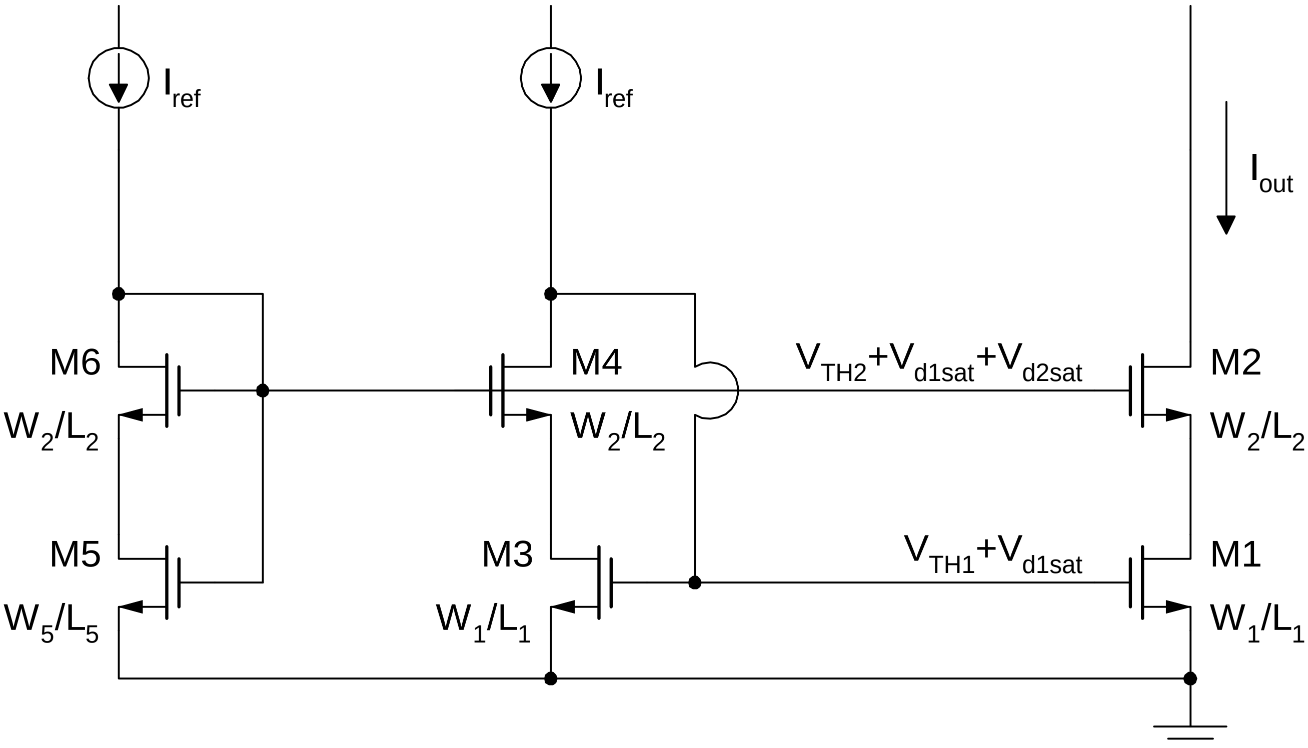
Reference:D:\Users\Bernhard\Lib\MathCAD\Default\defaults.mcd

# High-Swing Cascode Bias




Note: $V_{GS6} = V_{GS2} = V_{GS4}$

$V_{DS1} = V_{DS5}$

M5 is in triode

assume square-law

**Objective:** set $V_{DS5} = K \cdot V_{d1sat}$

where K is a function of device size ratios

KCL/KVL:

$$I_{D5} = \mu_n \cdot C_{ox} \cdot \frac{W_5}{L_5} \cdot \left( V_{GS5} - V_{TH1} - \frac{V_{DS5}}{2} \right) \cdot V_{DS5}$$

$$I_{D6} = \frac{1}{2} \cdot \mu_n \cdot C_{ox} \cdot \frac{W_2}{L_2} \cdot \left( V_{GS6} - V_{TH2} \right)^2$$

$$I_{D5} = I_{D6}$$

$$V_{GS5} = V_{GS6} + V_{DS5}$$

$$V_{GS6} = V_{TH2} + V_{d2sat}$$

hence

$$r_5 \cdot \left( \frac{V_{DS5}}{2} + V_{d2sat} + V_{TH2} - V_{TH1} \right) \cdot V_{DS5} = \frac{1}{2} \cdot r_2 \cdot \left( V_{d2sat} \right)^2$$

$$\Delta V_{TH} = V_{TH2} - V_{TH1}$$

$$r = \frac{r_5}{r_2}$$

given

$$r \cdot \left( V_{DS5} + 2 \cdot V_{d2sat} + 2 \cdot \Delta V_{TH} \right) \cdot V_{DS5} = V_{d2sat}{}^2$$

$$\text{find}\left(V_{d2sat}\right) \rightarrow \left[ r \cdot V_{DS5} + \left( r^2 \cdot V_{DS5}{}^2 + r \cdot V_{DS5}{}^2 + 2 \cdot r \cdot V_{DS5} \cdot \Delta V_{TH} \right)^{\left(\frac{1}{2}\right)} \quad r \cdot V_{DS5} - \left( r^2 \cdot V_{DS5}{}^2 + r \cdot V_{DS5}{}^2 + 2 \cdot r \cdot V_{DS5} \cdot \Delta V_{TH} \right)^{\left(\frac{1}{2}\right)} \right]$$

$$V_{d2sat} = r \cdot V_{DS5} \cdot \left( 1 + \sqrt{1 + \frac{1}{r} + \frac{2 \cdot \Delta V_{TH}}{r \cdot V_{DS5}}} \right)$$

check

given

$$x \cdot \left( 1 + \sqrt{1 + \frac{1}{x}} \right) = 1$$

$$\text{find}(x) \rightarrow \frac{1}{3}$$

should be 1/3

we need $V_{DS5} = K \cdot V_{d1sat}$

$$r_1 \cdot V_{d1sat}{}^2 = r_2 \cdot V_{d2sat}{}^2$$

hence

$$V_{d1sat} = V_{d2sat} \cdot \sqrt{\frac{r_2}{r_1}}$$

$$V_{d1sat} = V_{DS5} \cdot \left( \frac{r_5}{r_2} \right) \cdot \sqrt{\frac{r_2}{r_1}} \cdot \left( 1 + \sqrt{1 + \frac{1}{r} + \frac{2 \cdot \Delta V_{TH}}{r \cdot V_{DS5}}} \right)$$

$$V_{d1sat} = V_{DS5} \cdot \frac{r_5}{\sqrt{r_1 \cdot r_2}} \cdot \left( 1 + \sqrt{1 + \frac{r_2}{r_5} + \frac{2 \cdot \Delta V_{TH}}{r \cdot V_{DS5}}} \right)$$

ignoring body-effect:

$$V_{d1sat} = V_{DS5}\cdot\frac{r_5}{\sqrt{r_1\cdot r_2}}\cdot\left(1+\sqrt{1+\frac{r_2}{r_5}}\right)$$

$$V_{d1sat} = V_{DS5}\cdot\frac{W_5}{L_5}\cdot\sqrt{\frac{L_1\cdot L_2}{W_1\cdot W_2}}\cdot\left(1+\sqrt{1+\frac{W_2}{L_2}\cdot\frac{L_5}{W_5}}\right)$$

Problem: for $L_1 \neq L_2$ end up with ratios of channel length, no matter the choice of $L_5$

given

$$\frac{1}{K} = \frac{r_5}{\sqrt{r_1\cdot r_2}}\cdot\left(1+\sqrt{1+\frac{r_2}{r_5}}\right)$$

$$find(r_5) \rightarrow \left[\frac{1}{\left[2\cdot\left(-4\cdot r_1+K^2\cdot r_2\right)\right]}\cdot\left[2\cdot r_2\cdot K+4\cdot\left(r_1\cdot r_2\right)^{\left(\frac{1}{2}\right)}\right]\cdot\frac{r_1}{K} \quad \frac{1}{\left[2\cdot\left(-4\cdot r_1+K^2\cdot r_2\right)\right]}\cdot\left[2\cdot r_2\cdot K-4\cdot\left(r_1\cdot r_2\right)^{\left(\frac{1}{2}\right)}\right]\cdot\frac{r_1}{K}\right]$$

$$r_5(K,r_1,r_2) := r_1\cdot\frac{K\cdot r_2+2\cdot\sqrt{r_1\cdot r_2}}{K\cdot\left(4\cdot r_1+K^2\cdot r_2\right)}$$

(ugly) $V_{DS1} = K\cdot V_{d1sat}$

## *Examples:*

$L_2 := 0.25, 0.5 .. 1$

$r_5\left(2,\frac{100}{1},\frac{100}{L_2}\right) =$

| |
|---|
| 30 |
| 28.452 |
| 26.658 |
| 25 |

$r_5\left(2,\frac{10}{1},\frac{10}{L_2}\right) =$

| |
|---|
| 3 |
| 2.845 |
| 2.666 |
| 2.5 |

for large K=2, $(W/L)_5$ is fairly ***in***sensitive to L2

$r_5\left(1.2,\frac{100}{1},\frac{100}{L_2}\right) =$

| |
|---|
| 75.137 |
| 63.329 |
| 55.031 |
| 49.02 |

$r_5\left(1.2,\frac{10}{1},\frac{10}{L_2}\right) =$

| |
|---|
| 7.514 |
| 6.333 |
| 5.503 |
| 4.902 |

for small K=1.2, $(W/L)_5$ is fairly sensitive to L2

**Conclusion:** large K for insensitivity to process variations and mismatch. Well, we knew that already!