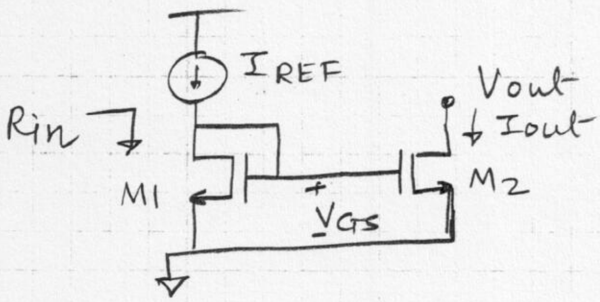
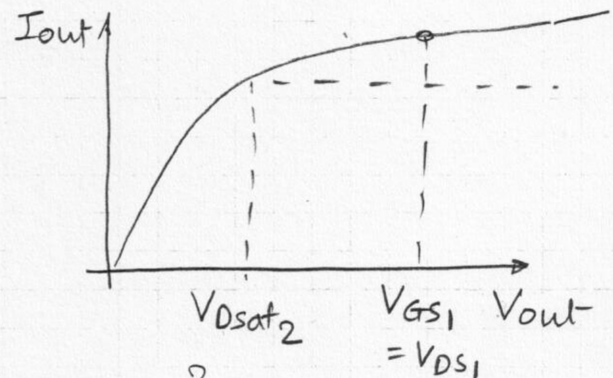
STAEDTLER® No. 937 811E Engineer's Computation Pad

Simple Current mirror



$$R_{in} = \frac{1}{g_{m_1} + g_{ds_1}} \approx \frac{1}{g_{m_1}}$$



$$I_{REF} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_1 (V_{GS} - V_{T_1})^2 (1 + \lambda_1 V_{GS_1})$$

$$I_{OUT} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_2 (V_{GS} - V_{T_2})^2 (1 + \lambda_2 V_{out})$$

Assume $V_{T_1} = V_{T_2}$

$$\frac{I_{OUT}}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1} \frac{(1 + \lambda_2 V_{OUT})}{\underbrace{(1 + \lambda_1 V_{GS})}_{\text{Small}}}$$

For accurate mirroring, keep L same $\Rightarrow \lambda_1 = \lambda_2$

$$\frac{I_{OUT}}{I_{REF}} = \frac{W_2}{W_1}\left(1 + \lambda (V_{out} - V_{GS})\right)$$

To keep λ small $\rightarrow$ use long channel device
L large $\gg L_{min}$

$$I_{OUT} = \frac{W_2}{W_1} I_{REF}$$

For accurate mirroring $W_2 = N W_1$ (N: Integer)

DO NOT SCALE THE TRANSISTOR SIZE.

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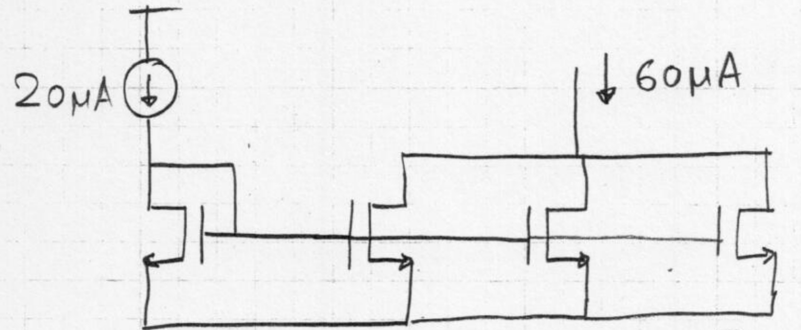
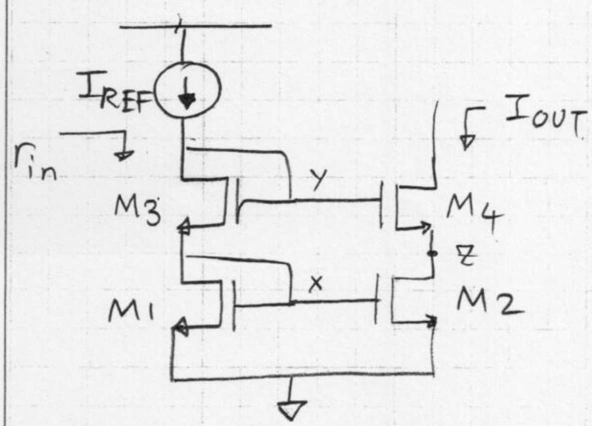
Example



$\frac{W}{L}$ $\frac{5\mu m}{1\mu m}$ $\frac{5\mu m}{1\mu m}$ $\frac{5\mu m}{1\mu m}$ $\frac{5\mu m}{1\mu m}$ ← Large L $\lambda\downarrow$

$$V_{out\,min} = V_{dsat_2}$$
$$R_{out} = \frac{1}{g_{ds_2}}$$

CASCODE CURRENT MIRROR

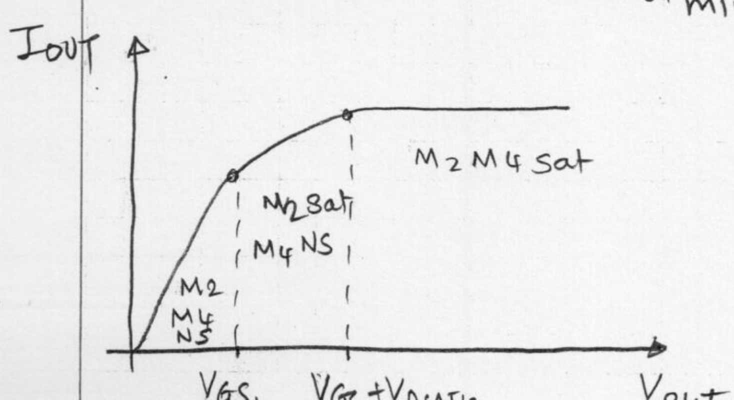


$$r_{in} = \frac{2}{g_m}$$

$$r_{out} \cong (g_{m_4} r_{o_4}) r_{o_2}$$

$$V_y = V_{GS_3} + V_{GS_1}$$
$$V_Z = \cancel{V_{GS_3}} + V_{GS_1} - \cancel{V_{GS_4}} = V_{GS_1}$$

$$V_{OUT\,min} = V_Z + V_{dsat_4}$$
$$= V_{GS_1} + V_{dsat_4}$$
$$\cong V_T + 2V_{dsat}$$
$$0.5V + 0.4V = 0.9V$$



NOT SUITABLE for low voltage

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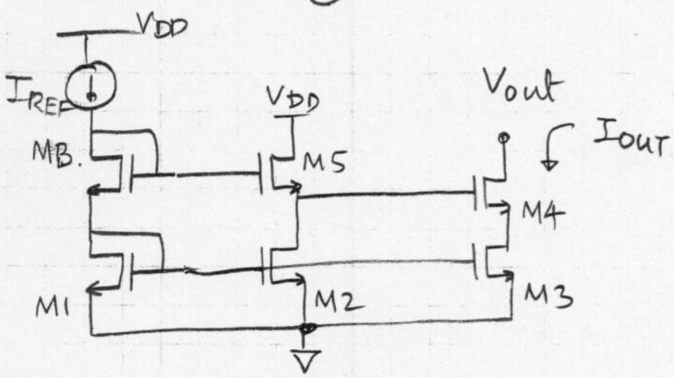
High Swing Cascode CM



DC imbalance M1 ↔ M3 different V_{DS}.

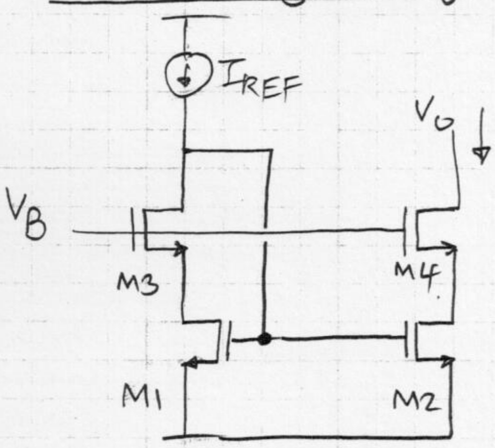
$M_1 - M_5$ identical.

$$\left(\frac{W}{L}\right)_B = \frac{1}{4}\left(\frac{W}{L}\right)_{1\text{-}5}$$

$$\Rightarrow V_{GS_B} = V_T + 2V_{dsat_1}$$

$$V_{OUT\,min} = 2V_{Dsat_1}$$

Low-voltage High swing Cascode CM.



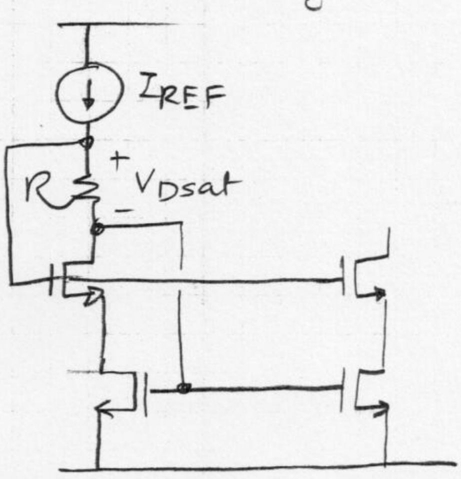
DC balance ✓

$$V_{DS_1} = V_{DS_2} = V_{Dsat}$$

$$V_B = V_T + 2V_{Dsat}$$

$$V_{o\,min} = 2V_{Dsat}$$

Smart Biasing



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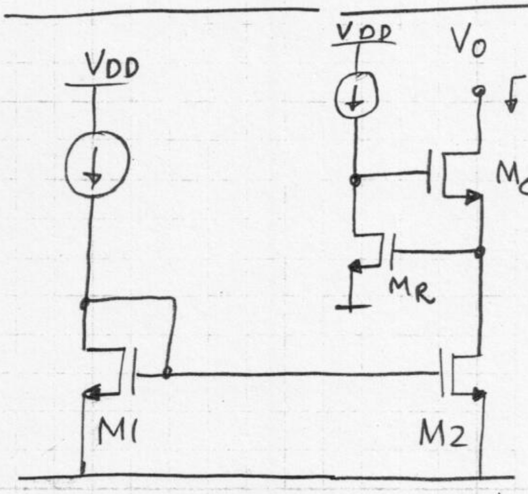
REGULATED CASCODE CM.

YANG - ALLSTOT
1990 - CAS Tran



Series feedback

$$V_{O_{min}} = V_{GS_R} + V_{Dsat_C}$$

$$= V_T + 2V_{dsat}$$

Feedback loop $M_R - M_C$ - loop gain = $(g_{m_R} r_{o_R}) \gg 1$

$$r_{out} \text{ (without feedback)} = r_{o_2} \cdot (g_{m_C} r_{o_C})$$

$$r_{out} \text{ (with feedback)} = r_{o_2} (g_{m_C} r_{o_C}) \cdot (g_{m_R} r_{o_R})$$

$$= (g_m r_o)^2 r_o$$

$$= (25)^2 \times 10K \approx \underline{6.25\,M\Omega}$$

Really large

→ In reality r_{out} limited by leakage current due to Drain-Bulk diode of M_c.

← Diode leakage at high temperature

1.5V 500nA → $\underline{3\,M\Omega}$

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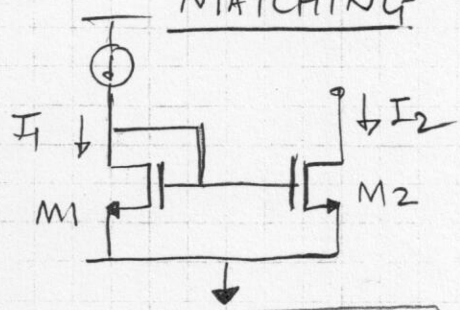
MATCHING CONSIDERATIONS



$$\beta = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)$$

$$I_1 = \beta_1 (V_{GS} - V_{T_1})^2 (1 + \lambda V_{DS_1})$$

$$I_2 = \beta_2 (V_{GS} - V_{T_2})^2 (1 + \lambda V_{DS_2})$$

Variat^n $\boxed{\mu_n, C_{ox}, W, L, V_T}$

$$\frac{I_2}{I_1} = \frac{\beta_2}{\beta_1}$$

(assume all else equal)

Incremental analysis

$$\left.\begin{aligned} \Delta\beta &= \beta_2 - \beta_1 \\ \beta &= \frac{\beta_1 + \beta_2}{2} \end{aligned}\right\} \quad \begin{aligned} \beta_1 &= \beta - \frac{\Delta\beta}{2} \\ \beta_2 &= \beta + \frac{\Delta\beta}{2} \end{aligned}$$

$$I_2 = \frac{\left(\beta + \frac{\Delta\beta}{2}\right)}{\left(\beta - \frac{\Delta\beta}{2}\right)} I_1 = \frac{\left(1 + \frac{\Delta\beta}{2\beta}\right)}{\left(1 - \frac{\Delta\beta}{2\beta}\right)} I_1 \cong \left(1 + \frac{\Delta\beta}{\beta}\right) I$$

Large β $\rightarrow$ large $\frac{W}{L}$ $\rightarrow$ smaller mismatch

V_T variations

$$V_{T_1} = V_T\left(1 + \frac{\Delta V_T}{2V_T}\right); \quad V_{T_2} = V_T\left(1 - \frac{\Delta V_T}{2V_T}\right)$$

$$\frac{I_2}{I_1} = \frac{(V_{GS} - V_{T_2})^2}{(V_{GS} - V_{T_1})^2} = \frac{\left(V_{GS} - V_T + \frac{\Delta V_T}{2}\right)^2}{\left(V_{GS} - V_T - \frac{\Delta V_T}{2}\right)^2}$$

$$= \frac{\left(1 + \frac{\Delta V_T}{2(V_{GS} - V_T)}\right)^2}{\left(1 - \frac{\Delta V_T}{2(V_{GS} - V_T)}\right)^2} = \left(1 + \frac{\Delta V_T}{(V_{GS} - V_T)}\right)\left(1 + \frac{\Delta V_T}{(V_{GS} - V_T)}\right)$$

$$= \left[1 + \frac{2\Delta V_T}{(V_{GS} - V_T)}\right]$$

To reduce mismatches increase $(V_{GS} - V_T)$ or <u>Vdsat</u>

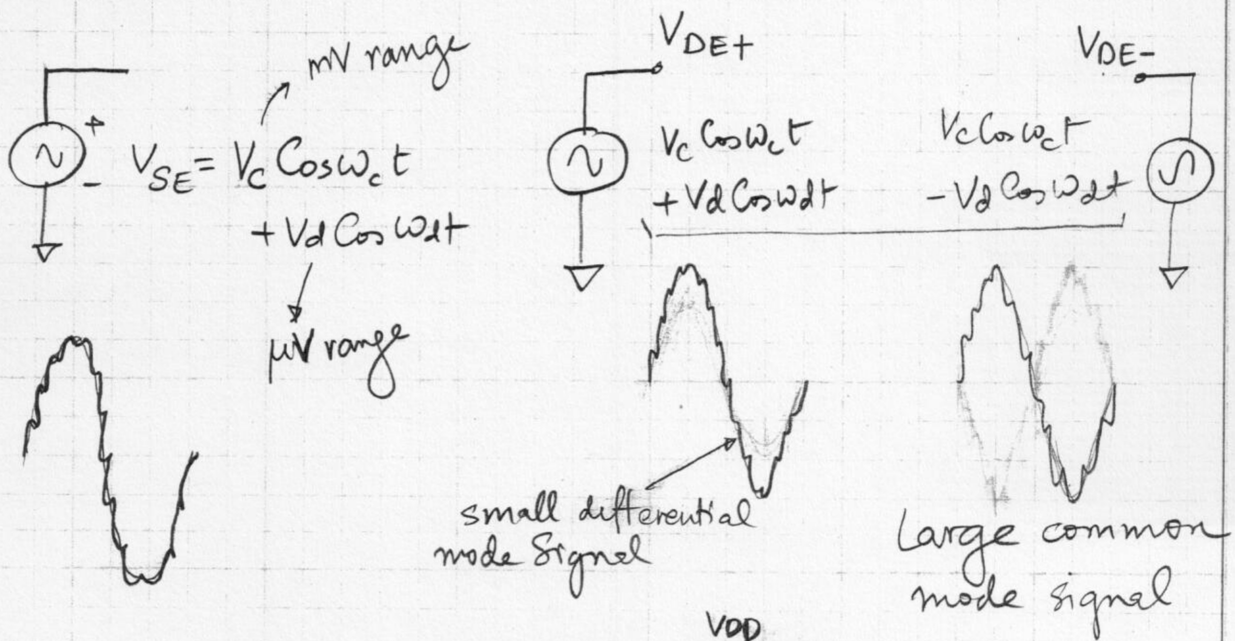
Tradeoff with o/p swing

NEW TOPIC DIFFERENTIAL AMPLIFIERS

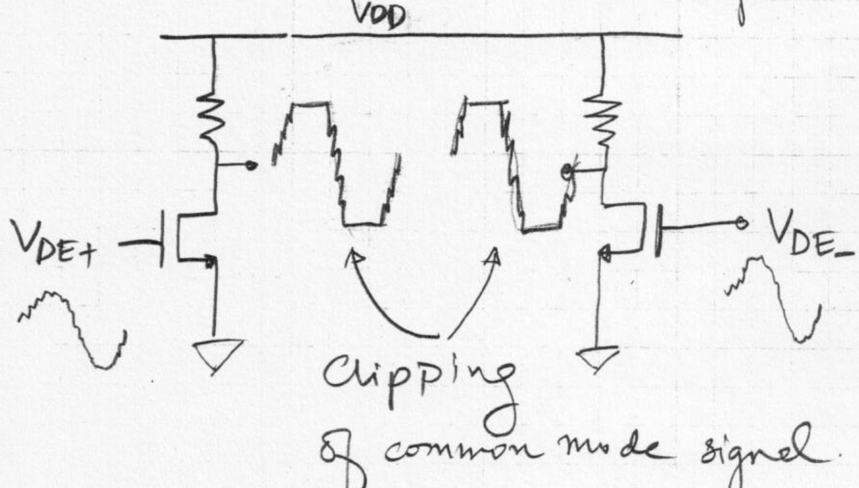
Why differential amplifier?

- Example – ECG
  - Detecting very small signal in presence of very large signal
  - Understanding whisper in presence of screaming voice
  - Difference Amplifier

Single Ended & Differential Signal



Large common mode signal could be 50 HZ Supply Hum, – common mode coupling



Psuedo - Differential

VDD - Noise