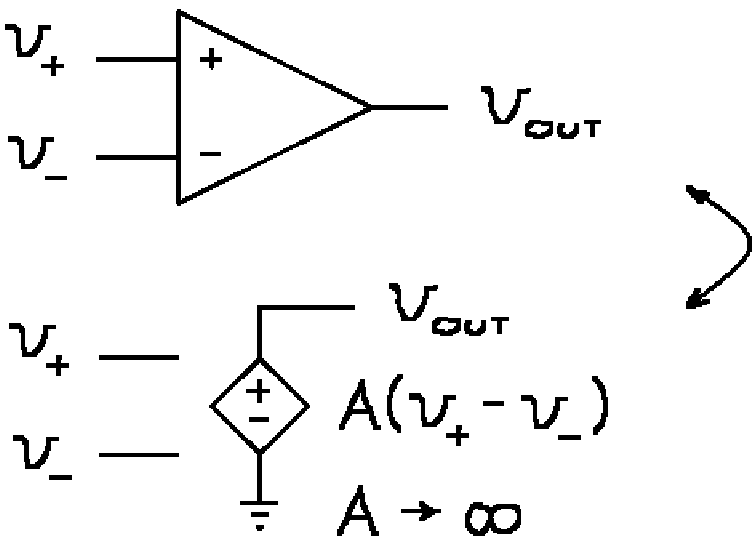
6.200 - Lecture 08

Op Amps & Amplifiers

- Ideal Op Amps
- Superposition
- Op-Amp-Based Amplifiers
- Analog Computing

Ideal Op Amp



v_+, v_- and v_{OUT} are referenced to ground

- Zero input currents
- Zero output resistance
- Algebraic differential output voltage
- Differential gain $A \to \infty$

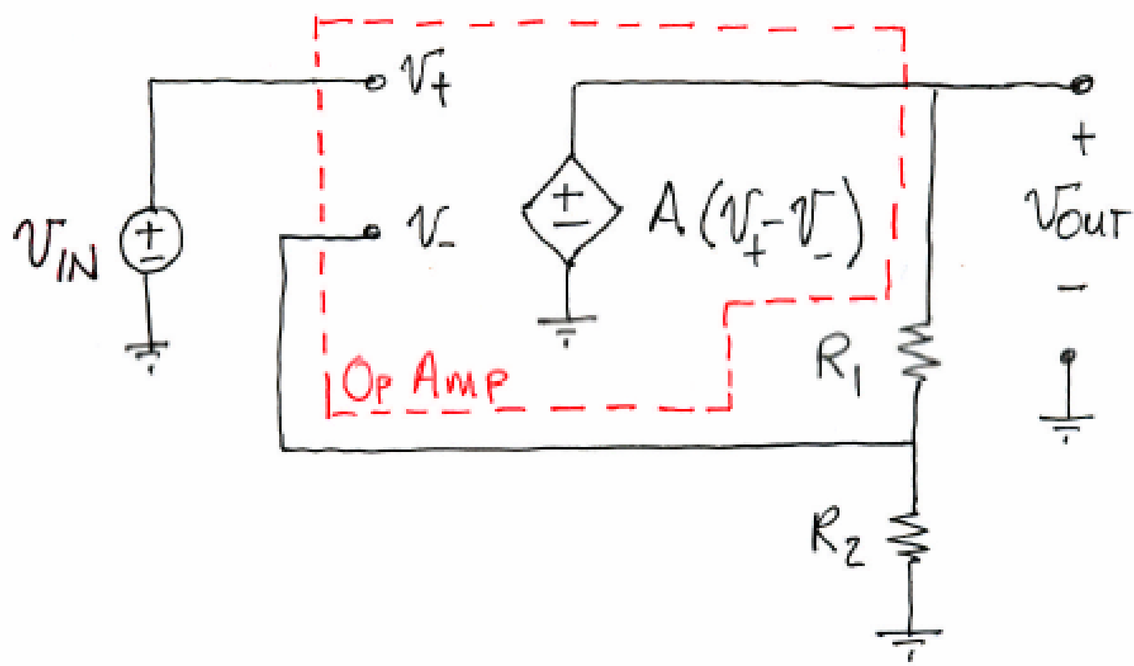
$V_+ = V_-$

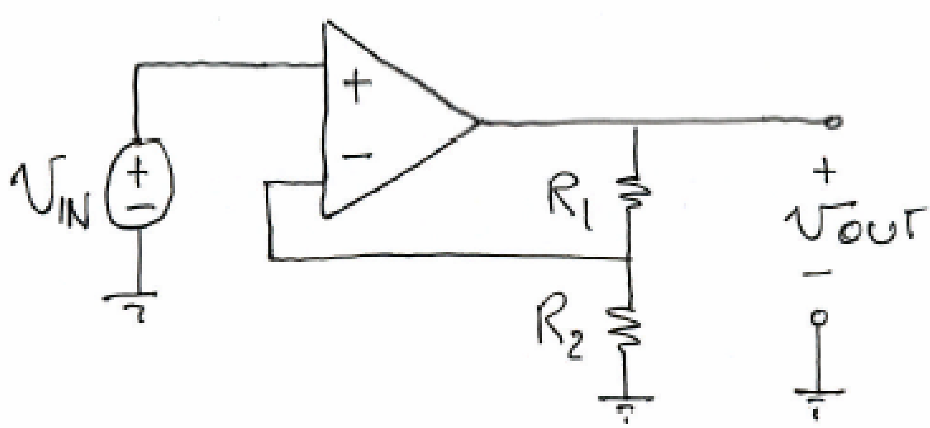
- Ideal op amp $\Rightarrow$ $V_+ - V_- = V_{OUT}/A$
- Stable system $\Rightarrow$ finite V_{OUT}
- Lim $A \to \infty$ $\Rightarrow$ $V_+ - V_- = V_{OUT}/A \to 0$

$$\Rightarrow \boxed{V_+ = V_-}$$

Non-Inverting Amplifier

Use negative feedback to trade gain for more ideal performance.





Power supply connections not shown.

Old Analysis

Node Method: $\frac{v_-}{R_2} + \frac{v_- - A(v_+ - v_-)}{R_1} = 0$ ($v_+ \downarrow v_{IN}$)

$$v_- = \frac{A R_2}{R_1 + (A+1) R_2} v_{IN}$$

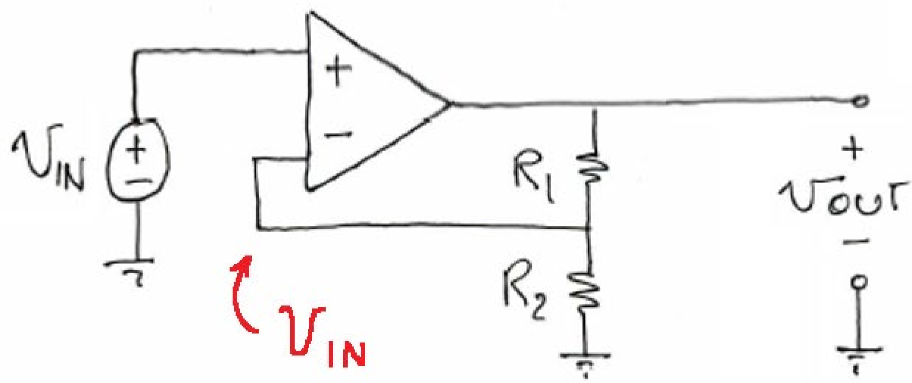
$$V_{OUT} = A(v_+ - v_-) \quad (v_+ \downarrow v_{IN})$$

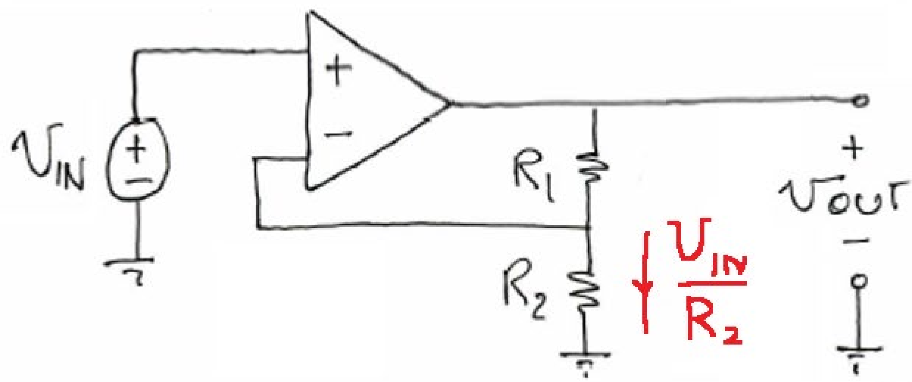
$$= \frac{A \cdot G}{A + G} v_{IN} \qquad G \equiv \frac{R_1 + R_2}{R_2}$$

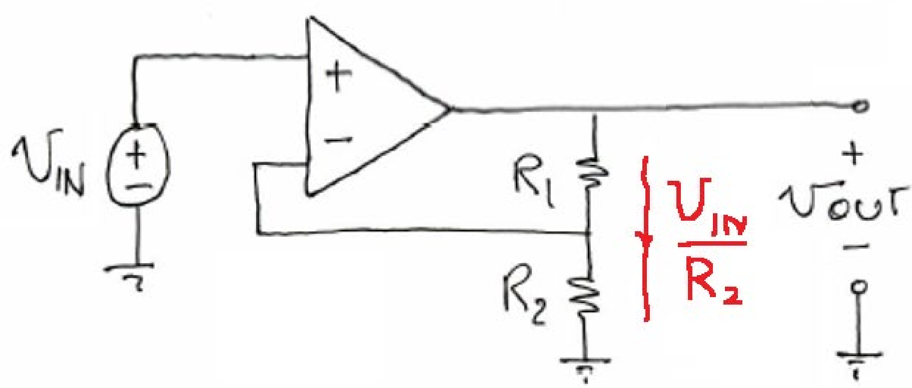
If $A \gg G$ then $v_{OUT} = G\, v_{IN}$

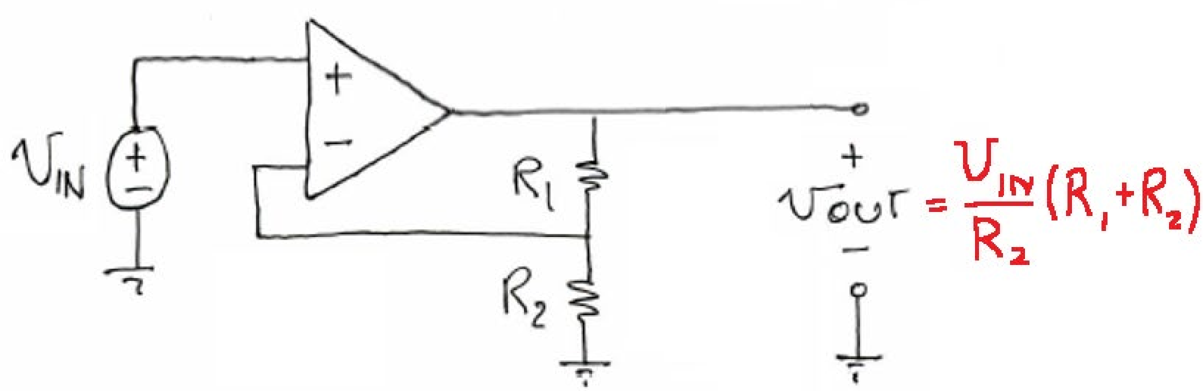
↑ Dependent only on resistors.

New Analysis Using $v_+ = v_-$

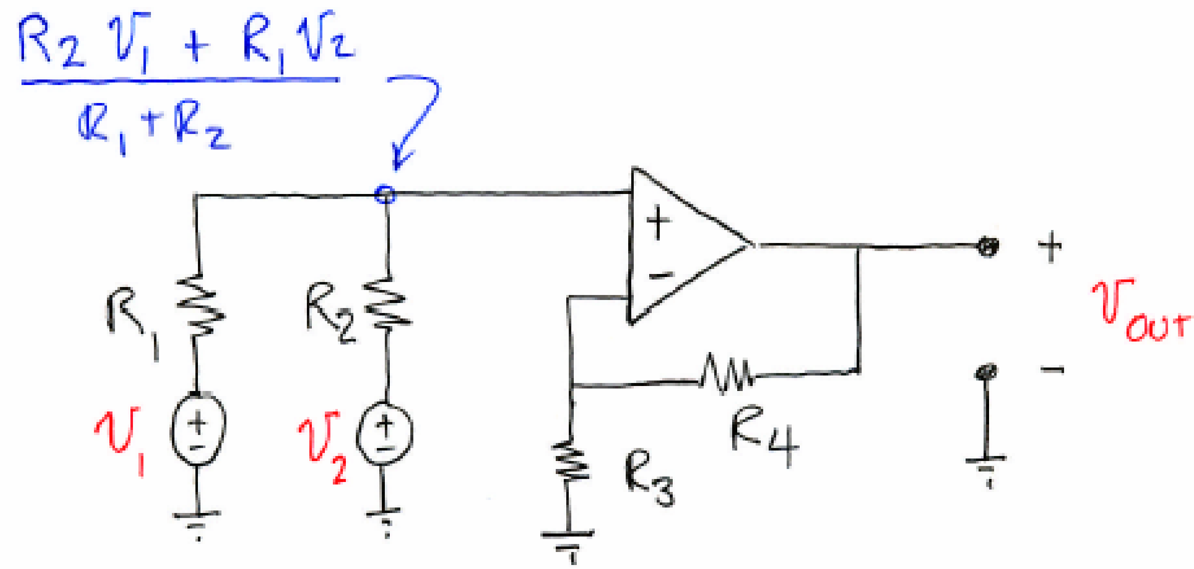




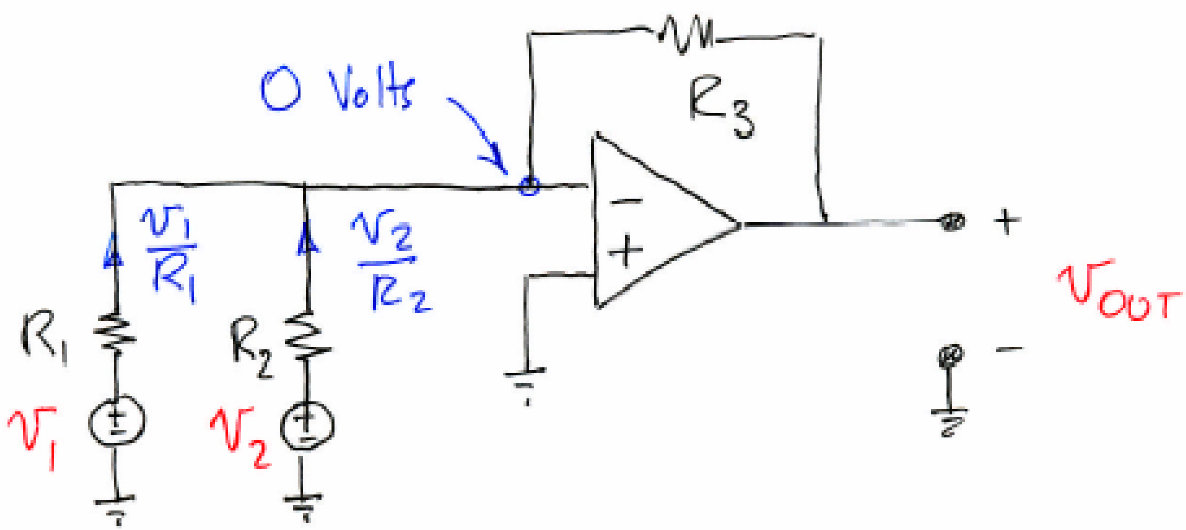




Addition

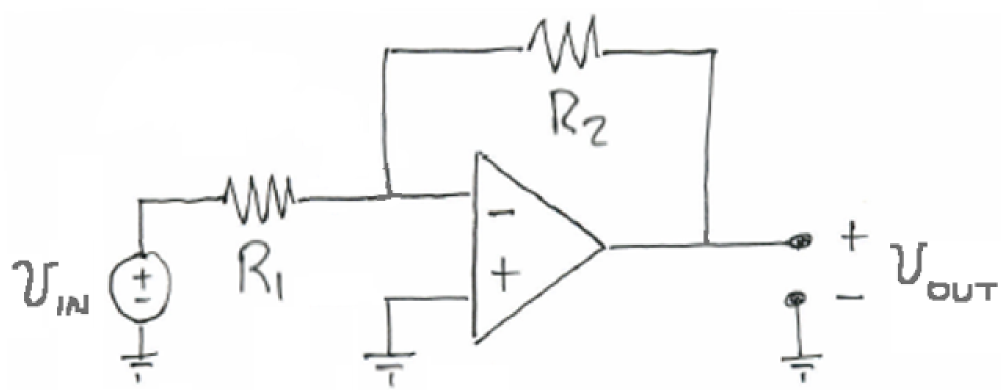


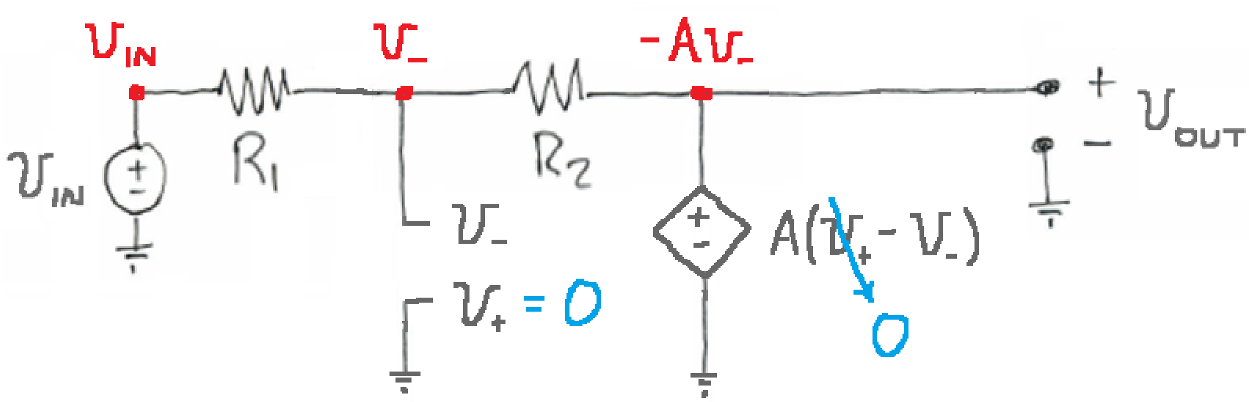
$$V_{OUT} = \frac{R_4 + R_3}{R_3}\left[\frac{R_2 V_1 + R_1 V_2}{R_1 + R_2}\right]$$



$$V_{OUT} = -R_3\left[\frac{V_1}{R_1} + \frac{V_2}{R_2}\right]$$

Inverting Amplifier



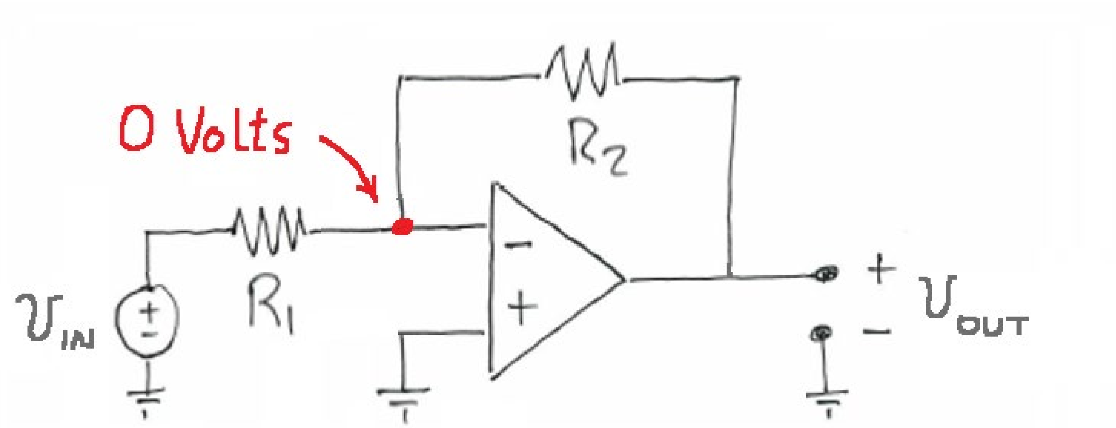


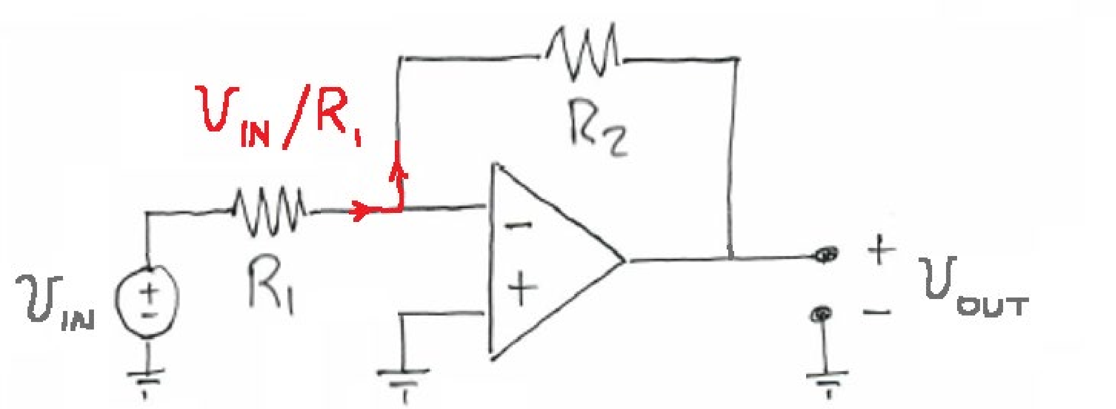
$$\frac{v_- - v_{IN}}{R_1} + \frac{v_- + Av_-}{R_2} = 0 \rightarrow v_- = \frac{R_2 V_{IN}}{(A+1)R_1 + R_2}$$

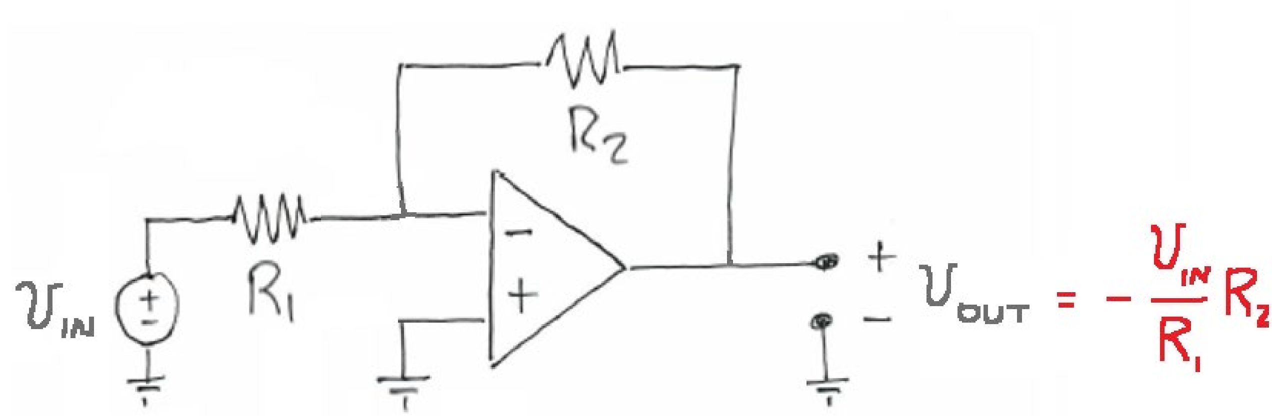
$$v_{OUT} = -Av_- = -\frac{AG}{A+1+G} v_{IN} , \quad G = R_2/R_1$$

If $A \gg G$ then $v_{OUT} = -G\, v_{IN}$

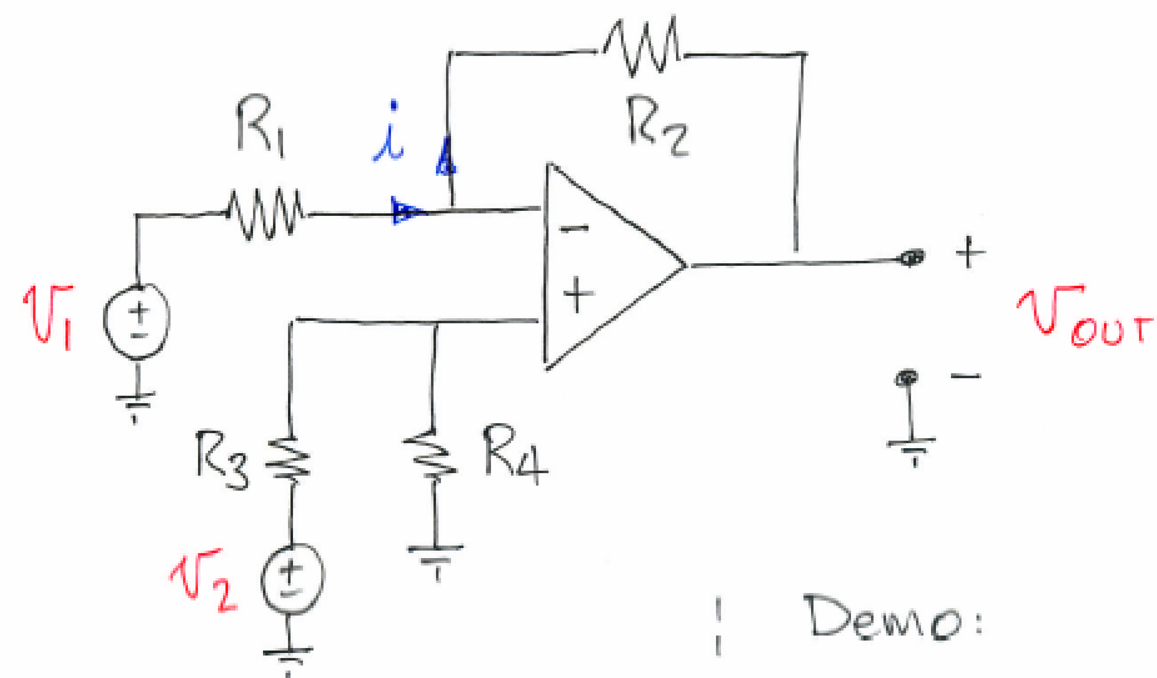
New Analysis Using $v_+ = v_-$



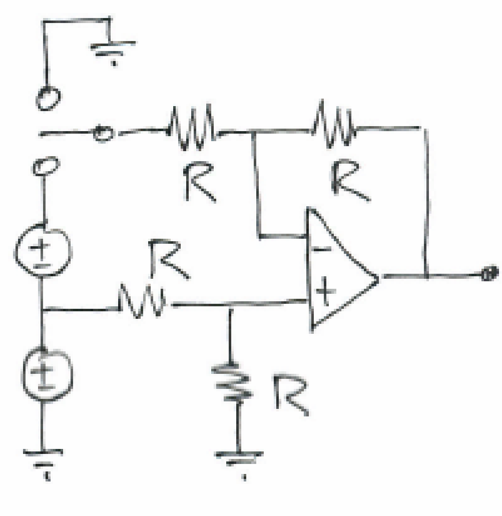




Subtraction



Demo:



$$v_- \approx v_+ = \frac{R_4}{R_3+R_4} v_2$$

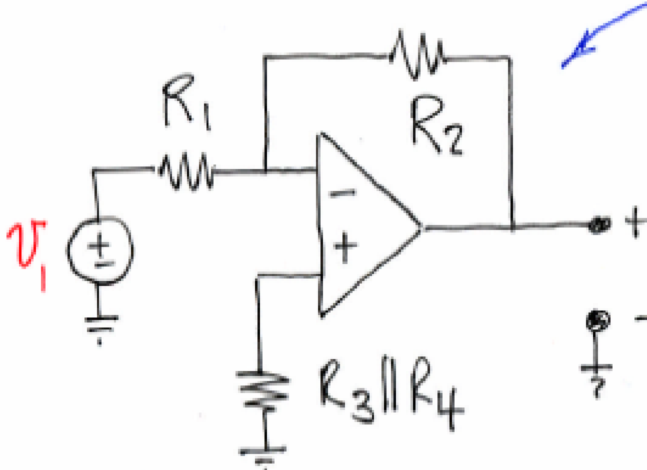
$$i = \frac{v_1 - v_-}{R_1}$$

$$v_{OUT} = v_- - R_2 i$$

$$v_{OUT} = \frac{R_4}{R_3+R_4} \cdot \frac{R_1+R_2}{R_1} v_2 - \frac{R_2}{R_1} v_1$$

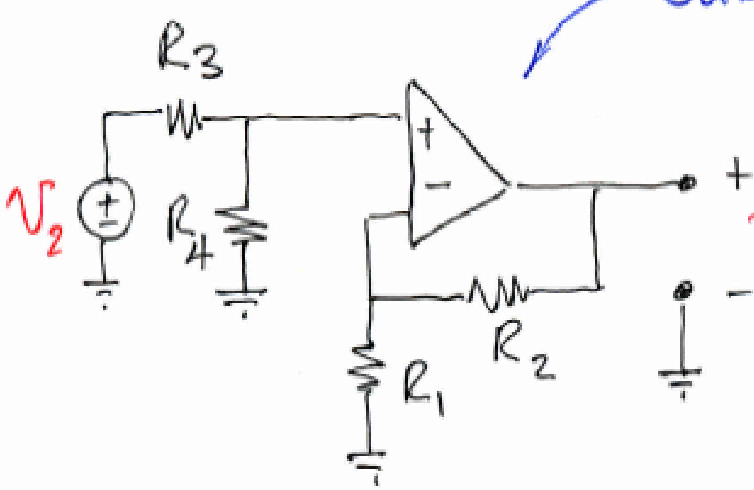
Subtraction By Superposition

Subtracter with $V_2 \equiv 0$



$$V_{OUT} = -\frac{R_2}{R_1} V_1$$

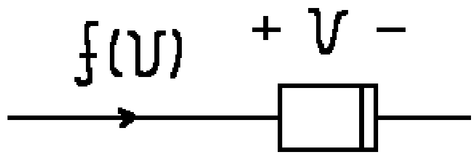
Subtracter with $V_1 \equiv 0$

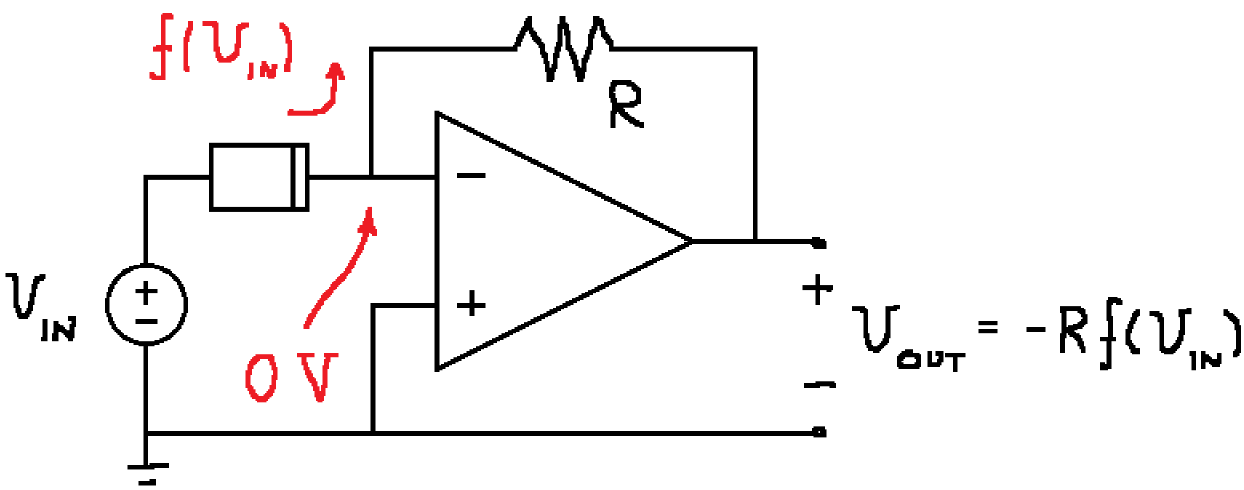


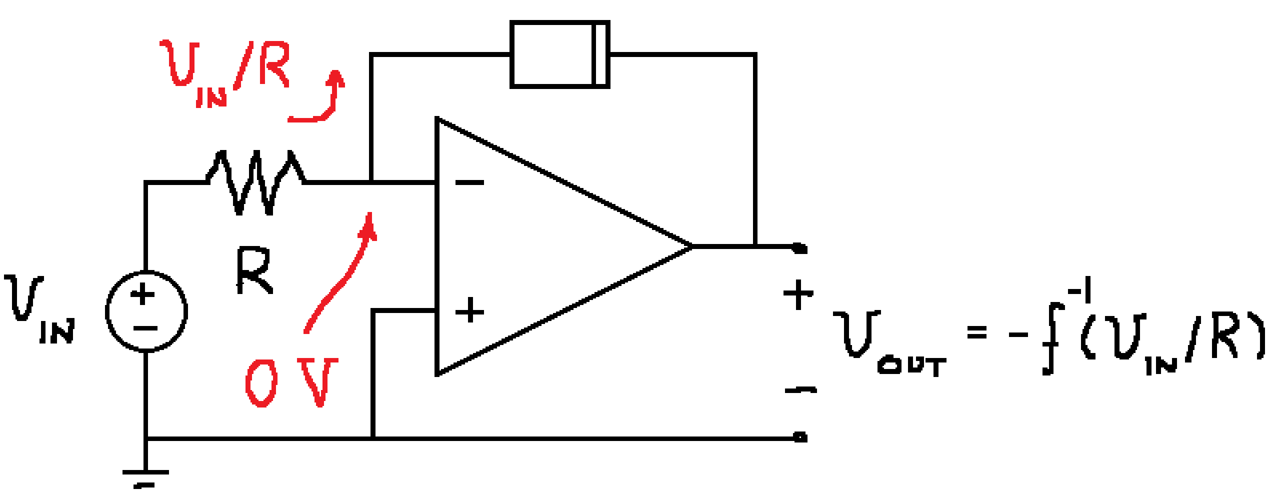
$$V_{OUT} = \frac{R_1+R_2}{R_1} \cdot \frac{R_4}{R_3+R_4} V_2$$

Subtracter: $V_{OUT} = \frac{R_1+R_2}{R_1} \cdot \frac{R_4}{R_3+R_4} V_2 - \frac{R_2}{R_1} V_1$

Nonlinear Functions

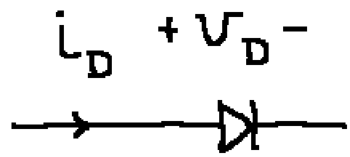






Exponential Diode

Expontial Diode:



$$i_D = I_s \left[e^{v_D / n V_T} - 1 \right]$$

I_s = Saturation Current ≈ 1 pA … 10 nA

$V_T = k_B T / q$

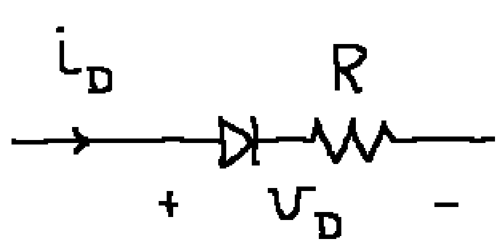
$k_B = 1.38 \cdot 10^{-23}$ J/K

T = Temperature

$q = 1.6 \cdot 10^{-19}$ C

n = Ideality Factor ≈ 1 … 2

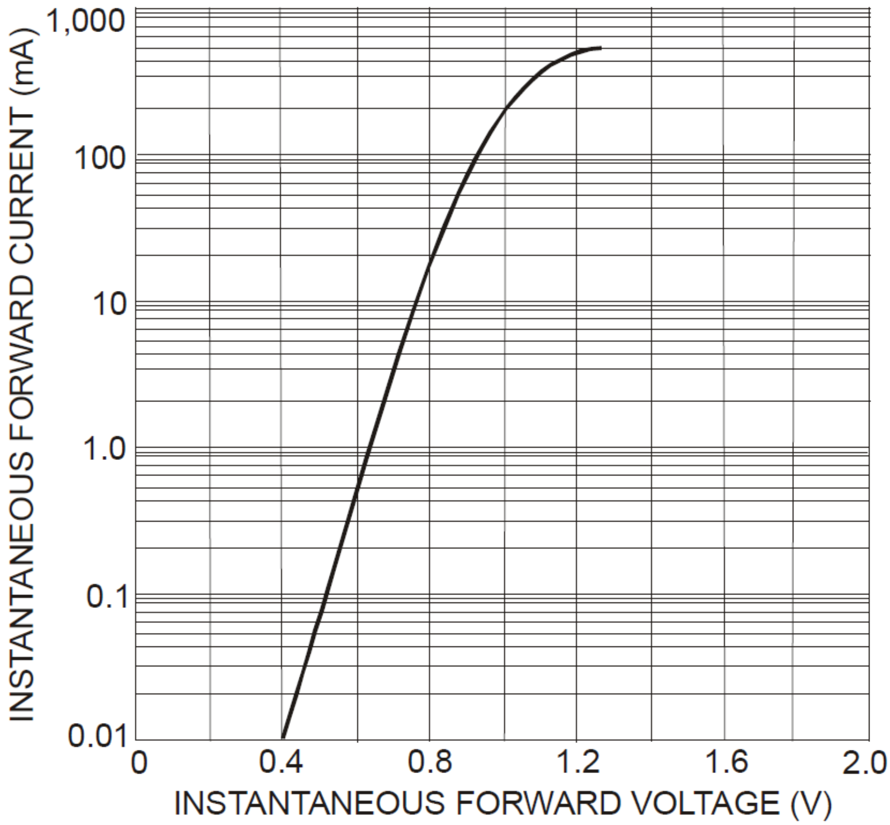
Practical Diode:

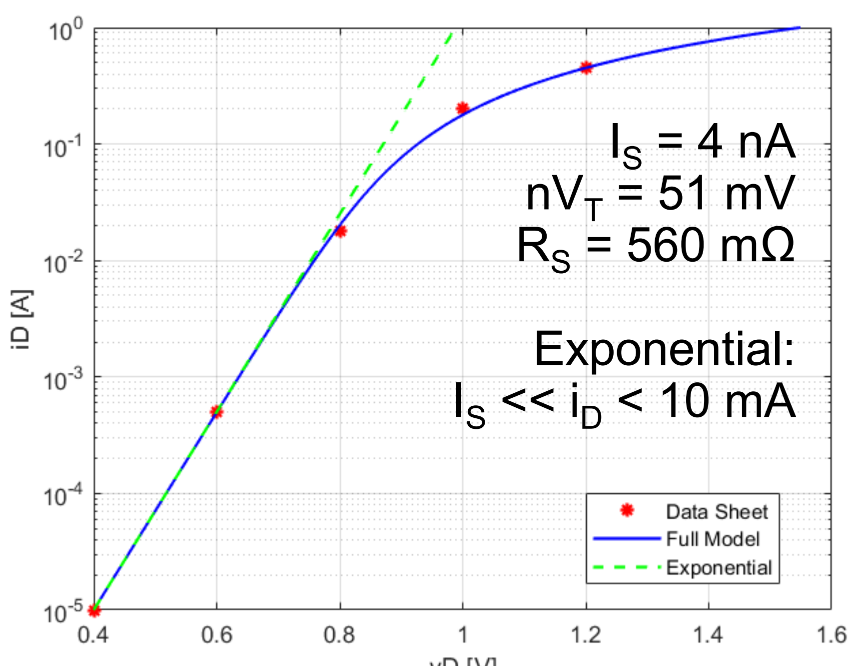


$$v_D = n V_T \ln \left(i_D / I_s + 1 \right) + R \, i_D$$

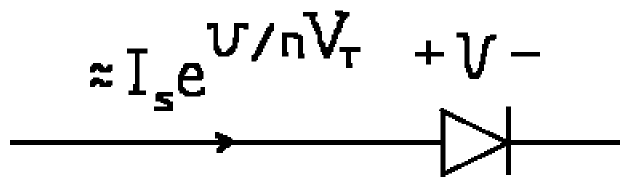
R = Body Resistance ≈ … 1Ω …

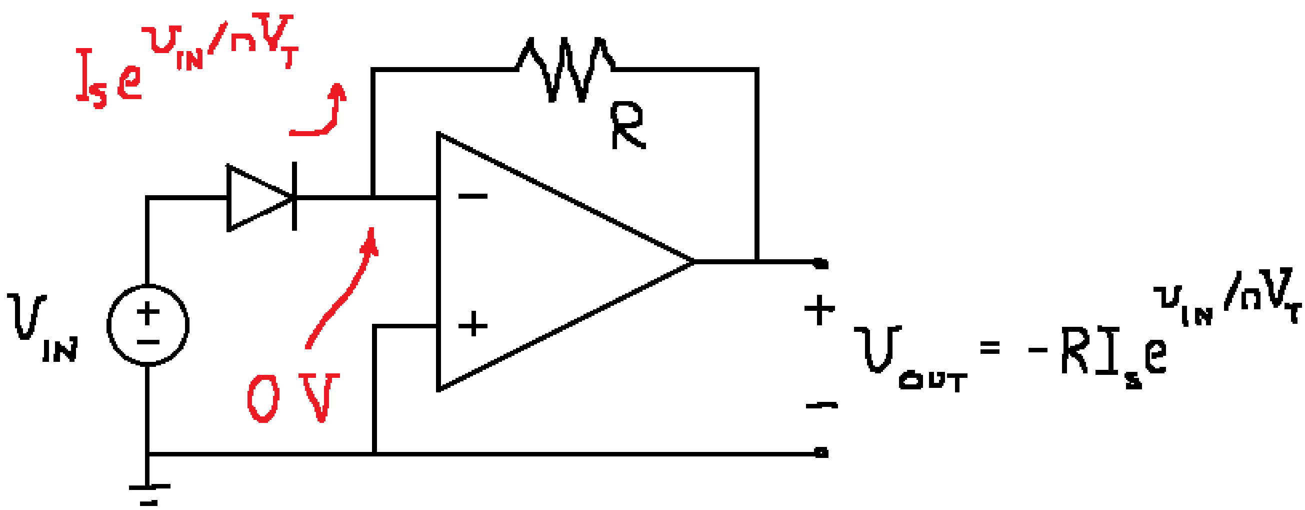
Exponential Diode – 1N4148

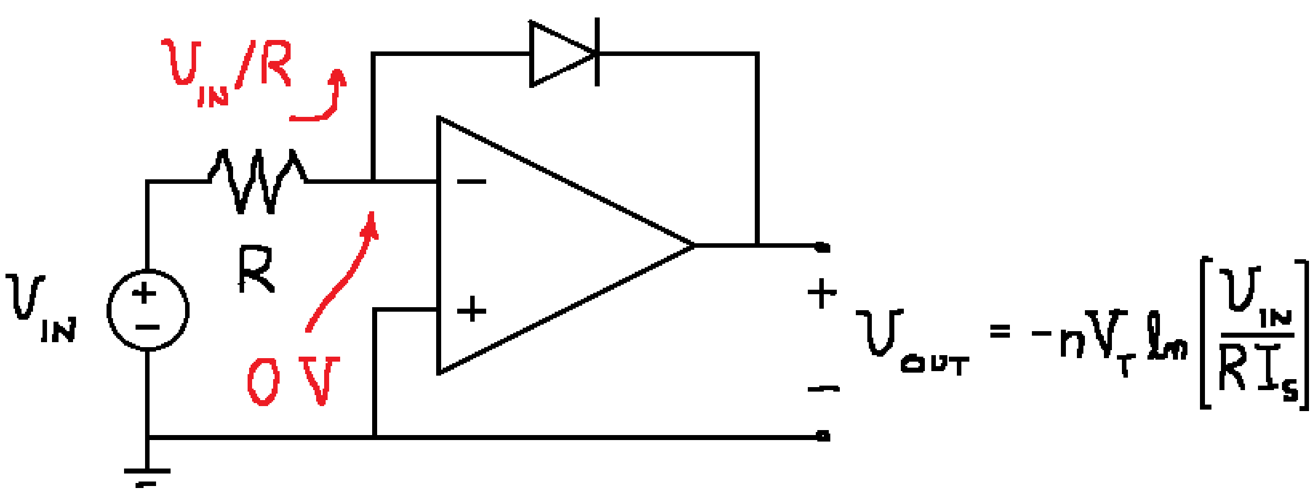




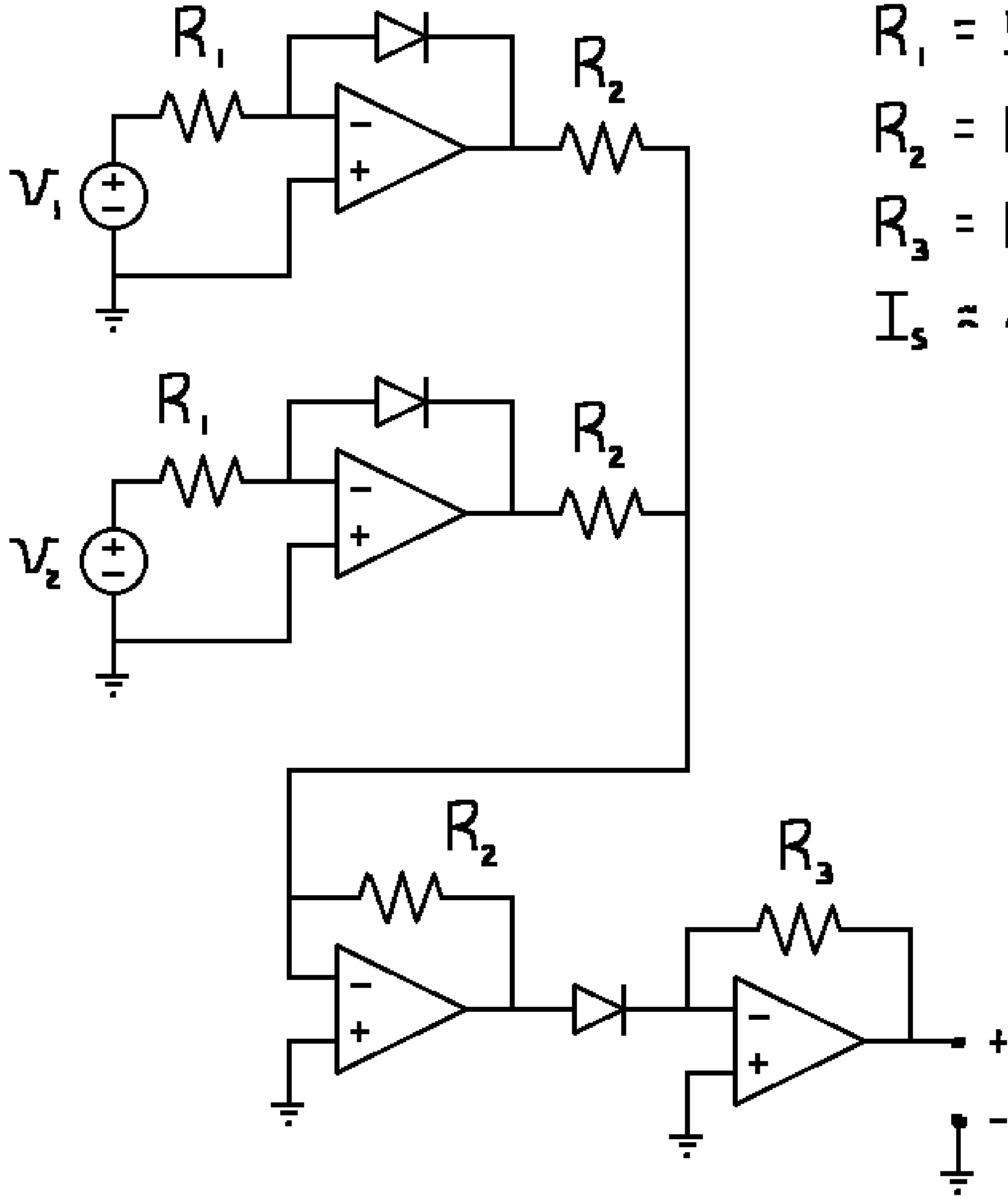
Exponential & Log Amps







Multiplier



$R_1 = 500\ k\Omega$

$R_2 = 10\ k\Omega$

$R_3 = 1\ k\Omega$

$I_s \approx 4\ nA$

$$-\frac{R_3 V_1 V_2}{R_1^2 I_s}$$

$$\approx -\frac{V_1 V_2}{1V}$$