Lecture 9: Vos and Input Bias Current

- Announcements:
- HW#3 online and due Friday via Gradescope
- Lab#2 will be 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
- This Wednesday, 9/12: I will be out of town.
  - So no ground lecture that day
  - This is a video lecture
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- Lecture Topics:
  - Input Offset Voltage
  - Input Bias Current
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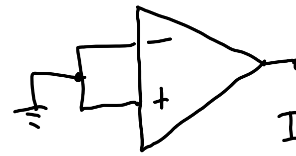
- Last Time:
- Started input offset voltage
- Now, continue with this …

Input Offset Voltage, Vos



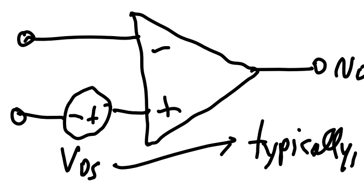
$v_o = A(v_+ - v_-)$

Ideal Case: $v_o = 0V$

Reality: $v_o \neq 0V$

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

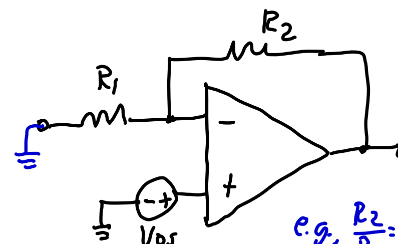
Model this w/ equivalent input offset voltage, V_{os}:



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

Effect of V_{os} on Op Amp Ckt. -

Example. Non-Inverting Amplifier

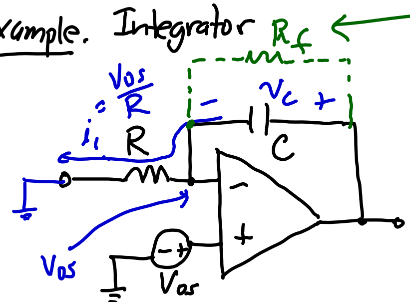


$V_o = V_{os}\left(1+\frac{R_2}{R_1}\right)$

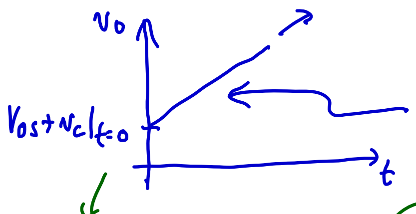
e.g., $\frac{R_2}{R_1} = 9$, $V_{os} = 5mV \rightarrow V_o = 50\ mV$

(not so bad...)

Example. Integrator



$$v_o = V_{OS} + \frac{1}{C}\int_0^t i_1\,dt$$
$$= V_{OS} + \frac{1}{C}\int_0^t \frac{V_{OS}}{R}\,dt$$
$$= V_{OS}\left(1+\frac{t}{RC}\right) + v_C\big|_{t=0}$$



continues to increase until op amp saturates!

Solution: place resistor R_f in shunt w/ C

↳ then $v_o = V_{OS}\left(1+\frac{R_f}{R}\right)$ ← prevents v_o from going to the rail!

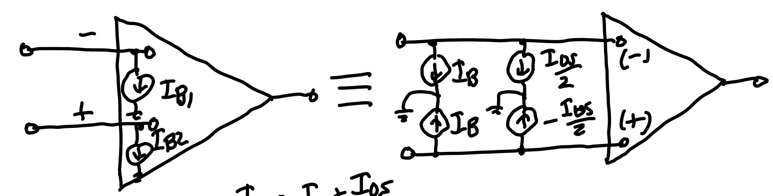
$\boxed{\text{Input Bias Currents}}$

⇒ many op amps require small currents into their input transistors that allow the transistors to function

⇒ currents are independent of Rin

over ↪

Schematically:



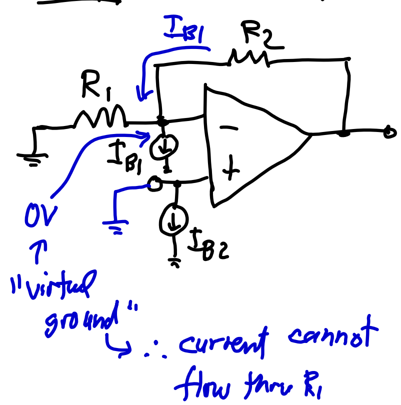
$I_{B1} = I_B + \frac{I_{OS}}{2}$

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

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)

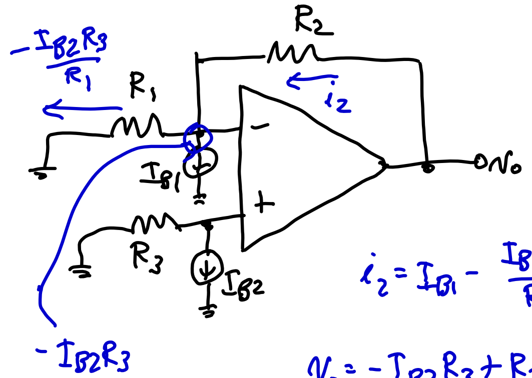
Difference or Differential Value $\Big\} = I_{OS} = |I_{B1} - I_{B2}| \triangleq$ input offset current (typ.: 10 nA for a bipolar op amp)

Example. Non-Inverting Amplifier



$v_o = I_{B1}R_2 = \underbrace{\left(I_B + \frac{I_{OS}}{2}\right)R_2}_{\text{not zero!}}$

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 $v_o \to 0$?

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

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

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

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

$v_o = -I_BR_3 + \frac{I_{OS}R_3}{2} + R_2\left(I_B + \frac{I_{OS}}{2} - \frac{I_BR_3}{R_1} + \frac{I_{OS}}{2}\frac{R_3}{R_1}\right)$

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

$= I_B\left(\cancel{R_2} - \frac{R_2\cancel{R_2}}{\cancel{R_1+R_2}} - \frac{R_1\cancel{R_2}}{\cancel{R_1+R_2}}\right) + \underbrace{\frac{I_{OS}}{2}\left(\frac{R_1R_2}{R_1+R_2} + R_2 + \frac{R_2R_2}{R_1+R_2}\right)}_{\frac{I_{OS}}{\cancel{2}}\frac{\cancel{2}(R_2)\cancel{(R_1+R_2)}}{\cancel{R_1+R_2}}}$

$\uparrow \; \frac{\cancel{R_1R_2}+\cancel{R_2R_2}}{\cancel{R_1+R_2}}$

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

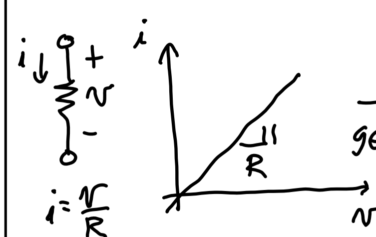
I_{OS}: 10nA; I_B: 100nA; $\frac{I_{OS}}{2}$: ~5nA

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

Generalized Circuit Elements

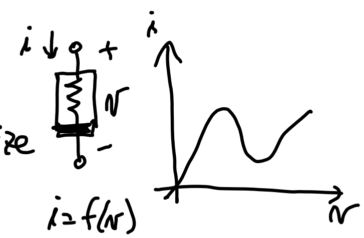
Resistor

Linear Resistor



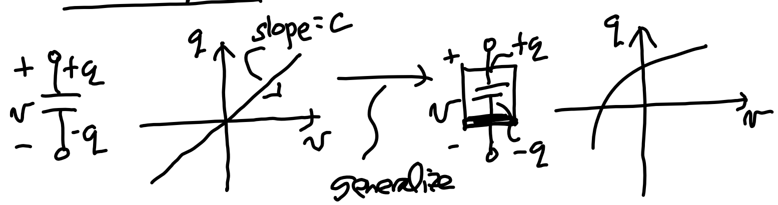
$\xrightarrow{\text{generalize}}$

Nonlinear Resistor



Capacitor

Linear Capacitor — Nonlinear Capacitor

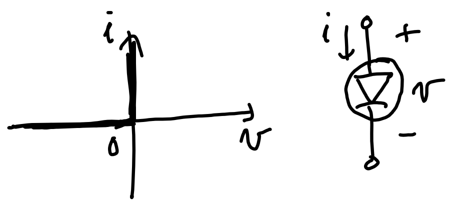


$q = Cv$ $q = f(v)$

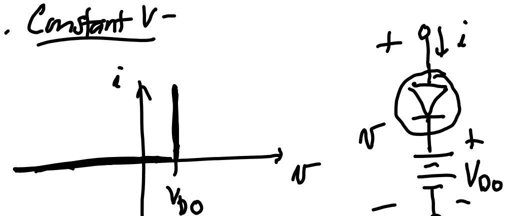
⇒ there are also nonlinear inductors → generally not seen in low-to-mid frequency integrated cktr.

Example. Diode → several models, all of which represent nonlinear resistors

A. Ideal -

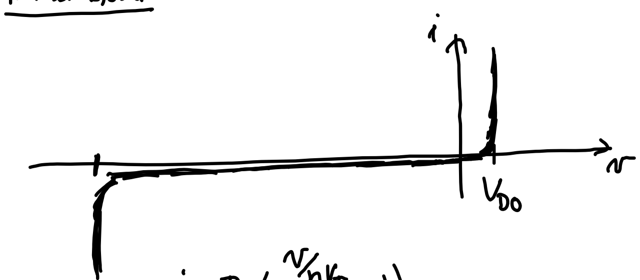


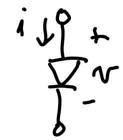
B. Constant V -



V_{DO} ← diode "on" voltage → usually from 0.5 to 0.7V

C. Actual Diode -





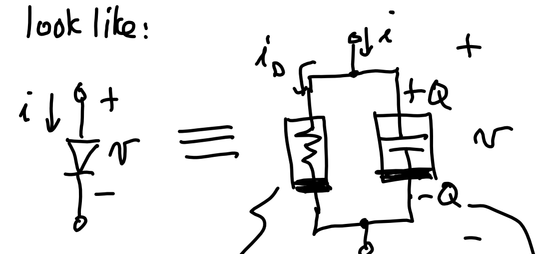
$i = I_S(e^{v/nV_T} - 1)$

$I_S \triangleq$ saturation current

$V_T = 25mV = \frac{kT}{q} \triangleq$ thermal voltage

$n = 1 \text{ à } 2$ ← discrete diodes
↑ IC diodes

Diode → not only a nonlinear resistor
→ also includes nonlinear capacitance
→ a more exact model for a diode would look like:



$i_D = f'(v) = I_S(e^{v/nV_T} - 1)$

$Q = f''(v) = q\left(\frac{N_A N_D}{N_A + N_D}\right) A W_{do} \sqrt{1 + \frac{v_R}{\phi_j}}$
$[v_R = -v]$