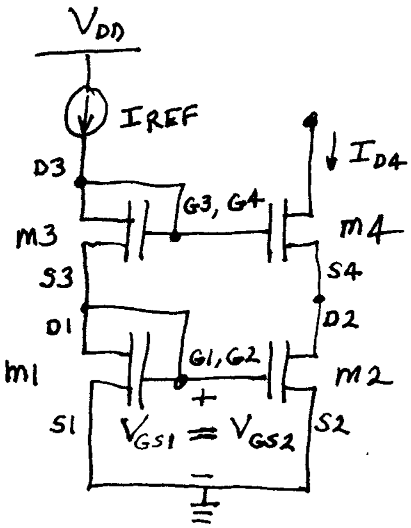
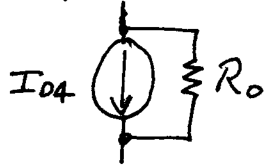
Cascode Connection of 2 Current Mirrors (20.1.1)



MOTIVATION: Increase Output resistance (R_o)

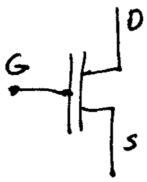
Make a more ideal current source.

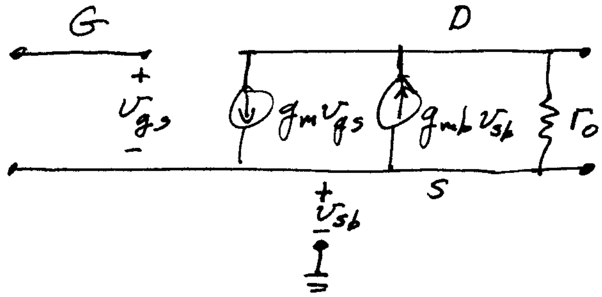


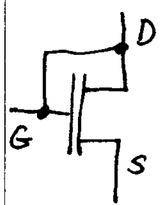
Drawback: Reduced output voltage swing.

OUTPUT RESISTANCE (low f)

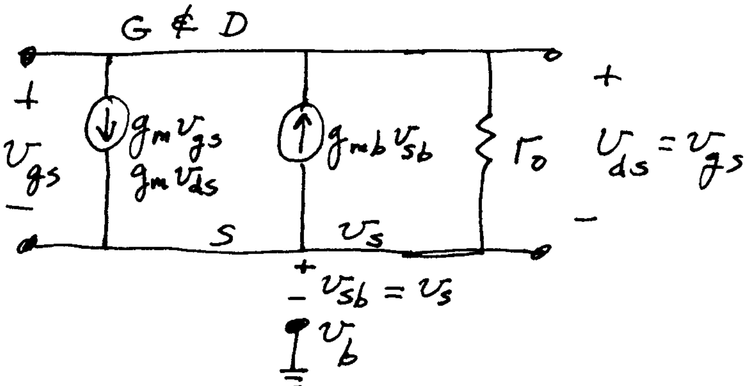
QUICK REVIEW

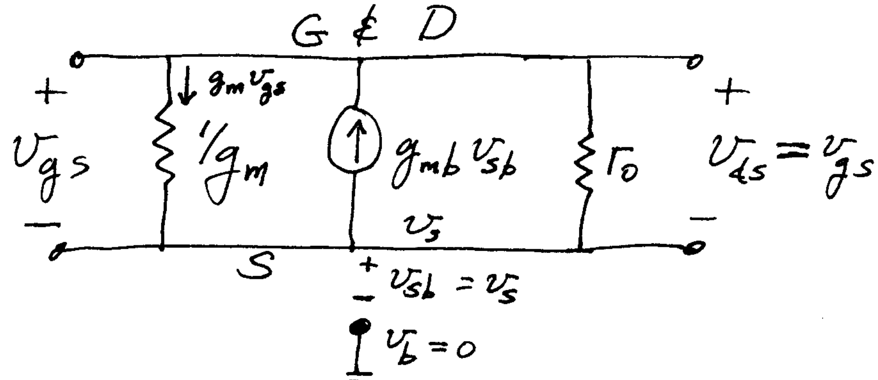






DIODE CONNECTED FET
D = G

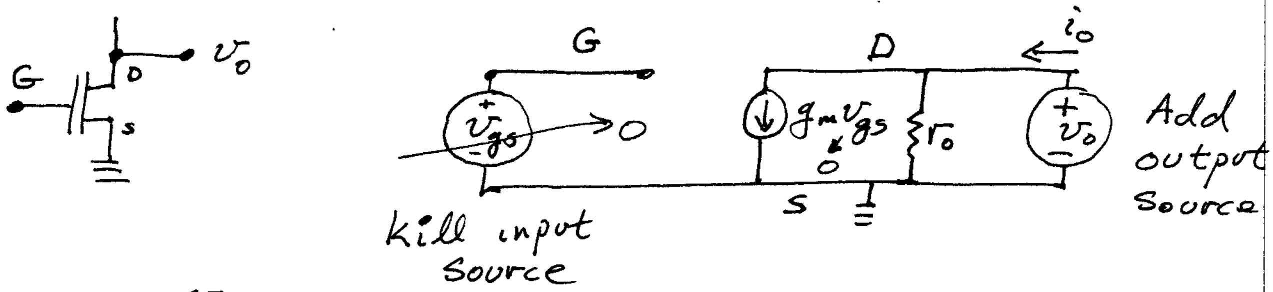




CALCULATING OUTPUT RESISTANCE

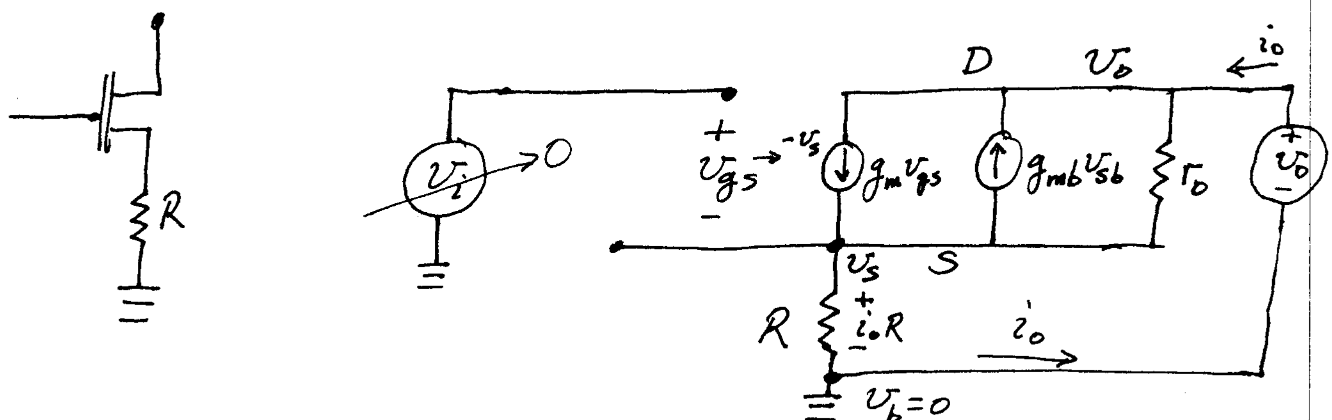
1. "Kill" any input ac sources:
   a. Short ac v- sources.
   b. Open ac I-sources.
2. Apply ac voltage (current) source at output
3. Calculate current (voltage) at output.
4. Ratio is output resistance v_o / i_o.

Common SOURCE Output resistance (R_o)



$$R_o = \frac{v_o}{i_o} = r_o$$

Common SOURCE with SOURCE Degeneration



KCL at drain:

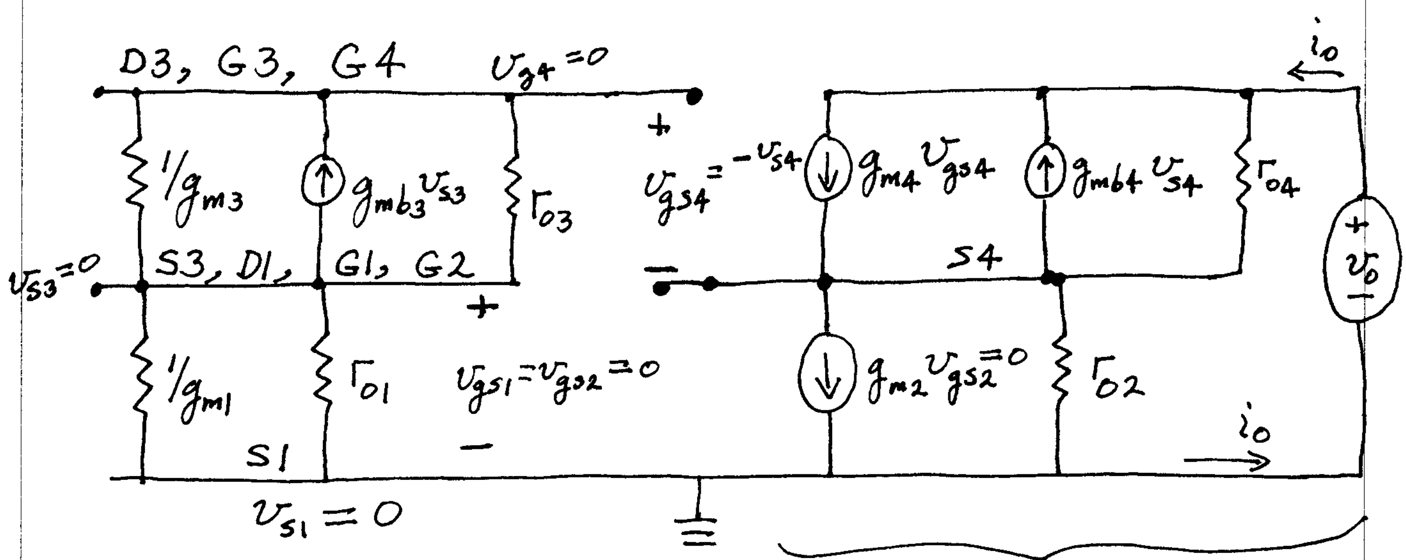
$$i_o - \frac{v_o - v_s}{r_o} + \underbrace{g_{mb}}_{\chi g_m} v_s + g_m v_s = 0$$

$$v_s = i_o R$$

$$i_o + i_o \frac{R}{r_o} + g_m(1+\chi)\, i_o R = \frac{v_o}{r_o}$$

$$\boxed{\frac{v_o}{i_o} = r_o + R + g_m(1+\chi) R r_o = R_{OUT}}$$

SMALL SIGNAL EQUIVALENT CIRCUIT OF CASCODE CURRENT MIRROR p. L4.1



$$\boxed{R_{out} = r_{o4} + r_{o2} + g_{m4}(1+\chi)\, r_{o4}\, r_{o2}}$$

This term dominates. $\gg r_o$

$g_m r_o$ is the gain (a_v) of a common source FET $\gg 1$

$$R_{out} \approx g_{m4}(1+\chi)\, r_{o4}\, r_{o2} \gg r_o$$

$R_{OUT} \approx g_{m4}\, r_o^2$. FOR simple current mirror, $R_{OUT} = r_o$.

STACK 3 high Fig. 20.9

$$R_{o3} = r_o + R_{OUT,2} + g_m(1+\chi)\, r_o\, R_{OUT,2}$$

$$R_{o3} \approx g_m^2\, r_o^3$$

BENEFIT INCREASED R_{OUT}

DRAWBACK REDUCED V_{D4} swing to keep M4 in saturation.

MINIMUM V_{D4} for M4 to stay in saturation?

$$V_{DS4} \geq V_{GS4} - V_{TH}$$

Choose (as before) $V_{GS1} = V_{GS2} = V_{GS3} = V_{GS4} = 1.2V$

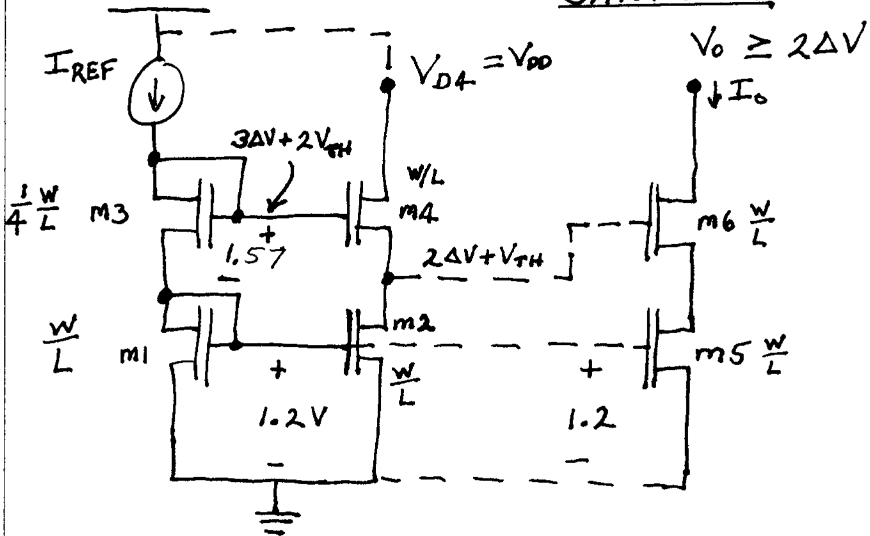
$$V_{DS4} \geq V_{GS4} - V_{TH} = 1.2 - 0.83 = 0.37 \equiv \Delta V$$

ΔV is referred to as the excess gate voltage.

$$V_{D4} \geq \Delta V + V_{D2} = 0.37 + 1.2 = \boxed{1.57\ V}$$ (LARGE)

(The minimum for the current mirror is $\Delta V = 0.37$ V.)

REDUCING MIN V_o for SATURATION



Dotted lines: Reduce $V_o \geq 2\Delta V$

where $\Delta V = V_{GS} - V_{TH}$.

- Reduce $\frac{W}{L}$ of M3 to $\frac{1}{4}\frac{W}{L}$
- $I_{REF} = \frac{1}{4} KP \frac{W}{L} (V_{GS3} - V_{THN})^2 = KP \frac{W}{L} (\underbrace{V_{GS1}}_{1.2V} - V_{TH})^2$

$$V_{GS3} - V_{TH} = 2(V_{GS1} - V_{TH}) = 2\Delta V$$

where $\Delta V = 0.37$ as before.

$$V_{GS3} = 2\Delta V + V_{TH} = 2(0.37) + 0.83 = 1.57\ V$$

$$V_{G3} = V_{GS3} + V_{GS1} = 2\Delta V + V_{TH} + (V_{GS1} - V_{TH}) + V_{TH}$$
$$= 3\Delta V + 2V_{TH}$$

$$V_{G3} = 3\Delta V + 2V_{TH}$$

- $V_{S4} = V_{G6} = V_{G3} - V_{GS3} = 3\Delta V + 2V_{TH} - (\Delta V + V_{TH})$

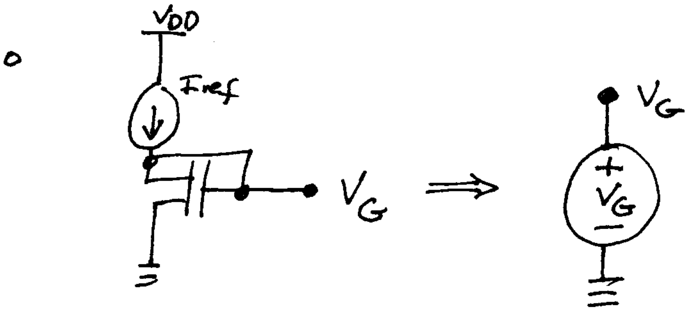
  $V_{G6} = 2\Delta V + V_{TH}$

- $V_{S6} = V_{G6} - V_{GS1} = 2\Delta V + V_{TH} - (\Delta V + V_{TH}) = \Delta V = 0.37\,V$

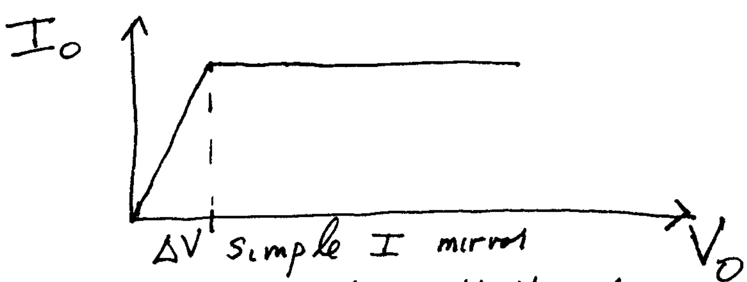
$\therefore\; V_{D6} = V_o \geq 2\Delta V = 0.74\ V$

NOTE

- M4 is used to drop down the gate voltage on M6 by $V_{GS} = 1.2\,V$.

- 

Acts like a constant voltage source.

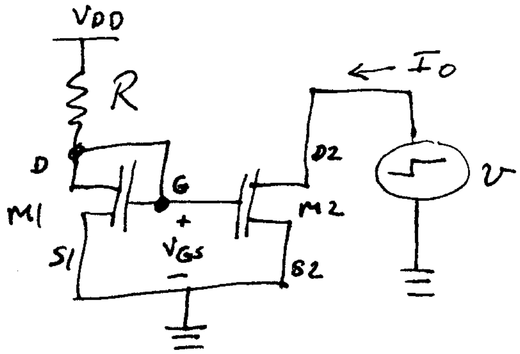


ΔV Simple I mirror

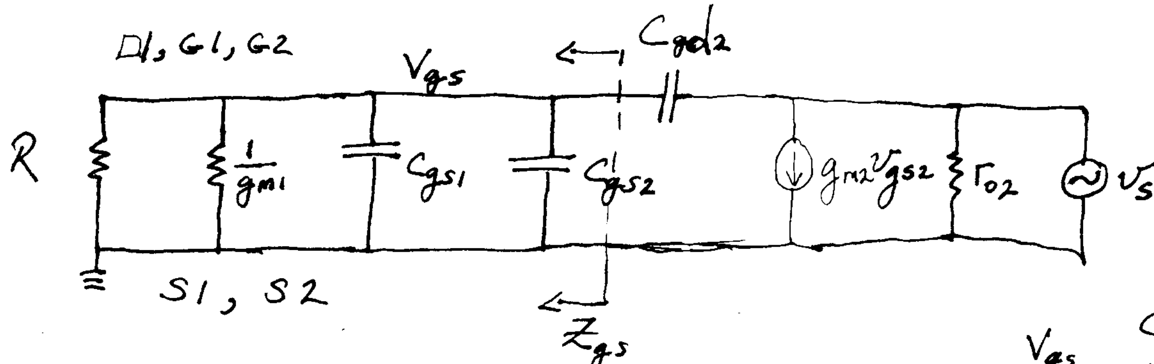
$2\Delta V$ Cascode with V_o reduction

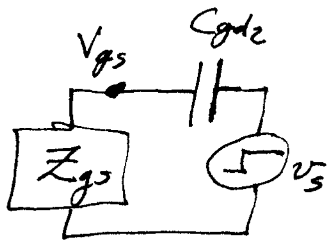
$2\Delta V + V_{TH}$ Cascode

TRANSIENT RESPONSE of CURRENT MIRROR



Small SIGNAL





$$Z_{gs} = \frac{R \| \frac{1}{g_{m1}}}{1 + j\omega R \| \frac{1}{g_{m1}} (C_{gs1} + C_{gs2})}$$

$$v_{gs} = v_s \frac{Z_{gs}}{Z_{gs} + \frac{1}{j\omega C_{gd2}}} =$$

$$= v_s \frac{1}{1 + \dfrac{1 + j\omega R_{eq}(C_{gs1} + C_{gs2})}{j\omega R_{eq} C_{gd2}}} \qquad R_{eq} \equiv R \| \frac{1}{g_m}$$

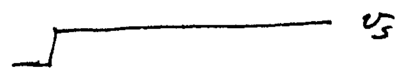
$$v_{gs} = v_s \frac{j\omega R_{eq} C_{gd2}}{1 + j\omega R_{eq}(C_{gs1} + C_{gs2} + C_{gd2})}$$

For instaneous v_s (i.e. $\omega \to \infty$)

$$v_{gs} = v_s \frac{C_{gd2}}{C_{gs1} + C_{gs2} + C_{gd2}}$$

$$i_o = g_{m2} v_{gs}$$

Now v_s is held fixed
i.e. DC.
$\omega = 0$



How long does it take V_{gs} to decay to DC value V_{GS}?

1) FOR $v_s < 0$, $v_{gs} < 0$. Current flows thru R to recharge gate node to V_{GS} (DC Value).

$$\Rightarrow \tau = RC = R(C_{gs1} + C_{gs2} + C_{gd2})$$

2) For $v_s > 0$, $v_{gs} > 0$. Current flows thru $1/g_m$ to discharge gate node to V_{GS}.

$$\tau = \frac{1}{g_m}(C_{gs1} + C_{gs2} + C_{gd2})$$