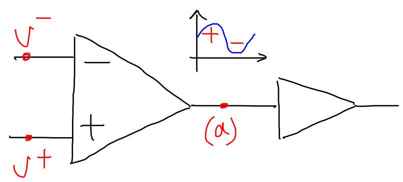
* Advantage of using differential signals:

Single ended Signal

(probe with respect to ground)

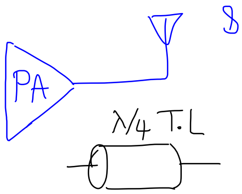


$$\begin{cases} V_{in} = v^+ - v^- \\ V_{out} = V_a \end{cases}$$

* Assume opamp output has distortion

$$V(a) = k_1 V_{in} + k_2 V_{in}^2 + k_3 V_{in}^3 + \cdots + Noise$$

Cordless phones
800MHz, 2.4GHz

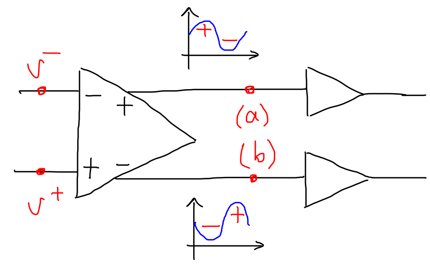


FCC

Bluetooth
2.4GHz
(weak)

Differential ended Signal

(probe with respect to other node)



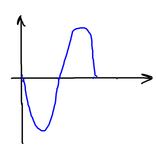
$$\begin{cases} V_{in} = v^+ - v^- \\ V_{out} = V_b - V_a \end{cases}$$

* Assume opamp output has distortion

$$\begin{cases} V(a) = k_1 v^- + k_2 (v^-)^2 + k_3 (v^-)^3 + \cdots + Noise \\ V(b) = k_1 v^+ + k_2 (v^+)^2 + k_3 (v^+)^3 + \cdots + Noise \end{cases}$$

$$v^- = -v^+$$

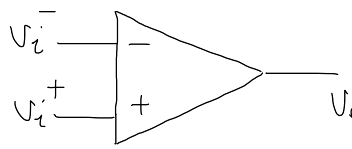
1. $V_{out} = V_b - V_a$ has twice amplitude



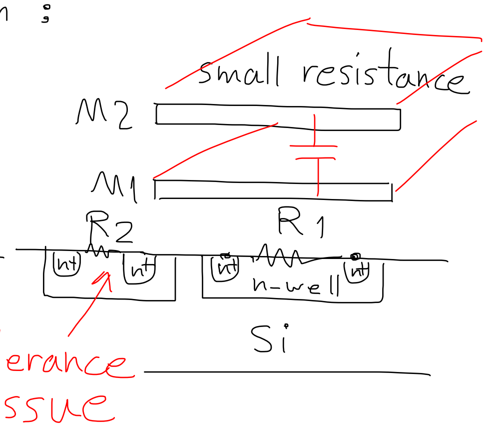
$V_b - V_a = k_1 (v^+ - v^-) + \cdots$
$k_3 (v^{+3} - v^{-3}) + \cdots$

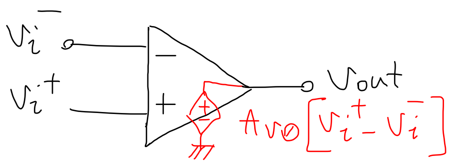
2. common Noise term gets cancelled
3. even harmonic distortions are cancelled
4. But circuit size and power dissipation might get doubled

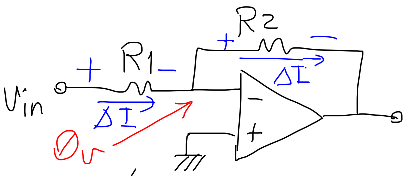
✳ Closed-loop versus Open-loop configuration :



$$V_{out} = g_{m2}(r_{ds2} \| r_{ds4})\, \underbrace{V_{dm}}_{V_i^+ - V_i^-}$$







(finite)

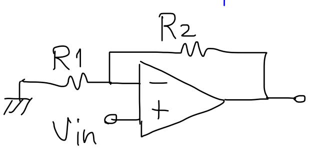
(inverting opamp)

if $A_{v0} \to \infty$

$$\frac{\text{finite}}{\infty} = 0 \equiv \frac{V_{out}}{A_v} = 0$$

$$V_i^+ - V_i^- = 0$$

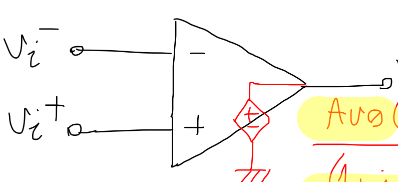
$$\Delta I = \frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_2} \Rightarrow \frac{V_{out}}{V_{in}} = \frac{-R_2}{R_1}$$



$$V_{out} = V_{in}\left(1 + \frac{R_2}{R_1}\right)$$ if $A_v \to \infty$

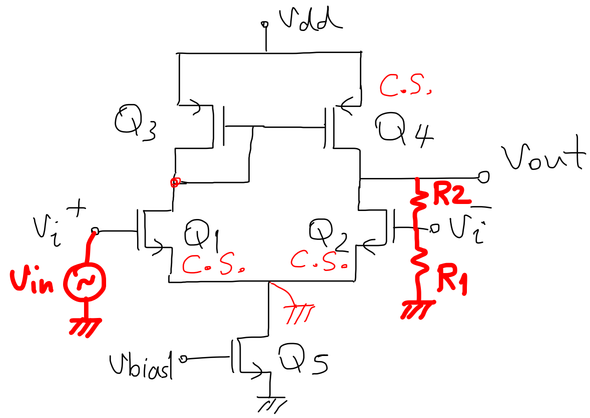
(non-inverting opamp)

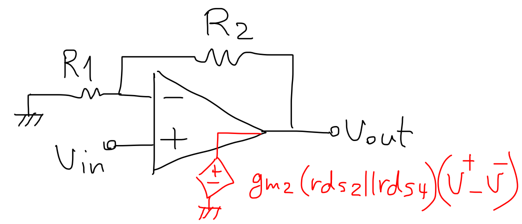
✳ Complete Opamp Modeling :



$$\frac{A_{v0}\left(1 - j\frac{\omega}{\omega_z}\right)}{\left(1 + j\frac{\omega}{\omega_{p1}}\right)\left(1 + j\frac{\omega}{\omega_{p2}}\right)}\left[V_i^+ - V_i^-\right]$$

* Closed-loop gain of +3 ⟶ non-inverting architecture

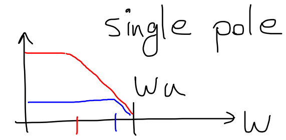




$$\begin{cases} R_2 = 20k\Omega \\ R_1 = 10k\Omega \end{cases}$$

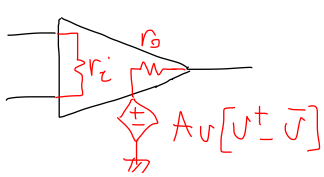
$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1} = 3$$

* Why use closed-loop amplifiers (instead of open-loop) in Electronic systems?

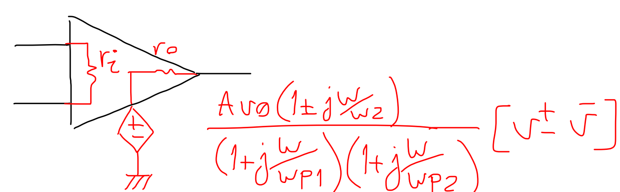


⟶ Because R_1 and R_2 can be used off-chip and trimmed to minimize the effect of process variation

* opamp model



⟹



example: $r_i = 100k\Omega$, $r_o = 5\Omega$, $A_v = 1000$

$$\text{ideal} \begin{cases} r_i \longrightarrow \infty \\ r_o \approx 0 \\ A_v \longrightarrow \infty \end{cases}$$