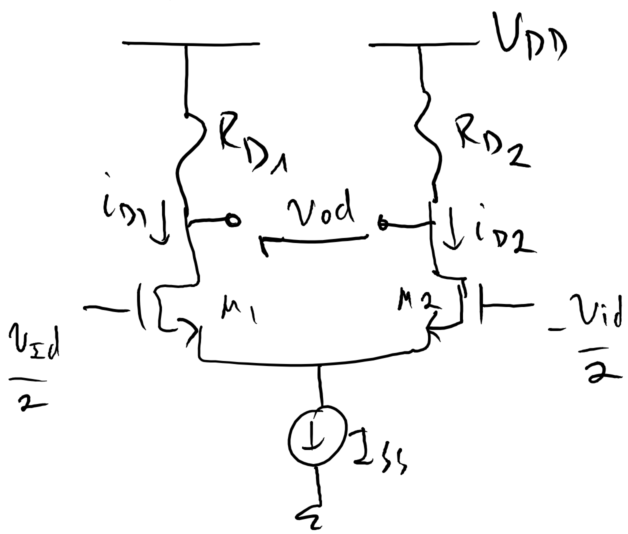
# Lecture 17 - Offset and freq response

Offset: ① Systematic offset: even at zero mismatch

② Random - mismatch between $V_{th1,2}$, $g_m$, ..., $\frac{W}{L}$, ...

Simple example:

a)




$$v_{od} = V_{DD} - i_{D1}R_{D1} - (V_{DD} - i_{D2}R_{D2})$$

$$= i_{D2}R_{D2} - i_{D1}R_{D1}$$

Look for $V_{os}$ as $v_{Id}$ for which $v_{od} = 0$

$$i_{D1}R_{D1} = i_{D2}R_{D2} \quad \left(i_{D2} = i_{D1}\cdot\frac{R_{D1}}{R_{D2}}\right)$$

$$V_{os} = v_{Id} = v_{GS1} - v_{GS2} = V_{th1} + V_{ov1} - V_{th2} - V_{ov2}$$

$$V_{ov1} = \sqrt{\frac{2i_{D1}}{k'(\frac{W}{L})_1}}, \quad V_{ov2} = \sqrt{\frac{2i_{D2}}{k'(\frac{W}{L})_2}}$$

$$= \Delta V_{th} + \sqrt{\frac{2i_{D1}}{k'(\frac{W}{L})_1}}\left(1 - \sqrt{\frac{R_{D1}}{R_{D2}}}\right)$$

$\Delta V_{th} = V_{th1} - V_{th2}$; $\left(1 - \sqrt{\frac{R_{D1}}{R_{D2}}}\right) \approx \frac{1}{2}\frac{\Delta R}{R}$; assumed $\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2$

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Incorporate W, L mismatch:

$$V_{os} = \Delta V_{th} + \frac{V_{ov}}{2} \cdot \left( -\frac{\Delta R}{R} - \frac{\Delta\left(\frac{W}{L}\right)}{\frac{W}{L}} \right)$$

$\Delta V_{th}$ ← process & layout

$\frac{\Delta R}{R}$ ← process

$\frac{\Delta(W/L)}{W/L}$ ← process layout

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**Example:** $V_{th1} - V_{th2} = 10\,mV$

$$\underbrace{V_{GS} - V_{th}}_{V_{ov}} = \sqrt{\frac{2 I_{D1}}{k' \frac{W}{L}}} = 500\,mV$$

$$\frac{R_{D1}}{R_{D2}} = 1.02 \quad (2\%\ \text{mismatch})$$

$$V_{os} = 10\,mV + V_{ov} \cdot \underbrace{\left(1 - \frac{R_{D1}}{R_{D2}}\right)}_{\cancel{2\%}\ 1\%} = 10\,mV + \cancel{10\,mV}\ 5\,mV$$

$$= 20\,mV$$

$f_T$ of MOS $\sim V_{ov} \uparrow \Rightarrow V_{os} \uparrow$

trade-off between accuracy & speed.

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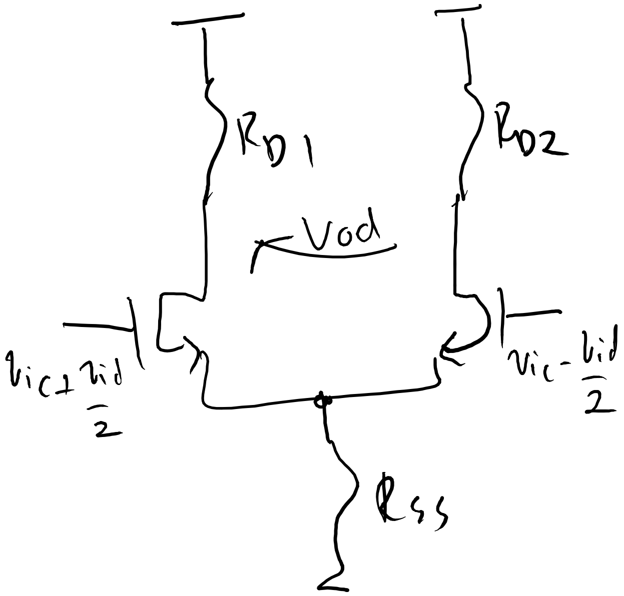
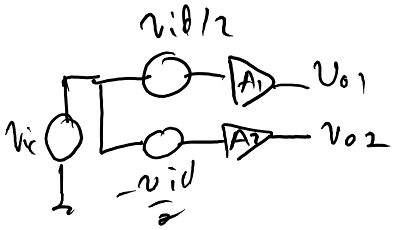



$A_{dm-cm} =$

$A_{cm-dm} =$

$$v_{od}\Big|_{v_{id}=0} = -\frac{g_{m1}R_{D1}}{1+2g_{m1}R_{SS}}v_{ic} + \frac{g_{m2}R_{D2}}{1+2g_{m2}R_{SS}}v_{ic}$$




$v_{od} = v_{o1} - v_{o2}$

$$v_{oc} = \frac{v_{o1}+v_{o2}}{2}$$

$$= -\frac{g_{m1}R_{D1} - g_{m2}R_{D2}}{1+2g_m R_{SS}} =$$

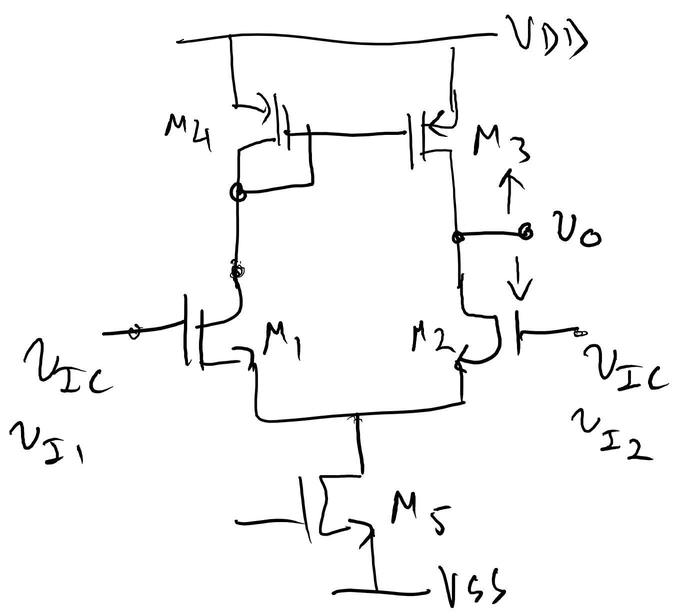
$$= -\frac{\left(g_m+\frac{\Delta g_m}{2}\right)\left(R+\frac{\Delta R}{2}\right) - \left(g_m-\frac{\Delta g_m}{2}\right)\left(R-\frac{\Delta R}{2}\right)}{1+2g_m R_{SS}}v_{ic}$$

$$A_{cm-dm} = -\frac{g_m\Delta R + \Delta g_m R}{1+2g_m R_{SS}} = \frac{v_{od}}{v_{ic}}\Big|_{v_{id}=0}$$

$$\underline{\underline{A_{dm-cm}}} = v_{oc}\Big|_{v_{ic}=0} = \frac{v_{o1}+v_{o2}}{2} = \frac{A_1\cdot\frac{v_{id}}{2} + A_2\cdot\left(-\frac{v_{id}}{2}\right)}{2} =$$

$$= \frac{A_1 - A_2}{4}$$

## Diff - pair CM input range:




$v_{IC}$ range:

$M_1$ SAT:

$$v_{IC} < V_{DD} - |V_{th_4}| - |V_{ov_4}| + V_{th_1}$$

$M_5$ SAT:

$$v_{IC} > V_{SS} + V_{ov_5} + V_{th_1} + V_{ov_1}$$

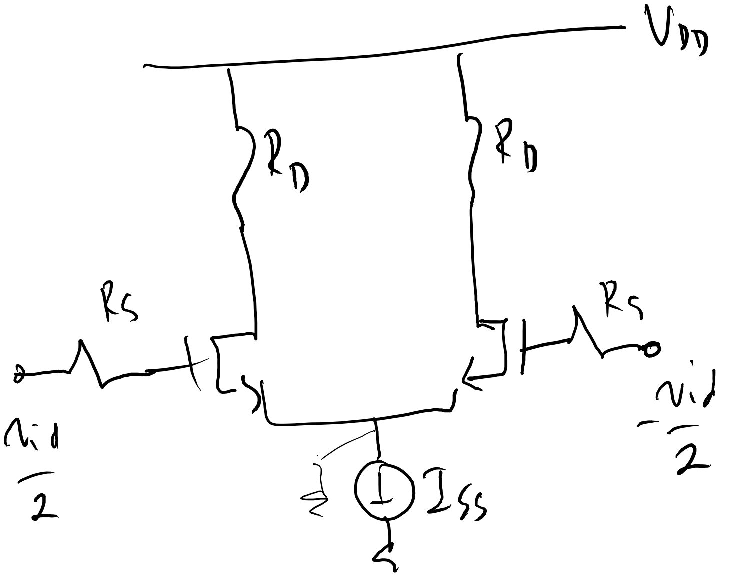
## $V_o$ range:

$M_2$ SAT: $V_{omin} > V_{I2_{max}} - V_{th2}$

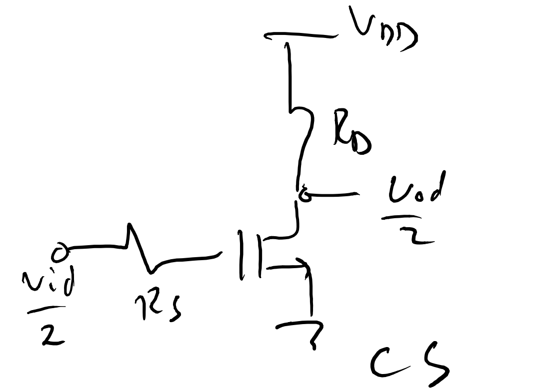
$M_3$ SAT: $V_{omax} < V_{DD} - |V_{ov_3}|$

## Freq response of diff-pairs.

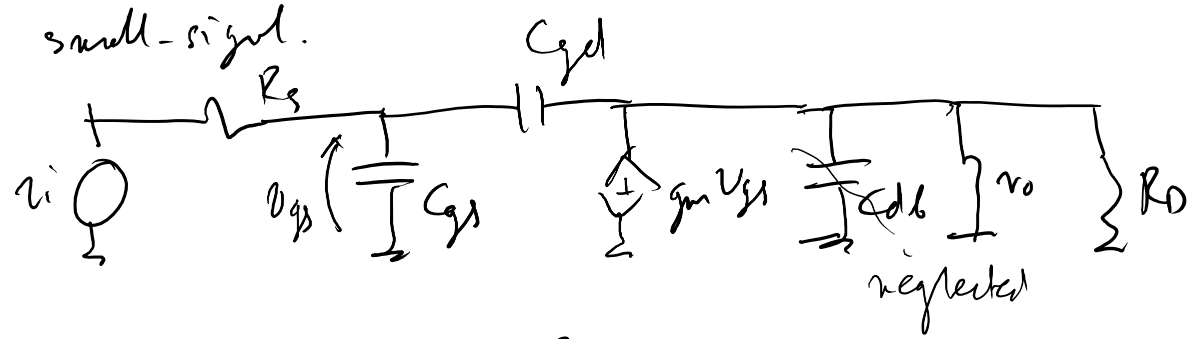
$$A(s) = A_0 \frac{\prod_j^{n_z} \left(1 - \frac{s}{z_j}\right)}{\prod_i^{n_p} \left(1 - \frac{s}{p_i}\right)} \qquad n_p > n_z$$




$\Rightarrow$




CS: small-signal.




$A_{vo} = -g_m R_D$, $z_1 = +\frac{g_m}{C_{gd}}$, $|z_1| >> \omega_T = \frac{g_m}{C_{gs}+C_{gd}}$, $C_{gs} >> C_{gd}$

poles OCTC:

$$p_1 = -\frac{1}{R_S\left(C_{gs} + C_{gd}(1+g_m R_D)\right)}$$

SCTC:

$$p_2 = -\left(\frac{1}{R_D C_{gd}} + \frac{1}{C_{gs}}\left(\frac{1}{R_S} + \frac{1}{R_D} + g_m\right)\right) \Rightarrow |p_2| > \omega_T$$

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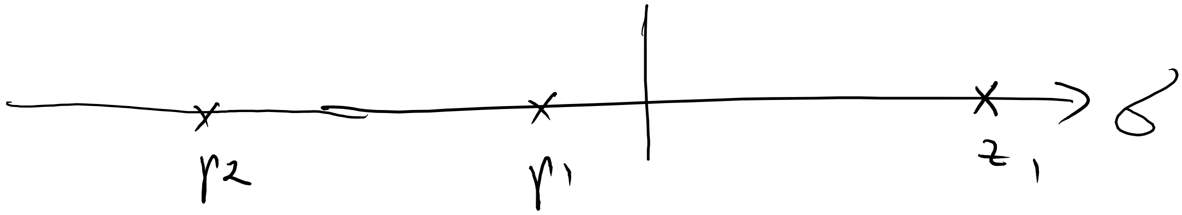
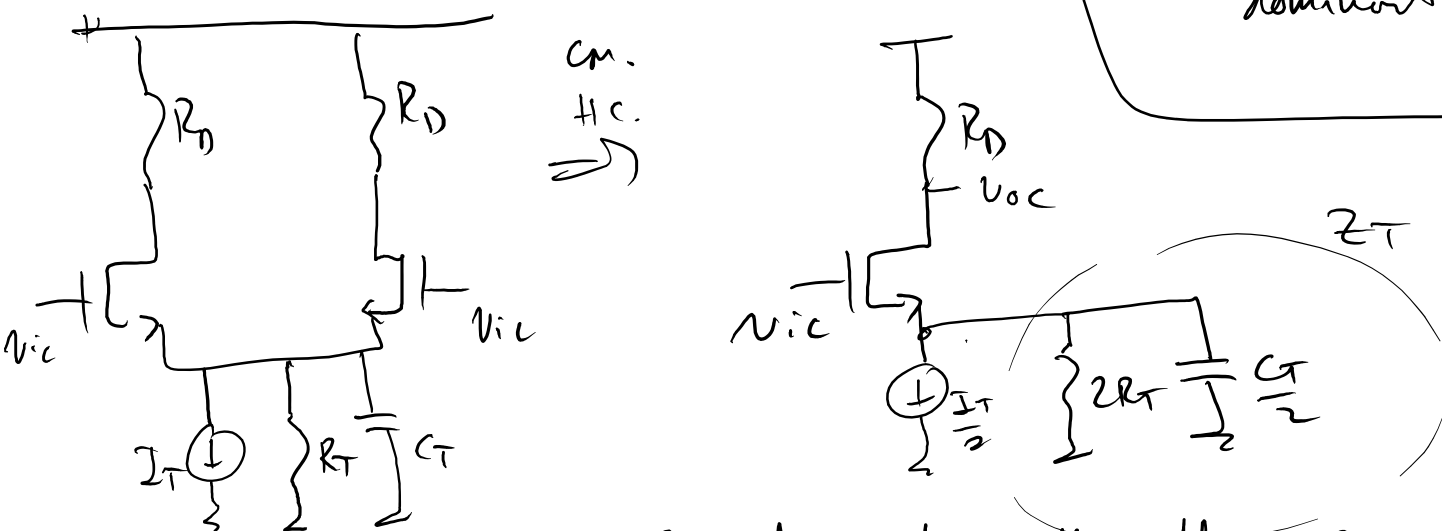



$$|Gain \times BW| = \frac{\cancel{g_m R_D}}{R_S \cdot \cancel{g_m} \cdot C_{gd} \cdot \cancel{R_D}} \simeq \frac{1}{R_S C_{gd}}$$

no dependence on $R_D$ in case Miller effect dominant.

CM response:

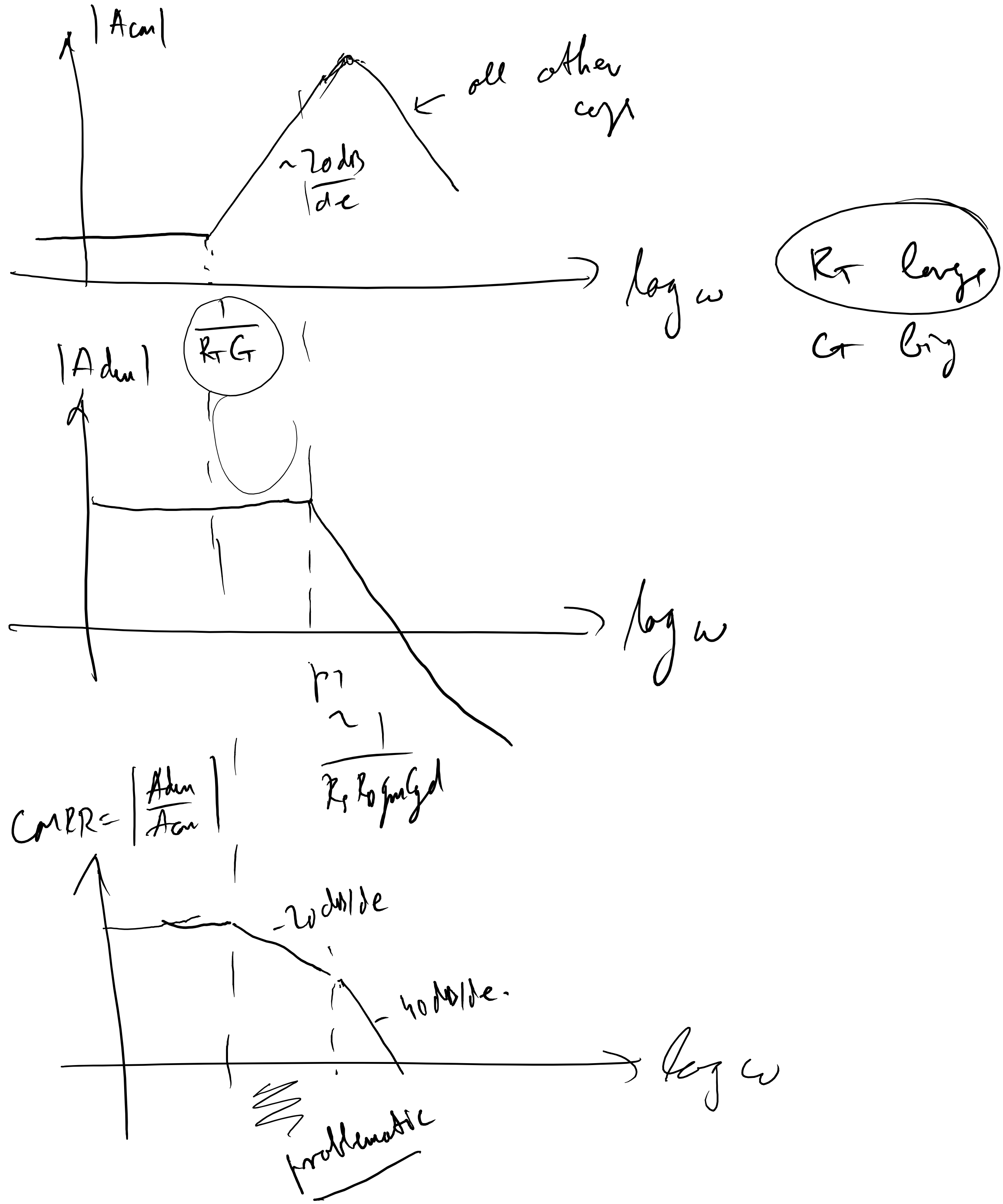



$C_T$ dominates all other caps.

$$A_{cm}(s) = \frac{v_{oc}}{v_{ic}} = -\frac{g_m R_D}{1 + g_m Z_T} \simeq -\frac{R_D}{Z_T}$$

$$Z_T = 2R_T \,||\, \frac{1}{s\frac{C_T}{2}} = \frac{2R_T}{1 + sC_T R_T} \quad \Rightarrow \quad A_{cm} \simeq -\frac{R_D}{2R_T}\underbrace{(1 + sC_T R_T)}_{zero}$$

bad!


|Acm|
all other caps
~20dB/dec
log ω
RT large
CT big
1/RTCT
|Adm|
log ω
p1 ~ 1/RsRogmCgd
CMRR = |Adm/Acm|
-20dB/dec
-40dB/dec
log ω
problematic