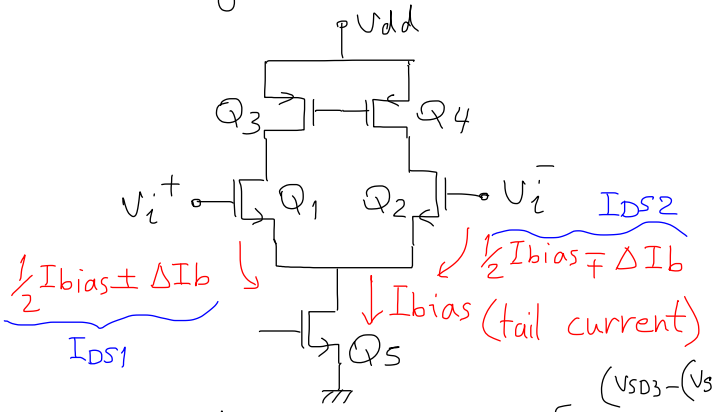
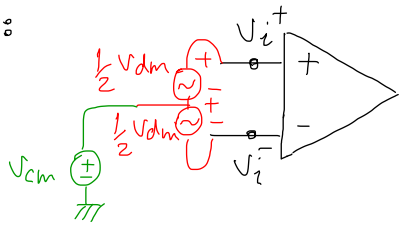
* Swing of differential-pair amplifiers:



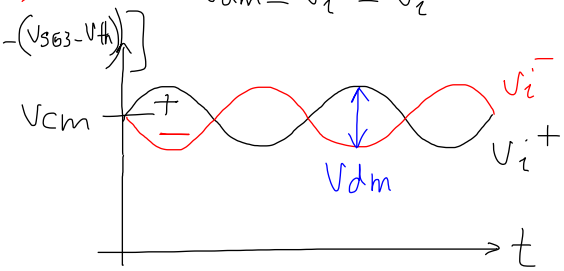


$$\begin{cases} V_i^- = V_{cm} - \frac{1}{2}V_{dm} \\ V_i^+ = V_{cm} + \frac{1}{2}V_{dm} \end{cases}$$

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

Q_3, $I_{SD3} = \frac{1}{2}\mu_p C_{ox}\frac{W_3}{L}(V_{SG3}-V_{th})[1+\lambda$

$$\begin{cases} I_{bias} = I_{DS1} + I_{DS2} \\ I_{out} = 2\Delta I_b = I_{DS1} - I_{DS2} \end{cases}$$



$$\begin{cases} Q_1 \text{ is in saturation}, \lambda \approx 0 \Rightarrow I_{DS1} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS1}-V_{th})^2 \\ Q_2 \text{ is in saturation}, \lambda \approx 0 \Rightarrow I_{DS2} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS2}-V_{th})^2 \end{cases}$$

$$\begin{cases} I_{bias} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[\underbrace{(V_{GS1}-V_{th})^2 + (V_{GS2}-V_{th})^2}_{A}\right] \\ I_{out} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[(V_{GS1}-V_{th})^2 - (V_{GS2}-V_{th})^2\right] = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[\overbrace{(V_{GS1}-V_{GS2})}^{V_{dm}} \times \underbrace{\left((V_{GS1}-V_{th})+(V_{GS2}-V_{th})\right)}_{B}\right] \end{cases}$$

$$B = \sqrt{2A - (V_{GS1}-V_{GS2})^2}$$

$$\Rightarrow I_{out} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{dm}\sqrt{\frac{4I_{bias}}{\mu_n C_{ox}\frac{W}{L}} - (V_{dm})^2}$$

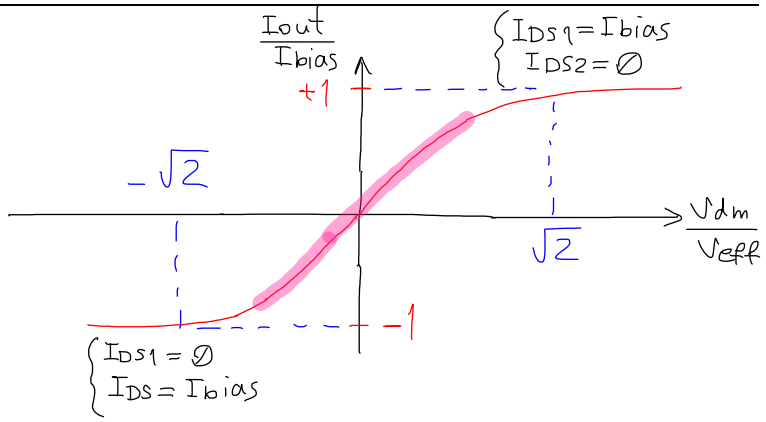
* Consider the case $I_{DS1} = I_{DS2} = \frac{1}{2}I_{bias}$ (when $V_{dm}=0$) $\Rightarrow \frac{1}{2}I_{bias} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{eff}^2$

$V_{eff} = V_{cm} - V_{th}$ because $V_i^+ = V_i^-$, $V_{dm} = 0$ $\Rightarrow$ $V_{eff}^2 = \frac{I_{bias}}{\mu_n C_{ox}\frac{W}{L}}$

$$\Rightarrow I_{out} = \frac{I_{bias}}{2V_{eff}^2}\cdot V_{dm}\sqrt{\frac{4I_{bias}}{I_{bias}/V_{eff}^2} - V_{dm}^2} \Rightarrow \frac{I_{out}}{I_{bias}} = \frac{V_{dm}}{V_{eff}}\sqrt{1-\left(\frac{V_{dm}}{2V_{eff}}\right)^2}$$

$$\begin{cases} I_{bias} = I_{DS1} + I_{DS2} \\ I_{out} = I_{DS1} - I_{DS2} \end{cases}$$

$$\frac{I_{out}}{I_{bias}} = \frac{V_{dm}}{V_{eff}} \sqrt{1 - \left(\frac{V_{dm}}{2V_{eff}}\right)^2}$$



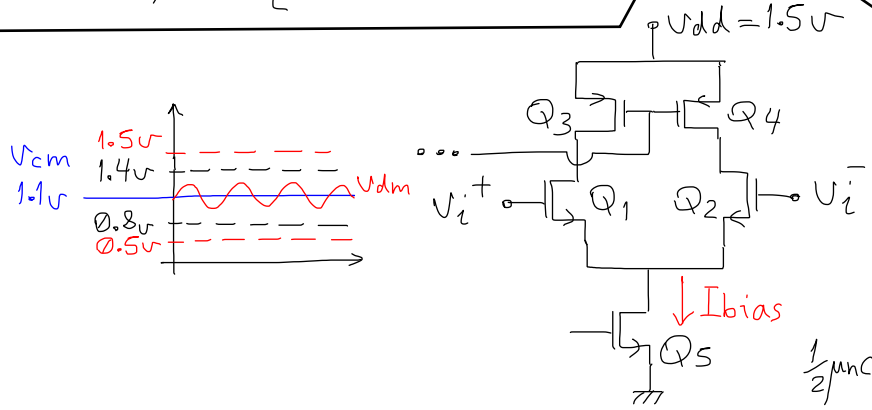
if $V_{dm} = \sqrt{2}\, V_{eff} \Rightarrow \frac{I_{out}}{I_{bias}} = \sqrt{2} \times \sqrt{1 - \left(\frac{\sqrt{2}}{2}\right)^2} = \sqrt{2} \times \frac{1}{\sqrt{2}} = 1$

$$\begin{cases} I_{out} = I_{DS1} - I_{DS2} \\ I_{bias} = I_{DS1} + I_{DS2} \end{cases}, \text{ @ } V_{dm} = \sqrt{2}\, V_{eff} \Rightarrow I_{out} = I_{bias}$$

$$I_{DS1} - I_{DS2} = I_{DS1} + I_{DS2}$$

$$\Rightarrow \begin{cases} I_{DS2} = \emptyset \\ I_{DS1} = I_{bias} \end{cases}$$

$$\begin{cases} Q_1: & I_{DS} = \frac{1}{2}\mu_n C_{ox} \frac{W}{L} (V_{eff})^2 \\ Q_2: & g_m = \mu_n C_{ox} \frac{W}{L} V_{eff} \end{cases}$$



$V_{th} = 0.5V$

$V_{dd} = 1.5V$

$P_{diss} = 3\ mW$

$I_{dd} = 2mA$

$I_{bias} = 2mA$

$\frac{1}{2}\mu_n C_{ox} \frac{W}{L} V_{eff}^2 = I_{DS1} = 1mA$

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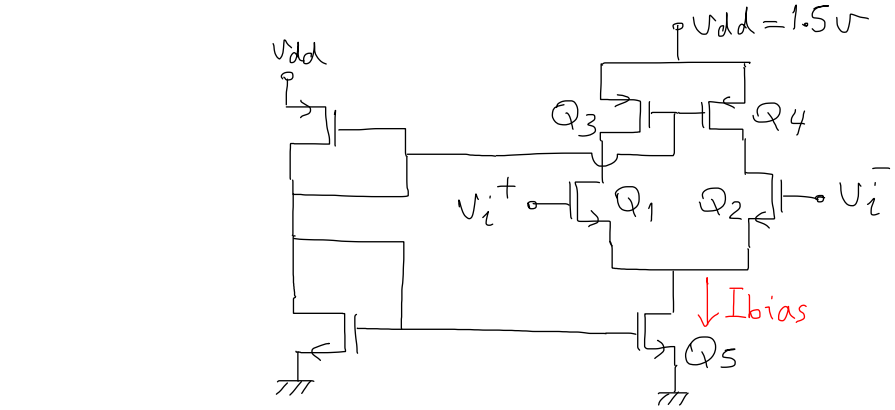
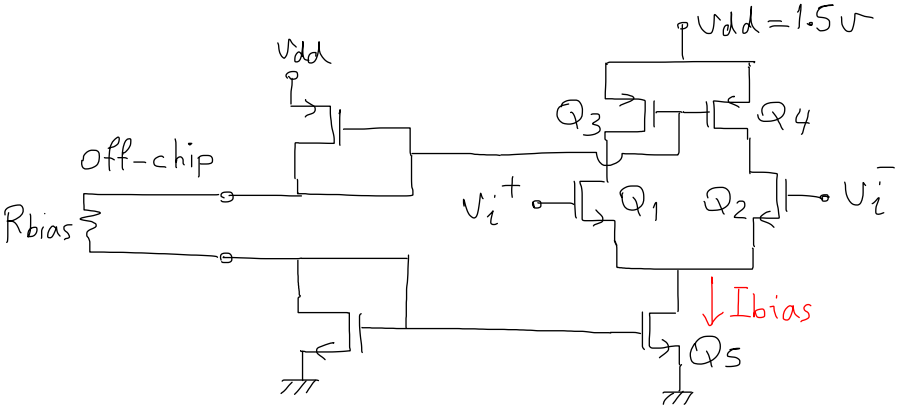
$\Rightarrow W_1, W_2$

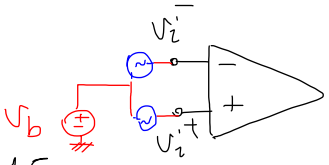
(1) $V_{i\,min}^{+} > V_{GS1} + V_{DS5} \Rightarrow V_{i\,min}^{+} > 0.8V$

(2) $V_{i\,max}^{+} < V_{dd} - V_{SD3} - V_{SD1} + V_{GS1} \Rightarrow V_{i\,max}^{+} < 1.4V$

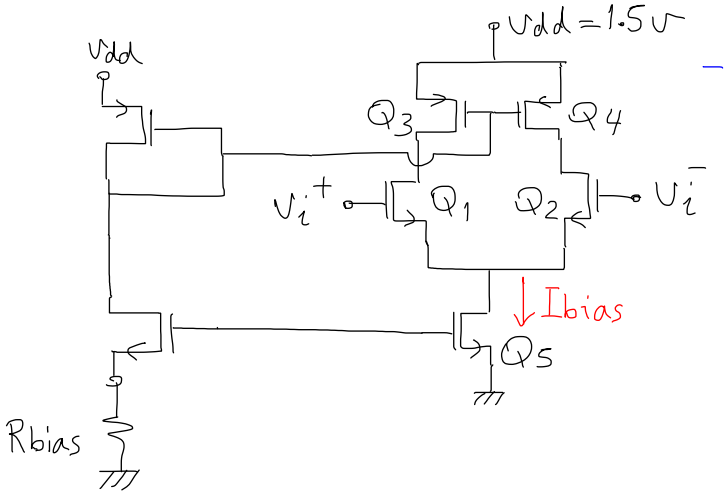
$1.5V \quad 0.3 \quad 0.3 \quad 0.5$



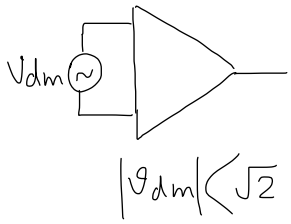


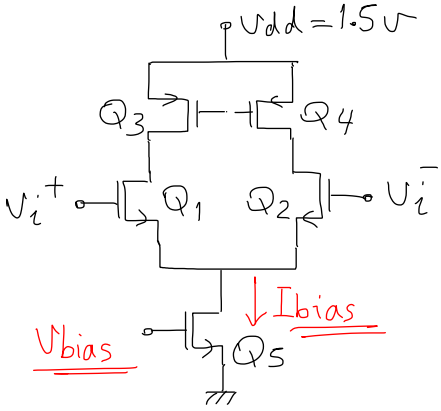


$-\sqrt{2}V_{eff} < V_{dm} < \sqrt{2}V_{eff}$

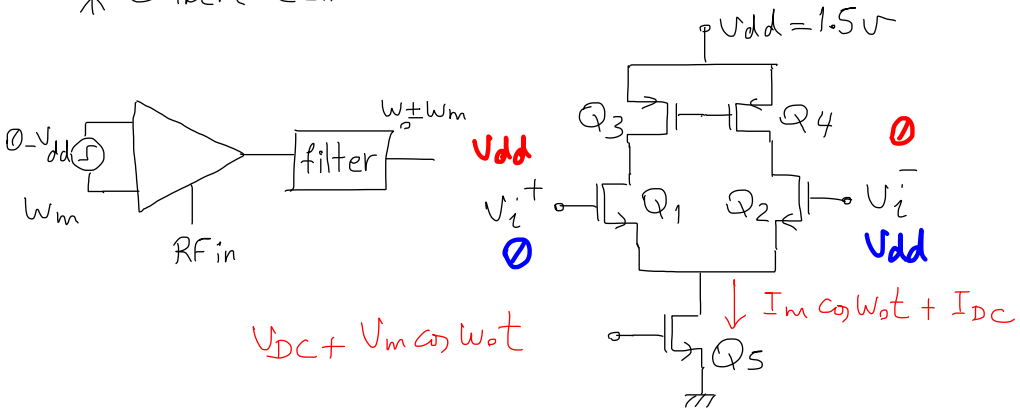


* Diff-pair





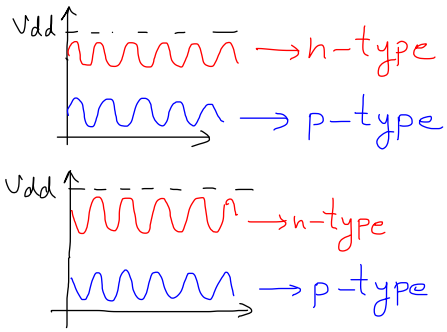
* Gilbert-Cell

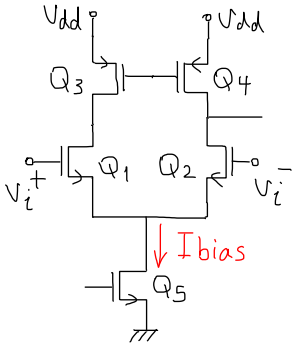


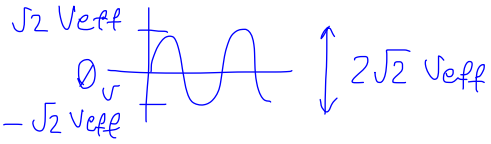
Q1 and Q2 are switched ON/OFF

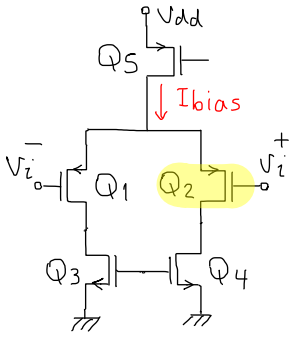
$$I_{DS1} = (I_m \cos\omega_0 t + I_{DC}) \times \text{pulse}$$

$$\frac{1}{2}\left[\cos\omega_m t - \frac{1}{3}\cos 3\omega_m t + \frac{1}{5}\cos 5\omega_m t - \cdots\right]$$


Vdd
n-type
p-type
Vdd
n-type
p-type


Vdd
Vdd
Q3
Q4
Q1
Q2
Vi+
Vi−
Ibias
Q5


√2 Veff
0
−√2 Veff
2√2 Veff


Vdd
Q5
Ibias
Vi−
Q1
Q2
Vi+
Q3
Q4