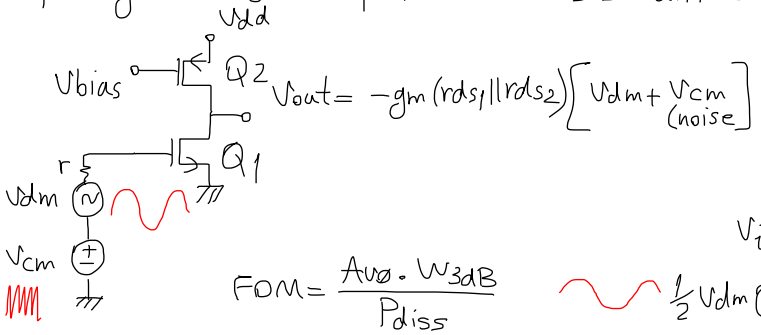
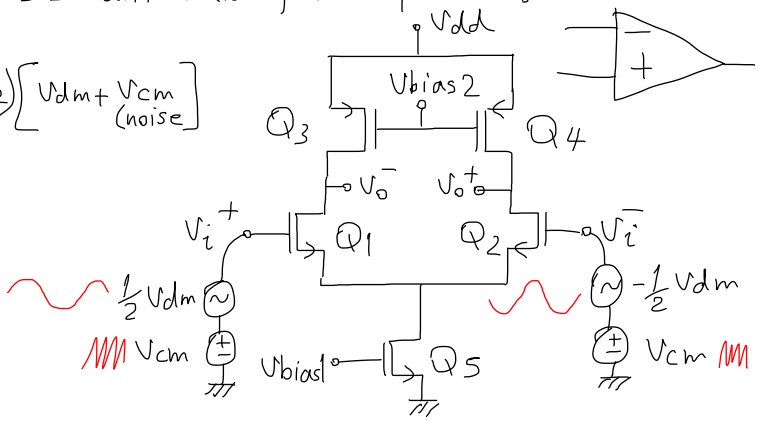
* Single-stage amplifiers versus differential pair amplifiers:



$$V_{out} = -g_m (r_{ds1} \| r_{ds2}) \left[V_{dm} + V_{cm\,(noise)} \right]$$



$$FOM = \frac{A_{v0} \cdot W_{3dB}}{P_{diss}}$$

Example of FOM:

A_{v0}	33	25
W_{3dB}	100M	2GHz
P_{diss}	1mw	7mw
FOM	1.2×10^6	1.3×10^6

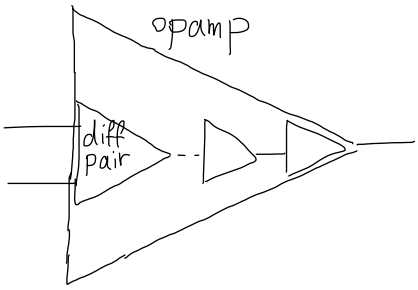
$$V_o^- = \underbrace{-g_{m1}(r_{ds1} \| r_{ds3})}_{\text{higher gain}} \frac{1}{2} V_{dm} - \underbrace{\frac{r_{ds3}}{2r_{ds5}}}_{\text{smaller gain}} V_{cm\,(noise)}$$

* common mode rejection ratio:

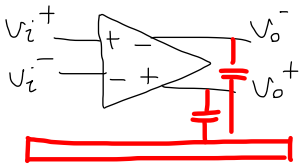
$$FOM = CMRR = \frac{A_{dm}\uparrow}{A_{cm}\downarrow} = \begin{cases} \dfrac{-g_{m1}(r_{ds1} \| r_{ds3})}{\frac{-r_{ds3}}{2r_{ds5}}} & ; \text{ for a diff-pair } (\approx 1000) \\ 1 & ; \text{ for all other amplifier} \end{cases}$$

amplifier

$$P_{diss}, A_{v0}, w_{p1}, \Delta V_{out} \Rightarrow FOM = \frac{A_{v0}\uparrow \times w_{p1}\uparrow \times \Delta V_{out}\uparrow}{P_{diss}\downarrow}$$



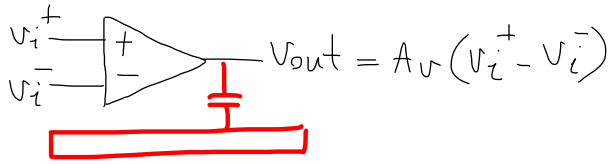
* Differential output versus single-ended output :

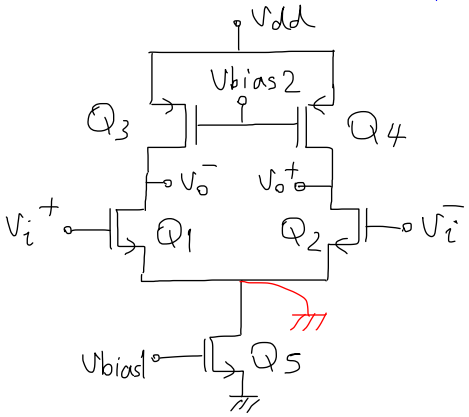


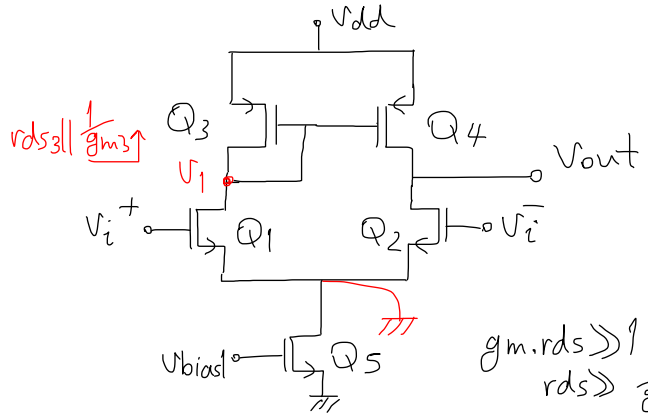
$V_{out} = V_o^+ - V_o^-$

$V_{in} = V_i^+ - V_i^-$

$V_{out} = A_v \cdot V_{in}$







$g_m \cdot r_{ds} \gg 1$

$r_{ds} \gg \frac{1}{g_m}$

$$V_o^- = -g_{m1}(r_{ds1} \| r_{ds3})\, V_i^+$$

$$V_o^+ = -g_{m2}(r_{ds2} \| r_{ds4})\, V_i^-$$

$$V_{out} = V_o^+ - V_o^-$$

$$V_{in} = V_i^+ - V_i^-$$

$$A_v = \frac{V_{out}}{V_{in}} = g_{m2}(r_{ds2} \| r_{ds4})$$

$$= \frac{-g_{m2}(r_{ds2} \| r_{ds4}) V_i^- - \left[-g_{m1}(r_{ds1} \| r_{ds3})\right] V_i^+}{V_i^+ - V_i^-}$$

$$= \frac{(V_i^+ - V_i^-)\, g_{m2}(r_{ds2} \| r_{ds4})}{V_i^+ - V_i^-}$$

$$\begin{cases} V_1 = -g_{m1}\left(r_{ds1} \| \frac{1}{g_{m3}}\right) V_i^+ \\ V_{out1} = -g_{m4}(r_{ds4} \| r_{ds2})\, V_1 \end{cases}$$

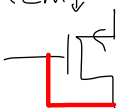
$$\begin{cases} V_{out2} = -g_{m2}(r_{ds2} \| r_{ds4})\, V_i^- \end{cases}$$

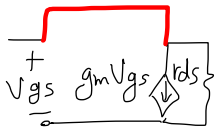
$$V_{out} = V_{out1} + V_{out2}$$

$$\begin{cases} V_{out1} = +g_{m4}(r_{ds4} \| r_{ds2})\, g_{m1} \frac{1}{g_{m3}} V_i^+ \\ V_{out2} = -g_{m2}(r_{ds2} \| r_{ds4})\, V_i^- \end{cases}$$

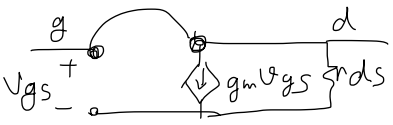
$$A_v = \frac{V_{out}}{V_i^+ - V_i^-} = g_{m2}(r_{ds2} \| r_{ds4})$$

$$CMRR = \frac{A_{dm} \uparrow}{A_{cm} \downarrow}$$



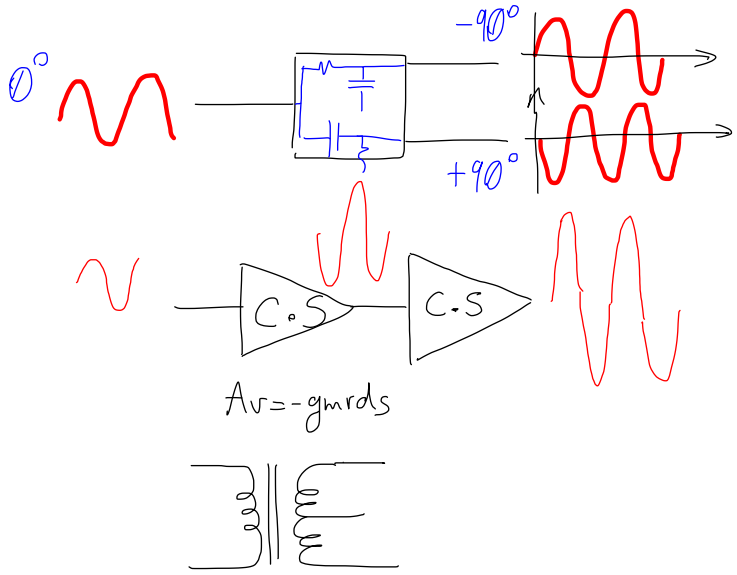


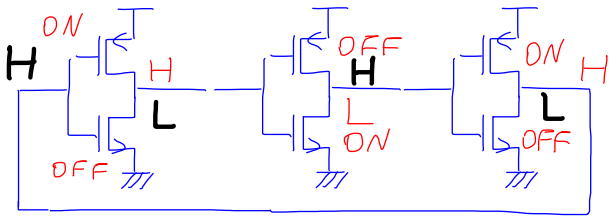
Note: because of symmetry $Q_1 \equiv Q_2$, $Q_3 \equiv Q_4$



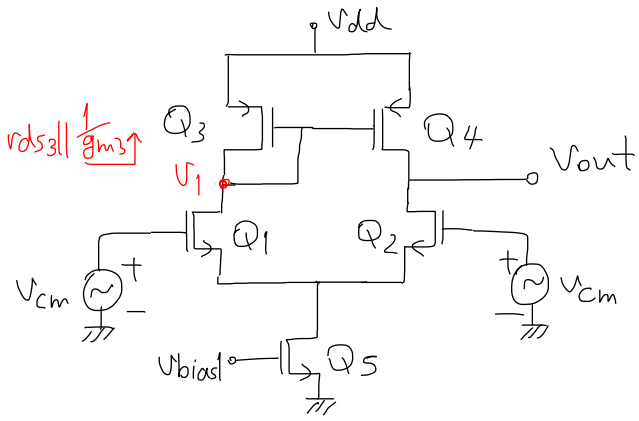
$\equiv \frac{1}{g_m} \| r_{ds}$

poly-phase filters





$$\omega_{3dB} = \frac{1}{\sum \tau_i} = \frac{1}{\tau} \propto \frac{g_m}{C}$$



$$A_{cm} = \frac{V_{out}}{V_{cm}}$$