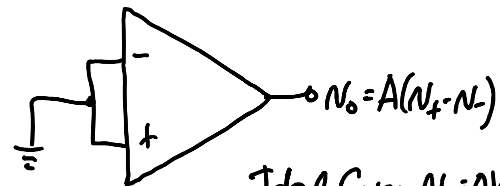
Lecture 9: Vos and Input Bias Current

- **Announcements**:
- HW#3 online and due Friday via Gradescope
- Lab#2 is a two week lab
  - Prelab is due in the second week
  - But you should have proof of having started it when you go to lab this week
  - You will still do the lab this week and continue next week
- ------------------------------------
- Lecture Topics:
  - Input Offset Voltage
  - Input Bias Current
  - Generalized Circuit Elements
- ------------------------------------
- **Last Time**:
- Covering input offset voltage
- Now, continue with this …

Input Offset Voltage, Vos

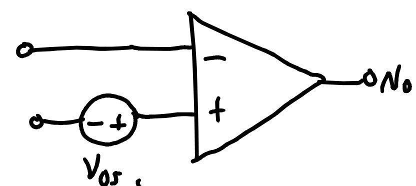


Ideal Case: $v_o = 0V$

Reality: $v_o \neq 0V$

(usually, $v_o = L^+$ or L^-)
↑ it rails out

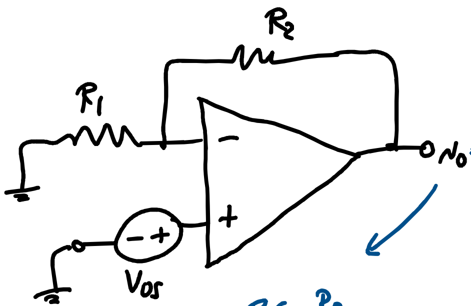
Model this w/ equivalent ckt:
↙ contains input offset Vos:



typically, $V_{os} \sim 1mV - 5mV$

Effect of Vos on Op Amp Ckts

Example. Non-Inverting Amplifier

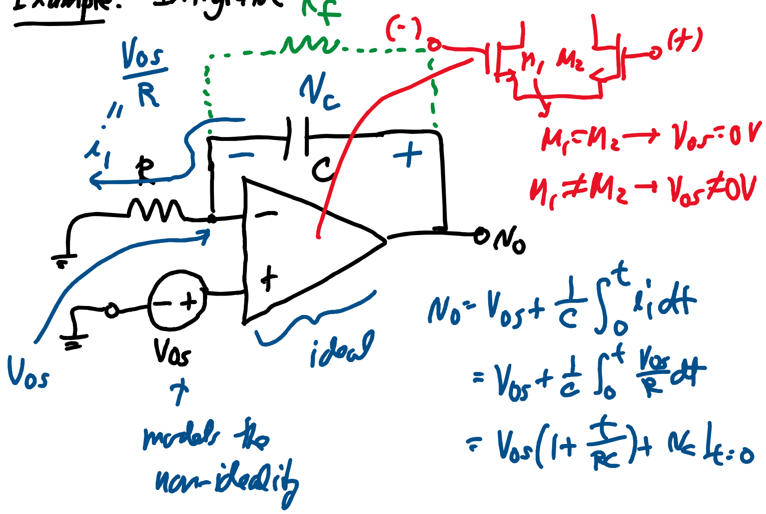


$v_o = \left(1+\frac{R_2}{R_1}\right)V_{os}$

e.g., $\frac{R_2}{R_1} = 9$, $V_{os} = 5mV \rightarrow V_o = 50mV$

(not so bad...)

Example. Integrator



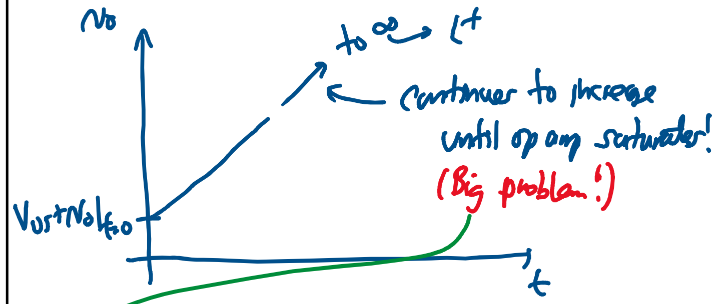
$M_1 = M_2 \rightarrow V_{os} = 0V$

$M_1 \neq M_2 \rightarrow V_{os} \neq 0V$

$v_o = V_{os} + \frac{1}{C}\int_0^t i_1 dt$

$= V_{os} + \frac{1}{C}\int_0^t \frac{V_{os}}{R} dt$

$= V_{os}\left(1+\frac{t}{RC}\right) + v_c|_{t=0}$



Solution: Place resistor Rf in parallel w/ C (shunt)

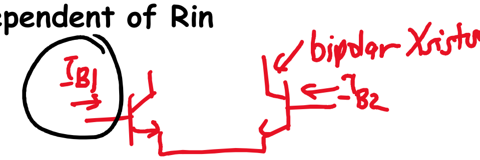
large, so $R_f \| \frac{1}{sC} \approx \frac{1}{sC}$ @ AC

But @ DC, Rf determines the bias pt.

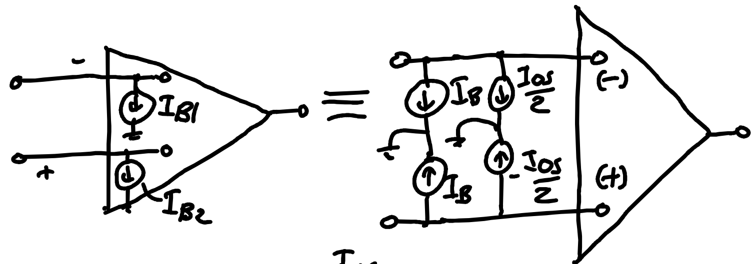
$v_o = V_{os}\left(1+\frac{R_f}{R}\right)$ → prevents the output from railing out!

Input Bias Current

- Many op amps require small currents into their input transistors that allow the transistors to function
- Currents are independent of Rin



Schematically:



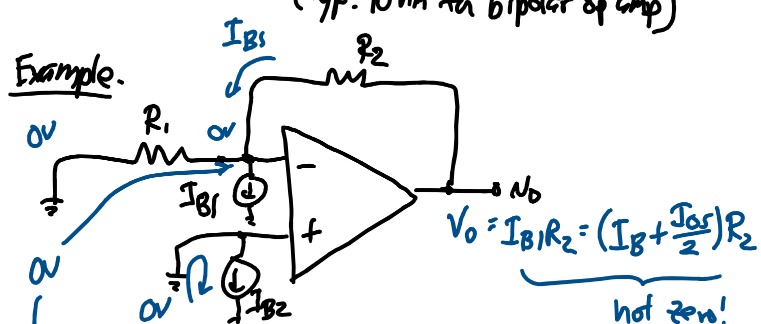
$I_{B1} = I_B + \frac{I_{os}}{2}$

$I_{B2} = I_B - \frac{I_{os}}{2}$

Average or Common-Mode Value $\Big\} = I_B = \frac{I_{B1}+I_{B2}}{2} \triangleq$ input bias current
(typ.: 100 nA for bipolar op amps)

Difference or Differential-Mode Value $\Big\} = I_{os} = |I_{B1} - I_{B2}| \triangleq$ input offset current
(typ: 10 nA for bipolar op amp)

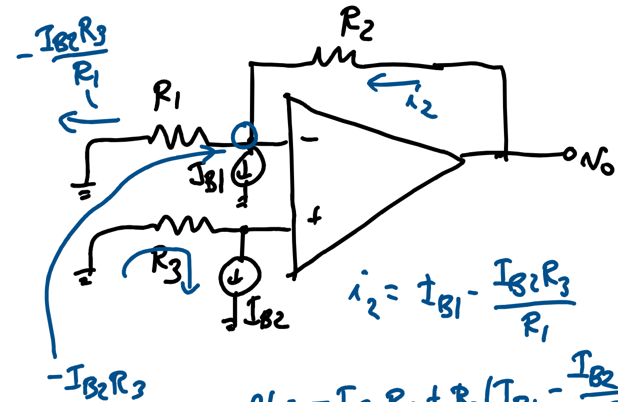
Example.



$V_o = I_{B1}R_2 = \left(I_B + \frac{I_{os}}{2}\right)R_2$ not zero!

0V ("virtual ground") → ∴ current cannot flow thru R_1

To reduce this effect: add resistor to the (+) input



$i_2 = I_{B1} - \frac{I_{B2}R_3}{R_1}$

$v_o = -I_{B2}R_3 + R_2\left(I_{B1} - \frac{I_{B2}R_3}{R_1}\right)$

What value of R_3 makes $v_o \to 0V$?

Case $I_{os} = 0$: (i.e., $I_{B1} = I_{B2} = I_B$)

$v_o = I_B\left(R_2 - R_3\left(1 + \frac{R_2}{R_1}\right)\right)$

[For $v_o = 0$] ⇒ $R_2 = R_3\left(1+\frac{R_2}{R_1}\right) \to R_3 = \frac{R_2}{1+\frac{R_2}{R_1}} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}}$

$\therefore R_3 = R_1 \| R_2 \to v_o = 0$ w/ $I_{os} = 0$

Case: $I_{os} \neq 0$ (i.e., $I_{B1} = I_B + \frac{I_{os}}{2}$, $I_{B2} = I_B - \frac{I_{os}}{2}$)

$$v_o = -I_{B2}R_3 + R_2\left(I_{B1} - \frac{I_{B2}R_3}{R_1}\right)$$

$$v_o = -I_B R_3 + \frac{I_{os}}{2}R_3 + R_2\left(I_B + \frac{I_{os}}{2} - \frac{I_B R_3}{R_1} + \frac{I_{os}}{2}\frac{R_3}{R_1}\right)$$

$[R_3 = R_1 \| R_2] \Rightarrow$

$$= I_B\left(R_2 - \frac{R_2R_2}{R_1+R_2} - \frac{R_1R_2}{R_1+R_2}\right) + \frac{I_{os}}{2}\left(\frac{R_1R_2}{R_1+R_2} + R_2 + \frac{R_2R_2}{R_1+R_2}\right)$$

$$R_2 = \frac{R_1R_2 + R_2R_2}{R_1+R_2} \qquad\qquad \frac{I_{os}}{2}\,\frac{2R_2(R_1+R_2)}{R_1+R_2}$$

$\therefore\ v_o = I_{os}R_2 \ll \left(I_B + \frac{I_{os}}{2}\right)R_2$

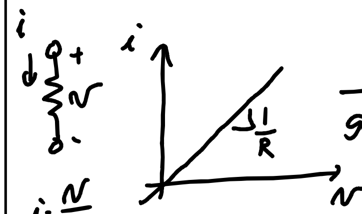
(I_{os}: 10nA; I_B: 100nA; $\frac{I_{os}}{2}$: ~5nA)

$\therefore$ setting $R_3 = R_1 \| R_2$ still helps even if $I_{os} \neq 0$!

Generalized Circuit Elements

Resistor

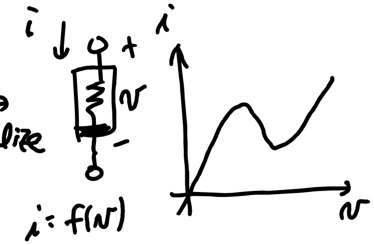
Linear Resistor



$i = \frac{v}{R}$

→ generalize

Nonlinear Resistor



$i = f(v)$