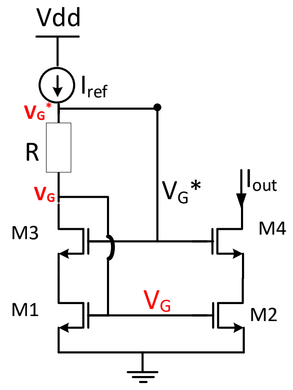
Série N3: « Current Sources »

Données de la technologie: V_{DD} = 1.8 V , L_{min} = 0.18 µm; Cox = 8fF/µm^2

nMOS: $k_{P,n}$ = 184 µA/V^2 ; V_{Tn} = 0.3 V; $U_{a,N}$ = 4.6 V/µm, n=1.2 **pMOS: $k_{P,p}$ = 43 µA/V^2 ; V_{Tp} = 0.45 V; $U_{a,P}$ =12.5 V/µm ; n=1.3**

Exercise N1 : Self Biasing wide swing current mirror



1. Determine R for a maximum output dynamic range.

The maximum output swing is achieved for a $V_{D,2} = V_{D,sat} = V_G - V_{Tn}$

M_4 and M_2 having the size and drain current → $V_{GS4} = V_G$

➔ $V_G^* = V_{GS4} + V_{D2} = 2V_G - V_{Tn}$. Since $V_G^* - V_G = R\, I_{ref}$

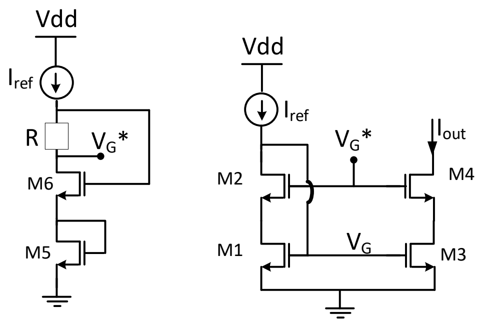
➔ $R = (V_G - V_{Tn})/I_{ref}$

2. Determine the maximum values of $R.I_{ref}$ such that M_3 remains in saturation.

M_3 in saturation → $V_{D3} > V_{G3} - V_{Tn}$, since $V_{D3} = V_G$ and $V_{G3} = V_G^*$

→ $V_G^* - V_G < V_{Tn}$ → $R\, I_{ref} < V_{Tn}$

Exercise N2 : Wide swing current mirror



$(W/L)_{1,2,6,5}$ = 20/1, $(W/L)_{3,4}$ = 60/1, $I_{ref} = I_1$ = 100 uA

1. Determine V_G, V_G^* and R for a maximum output dynamic range.

V_G=?

Inversion factor of M1:

$$I_{F1} = \frac{I_{D1}}{I_{s1}} = \frac{I_{ref}}{2nk_{p,n}\frac{W}{L}U_T^2} = \frac{100}{2\ 1.2\ 184\ 20\ 0.026^2} \approx 16\ > 10$$

$$\rightarrow M1\ in\ strong\ inversion$$

V_{G1} can calculated using the square law as

$$V_G = \sqrt{\frac{2I_{ref}}{k_{p,n}(\frac{W}{L})}} + V_{To,n} = \sqrt{\frac{2\ 100}{184\ 20}} + 0.3 \quad V_G = 0.53\ V$$

V_G^*=?

The maximum output swing is achieved for a $V_{D,3} = V_{D,sat} = V_G - V_{Tn}$ →$V_G^* = 2V_G - V_{Tn}$= 0.76V

R=?

$R\, I_{ref} = V_{G6} - V_G^* = V_{GS6} + V_{G5} - V_G^*$

$M_{1,2,6,5}$ with the same sizes and same drain current results in $V_{GS6} = V_{G5} = V_G$= 0.53 V

➔ $R\, I_{ref} = 2V_G - V_G^* = V_{Tn}$ and $R = V_{Tn}/I_{ref} = 0.3/100\mu = 3\ k\Omega$.

2. Estimate the deviation of I_{out} from 300 uA if the drain voltage of M4 is higher than V_G by 1V.

ΔI_{out} = ? for a ΔV_{out}= 1V

$\Delta I_{out} = r_{o,casc}^{-1}\, \Delta V_{out} \approx (g_{m4} r_{o4}^2)^{-1}\, \Delta V_{out\ t}$

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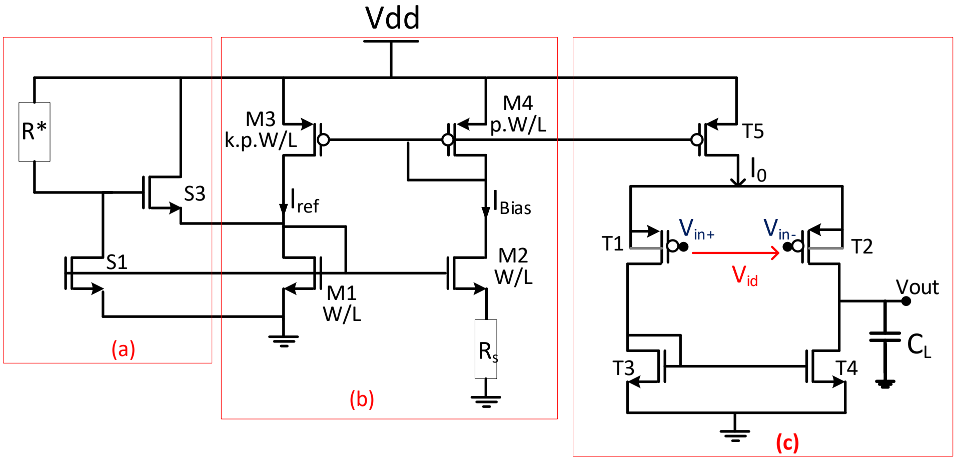
With $g_{m4} = \sqrt{2k_{p,n}(W/L)I_{out}} = \sqrt{2\ 184\ 60\ 300} = 2573\ \mu S$

$r_{o4} = \frac{L.Ua}{I_{out}} = \frac{4.6}{300\ 10^{-6}} = 15.333\ k\Omega$

→ $\Delta I_{out} = (2573\ .15{,}33)^{-1} = 1.53\ \mu A$

Exercise N3 : Biasing circuit for OTA



1. Explain the operation of (a).

   The circuit (a) is a start-up circuit that will enable to avoid the degenerated state $I_{ref} = 0$ of the β-multiplier (b). In fact, when I_{ref} is null, $V_{GS,S3}$ equals V_{dd} and a significant current is injected by S3 into the drain of M1. This will trigger the positive feedback and set I_{bias} to its desired study-state value defined by R_s. At the same time $V_{GS,S3}$ decreases and should go blow V_{T0} at the study state to cancel the impact of the start-up circuit on the β-multiplier operation.

2. Explain the operation of (b) and size all its transistors and R_s to meet the following specifications: $\mathbf{I_{BIAS}}$=10 µA, $V_{ov,n1}$=$V_{ov,p}$= 0.2 V and k=4.

   The circuit (b) is a Beta-multiplier (see the course for the operation).

We can demonstrate that $I_{Bias} = \frac{2}{\beta_1 R_S^2}\left(\sqrt{k} - 1\right)^2$

If we know vov of M1 we can calculate its W/L

$M1 \rightarrow \left(\frac{W}{L}\right)_1 = \frac{2kI_{bias}}{k_{p,n}V_{ov}^2}$ $and\ for\ M3 \rightarrow \left(\frac{W}{L}\right)_3 = \frac{2kI_{bias}}{k_{p,p}V_{ov}^2}$

NA:

$(W/L)_{1,2} = 11$; $(W/L)_3 = 46$; $(W/L)_4 = (W/kL)_3 = 11.5$.

$R_s \approx 10\ k\Omega$

Note: $V_{ov2} = V_{ov1} - R_sI_{Bias} = 0.1V$ (< 0.2V)→ *Moderate inversion* this can result in some inaccuracy that should be evaluated by simulation and eventually corrected by decreasing the sizes $(W/L)_{1,2}$.

We can also start by $V_{ov2} = 0.2V$ to be sure that M2 is in strong inversion → $(W/L)_{1,2} = 2.7$ → $R_s \approx 20\ K\Omega$ ($V_{ov1} = V_{ov2} + R_sI_{Bias} \approx 0.4$ V)

3. If the all nMOS transistors of (a) and (b) have the same size, propose a value for R*.

At study-state the transistor S3 should be switched off in order to don't disturb the Beta-multiplier. For the following condition have to be fulfilled:

$V_{G,S3}-V_{G,M1} < V_{T0n}$ → $V_{dd} - R^*I_{ref} - V_{G,M1} < V_{T0n}$ → $R^* > (V_{dd} - V_{ov1} - 2V_{T0n})/\ I_{ref}$

R* > 25 kΩ (> 20 kΩ if we chose $V_{ov1} = 0.4$ V).