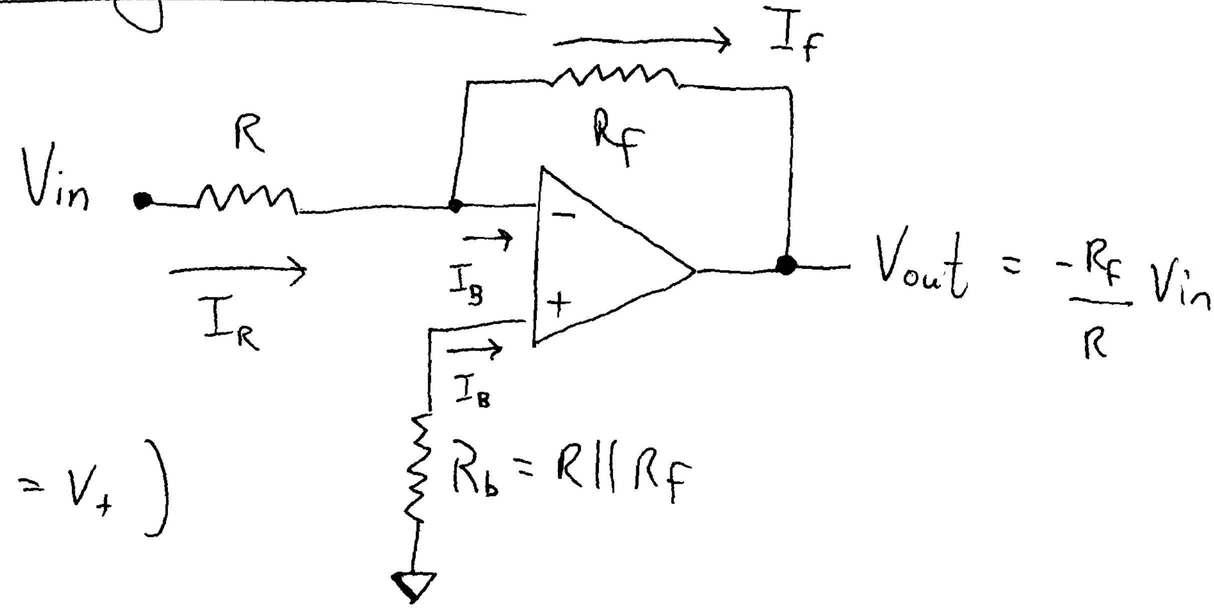
Use $\quad I_R = I_B + I_f$

or $\quad \dfrac{V_{in}}{R} = I_B - \dfrac{V_{out}}{R_f}$

"bias current correction"

$$\boxed{V_{out} = -\frac{R_f}{R} V_{in} + I_B R_f}$$

## Correcting $I_B$ error:




$(V_- = V_+)$

Conservation of current yields,

$$I_R = I_B + I_F.$$

$$\rightarrow \frac{V_{in} - V_-}{R} = I_B + \frac{V_- - V_{out}}{R_f}$$

Use $V_- = V_+$ yields;

$$\frac{V_{in}}{R} - V_+\left(\frac{1}{R} + \frac{1}{R_f}\right) - I_B = \frac{-V_{out}}{R_f}$$

$$\frac{V_{in}}{R} - V_+ \underbrace{\left( \frac{1}{R} + \frac{1}{R_f} \right)}_{(R \| R_f)^{-1}} - I_B = \frac{-V_{out}}{R_f}$$

$$\frac{V_{in}}{R} - V_+ (R \| R_f)^{-1} - I_B = \frac{-V_{out}}{R_f}$$

From the circuit $(0 - V_+) = I_B \, R \| R_f$

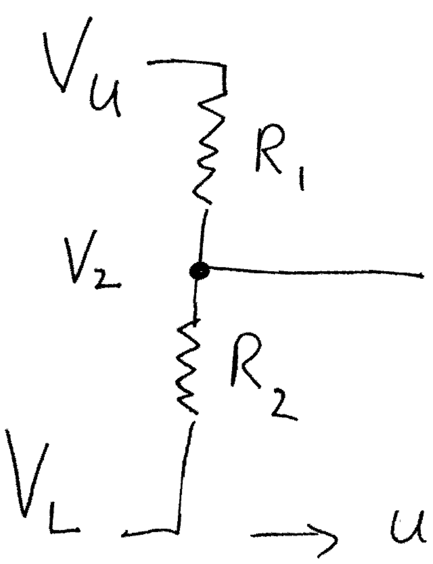
So, $I_B = V_+ \left( \frac{1}{R} + \frac{1}{R_f} \right)$

$$\boxed{V_{out} = \frac{-R_f}{R} V_{in}}$$

# Inverting Amp Potential formalism

You can also solve for $V_{out}$ using potentials instead of conservation of current. It's important with all of these examples to remember that $G = G(\omega)$ is <u>not</u> constant. Sometimes you need to use that.

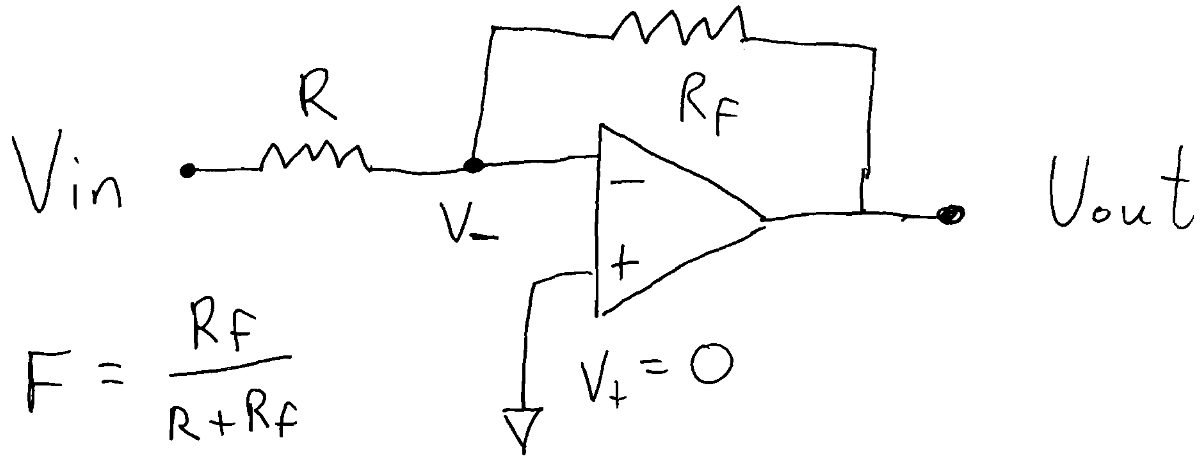
## General Divider:




Note $V_{out} = V_2 - V_L$

$$V_{out} = (V_u - V_L)\left(\frac{R_2}{R_1 + R_2}\right)$$

$\rightarrow$ usually ground, but not always




$$F = \frac{R_F}{R+R_F}$$

Use the general divider scheme to calculate Vout.

$$V_- - V_{out} = F\,(V_{in} - V_{out})$$

$$V_- = F\,V_{in} + V_{out}\,(1-F)$$

$$V_{out} = G\,(V_+ - V_-)$$

$$V_{out} = G\,(0 - F\,V_{in} - V_{out}\,(1-F))$$

$$V_{out} = -GF\,V_{in} - G(1-F)\,V_{out}$$

$$V_{out}\,(1 + G(1-F)) = -GF\,V_{in}$$

$$V_{out}\left(G(1-F)\right) \cong -GF\,V_{in}$$

$$V_{out} \cong \underbrace{\left(\frac{-F}{1-F}\right)} V_{in}$$

$$\frac{-F}{1-F} = -\frac{R_f}{R}$$

$$\boxed{V_{out} \cong -\frac{R_f}{R} V_{in}}$$

If $\omega$ is large, then you cannot make the $G$ large approximation, and you have to use the total equation.

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