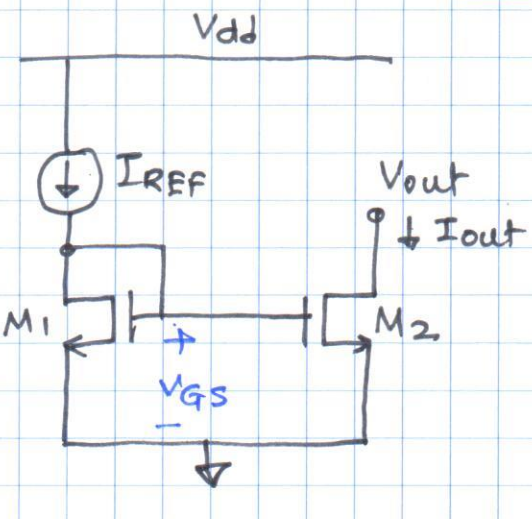
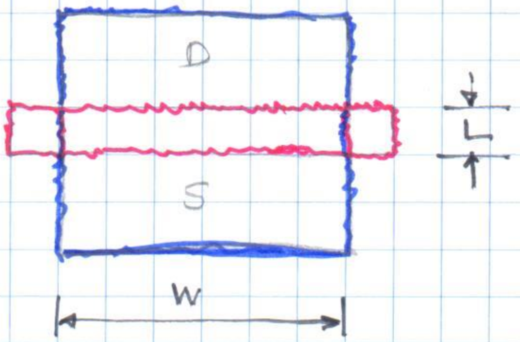
Simple Current Mirror (Revisit)



$$\frac{I_{out}}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1} \frac{(1+\lambda_2 V_{out})}{(1+\lambda_1 V_{GS})}$$

★ Random Process Variations



Edges defining transistor gate region - Noisy due to photolithograhy.

σ — standard deviation.

σ^2 — variance

$$I \propto (W/L) \Rightarrow \left(\frac{\sigma_I}{I}\right)^2 \propto \left(\frac{\sigma_W}{W}\right)^2 + \left(\frac{\sigma_L}{L}\right)^2$$

W & L indep. variables.

If W >> L (Typ for ~~all~~ analog design)

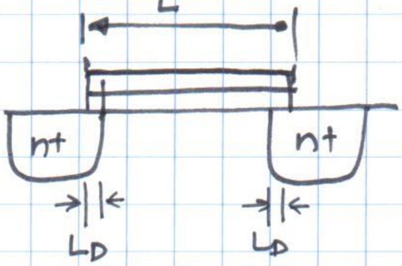
$$\left(\frac{\sigma_I}{I}\right)^2 \propto \left(\frac{\sigma_L}{L}\right)^2$$

To be more accurate you have to consider V_T mismatches, μ, C_{ox} etc

* **Systematic Errors** {
- Layout Errors (different orientation)
- Design Errors (different V_{DS} for example)

Each defining edge (dimension) can have errors.

Consider channel length L

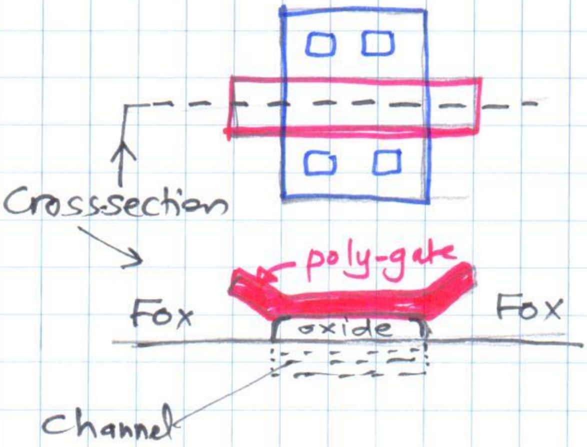


L_D - due to lateral diffusion of S/D

$L_{eff} = L_{drawn} - 2L_D$.

⇒ L_{drawn} & $N L_{drawn}$ will not give you scaling by N for L_{eff}.

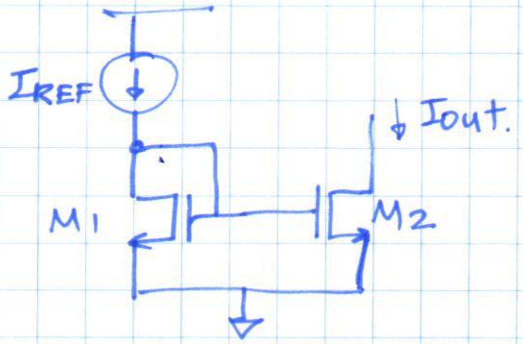
Consider Channel Width W - MOS Cross-section



Desired W

Lactual W + ΔW

$$\text{Desired } I_{out} = \overset{\text{integer}}{N} I_{REF}$$



Case I $M_1 = W/L$; $M_2 = NW/L$

$$\frac{I_{out}}{I_{REF}} = \underbrace{\left(\frac{NW+\Delta W}{L+\Delta L}\right)}_{M_2} \times \underbrace{\left(\frac{L+\Delta L}{W+\Delta W}\right)}_{M_1}$$

$$= \frac{NW+\Delta W}{W+\Delta W}$$

Case II $M_1 = W/L$; $M_2 = N$ devices of W/L ⇒ $\frac{I_{out}}{I_{REF}} = \frac{NW+N\Delta W}{W+\Delta W} = N$.

Differential Amplifiers

Why differential amplifiers.

- ECG example
- Detecting very small (differential) signal in presence of very large (common-mode) signal.
- Whisper in presence of screams.

Concept

Single-Ended (SE) Signal

$$V_{SE} = V_c \cos \omega_c t + V_d \cos \omega_d t$$

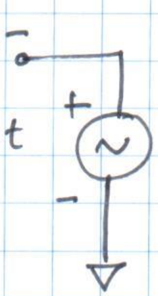
large undesired signal (mV)

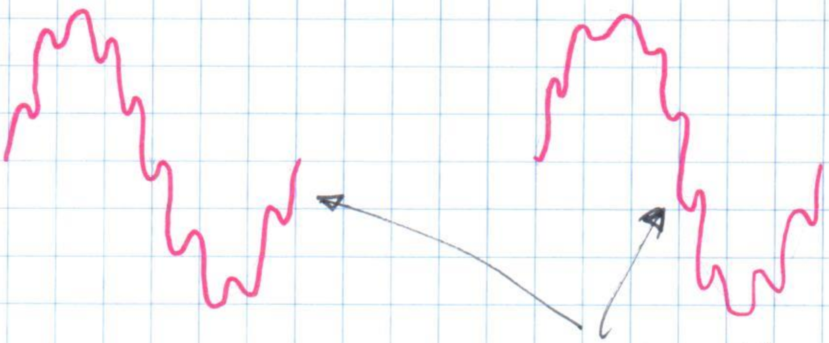
Small desired signal (μV)

Differential (DE) Signal

$V_c \cos \omega_c t + V_d \cos \omega_d t$

$V_c \cos \omega_c t - V_d \cos \omega_d t$



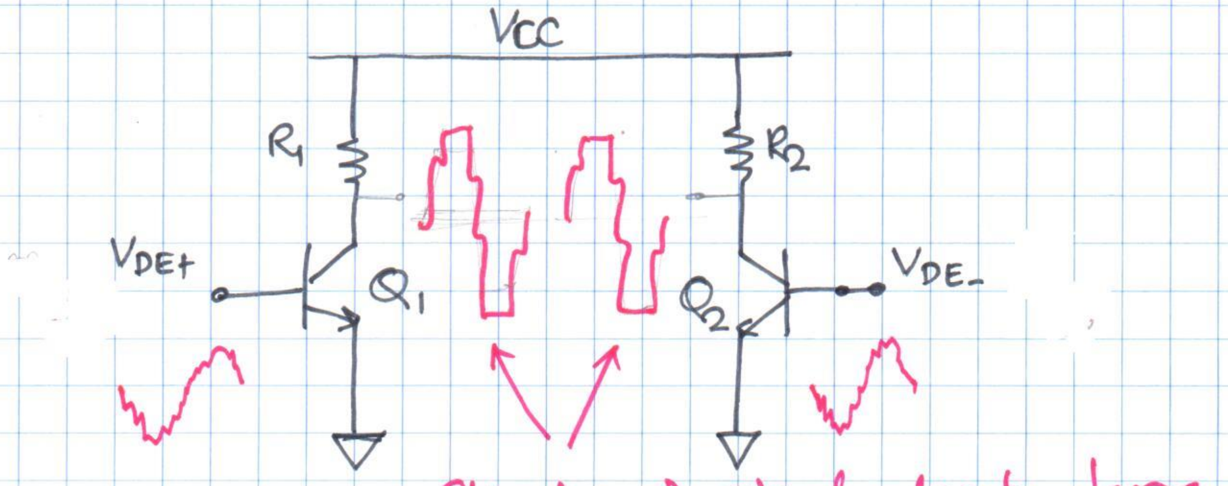


Large common-mode signal

Small differential signal

– ex. due to 50 Hz supply hum,

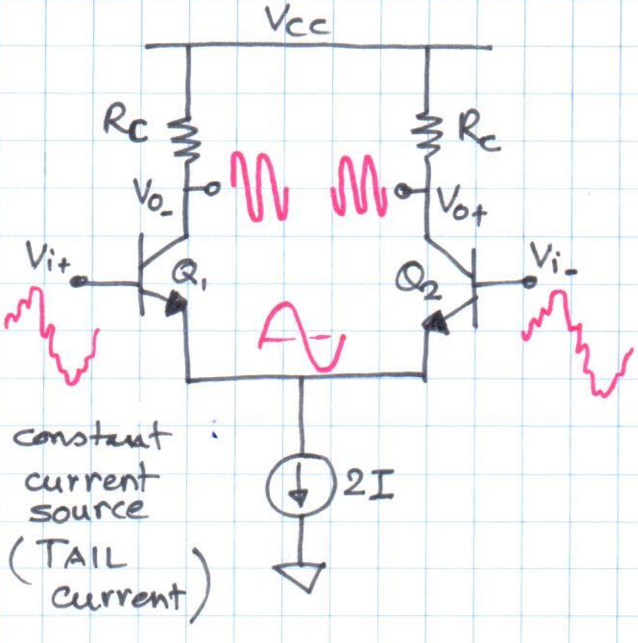
Two identical amplifiers driven by V_{DE+} & V_{DE-}
(Psuedo-Differential)



Clipping of signal due to large common-mode signal

Goal: Amplify only Differential Signal (desired)
— Reject common-mode signal (Undesired).

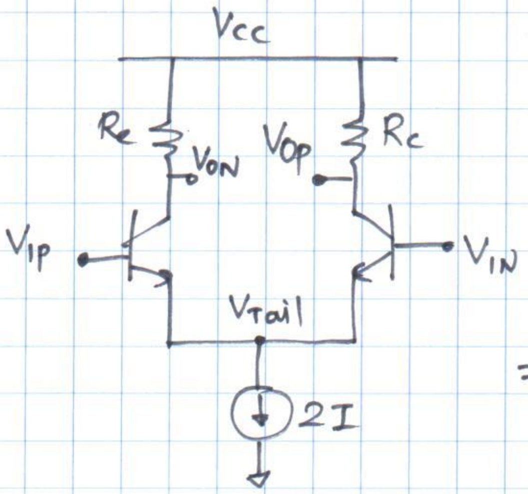
Basic Differential Pair — ✫ innovation



common-mode signal appears across current source.

Only Differential Signal is amplified at o/p.

Qualitative understanding of Diff. pair

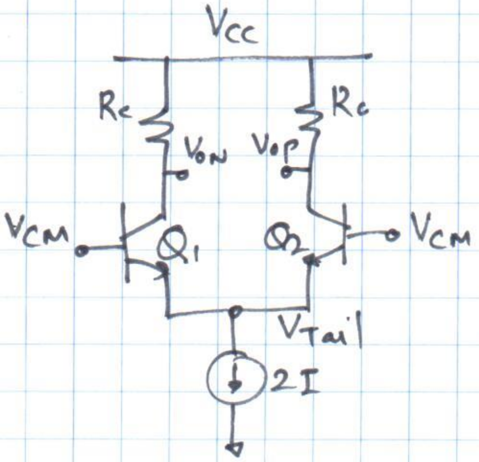


$$V_{CM} = \frac{V_{IP} + V_{IN}}{2}$$

$$V_{DM} = V_{IP} - V_{IN}$$

$$\Rightarrow V_{IP} = V_{CM} + \frac{V_{DM}}{2}$$

$$V_{IN} = V_{CM} - \frac{V_{DM}}{2}$$

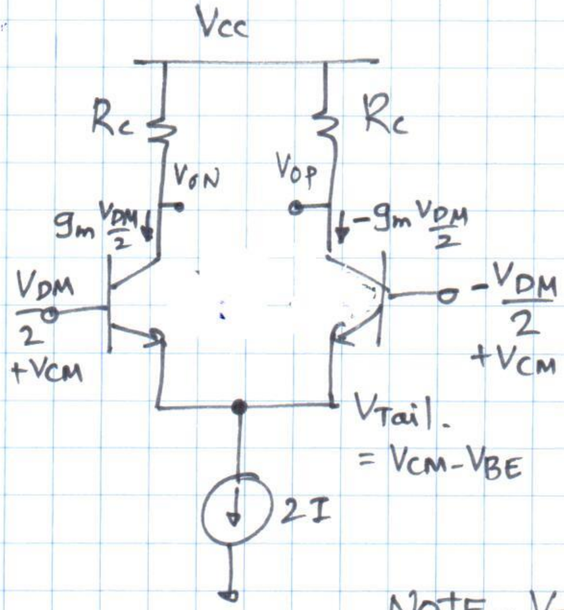


When "only" V_{CM} is applied to both i/ps

Q_1 & Q_2 each carry I.

$$V_{OP} = V_{ON} = \underbrace{V_{CC} - IR_C}_{\text{Indep. of } V_{CM}}$$

$$V_{Tail} = V_{CM} - V_{BE}$$



When V_{DM} is applied. (on top of V_{CM})

$$V_{OP} = V_{CC} - IR_C + g_m \frac{V_{DM}}{2} \cdot R_C$$

$$V_{ON} = V_{CC} - IR_C - g_m \frac{V_{DM}}{2} \cdot R_C$$

$$V_{OP} - V_{ON} = g_m V_{DM} \cdot R_C$$

$$\frac{V_{out\,diff}}{V_{in\,diff}} = \frac{V_{OP} - V_{ON}}{V_{DM}} = g_m R_C$$

↑ Transcond of each transistor

NOTE: V_{Tail} is indep. of V_{DM} — virtual ground.