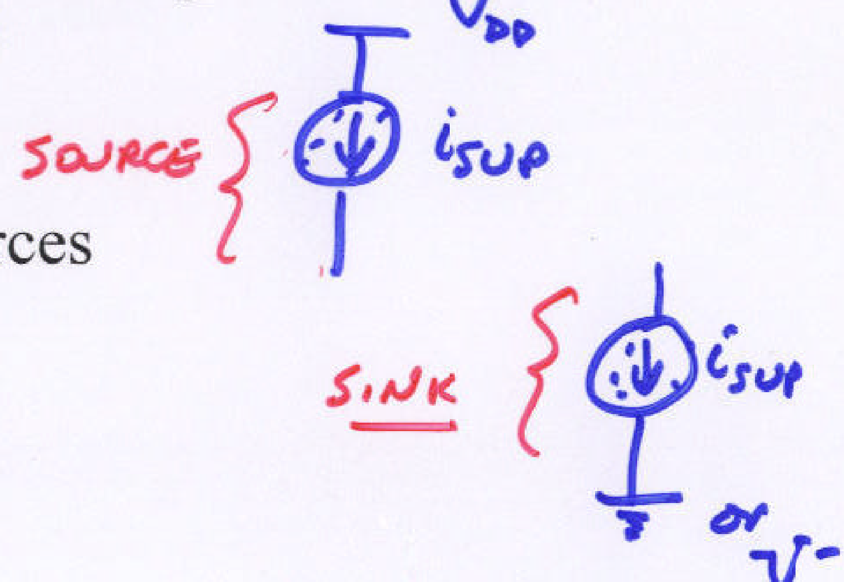
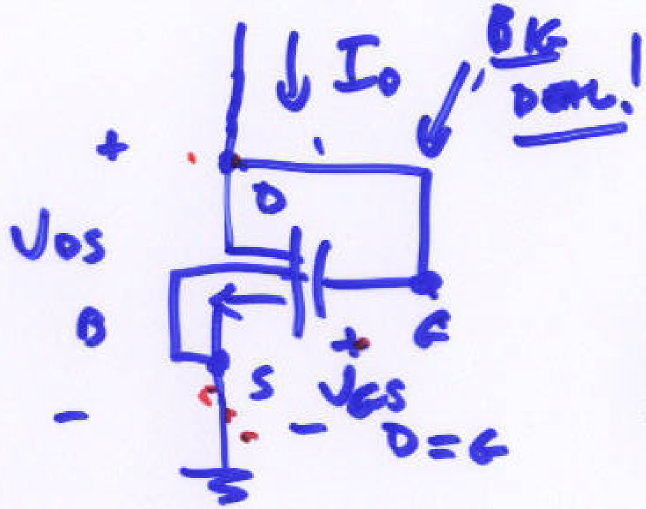
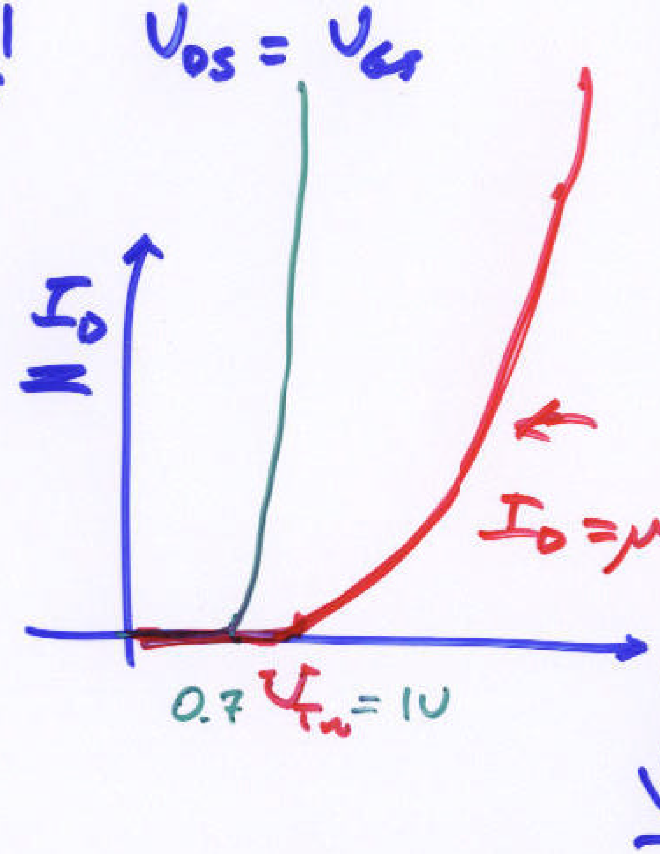
R. T. Howe

Lecture 33

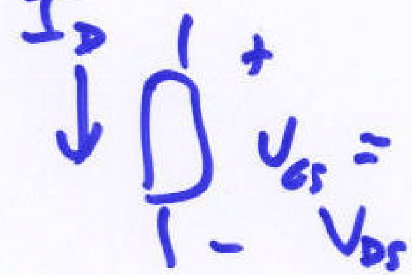
- Last time:
  - Frequency response of voltage and current buffers
  - Voltage/Current sources using MOS transistors § 9.4
- Today : FUN/EASY
  - Improved current sources
  - Current mirrors







$I_D = \mu_n C_{ox} \left(\frac{W}{2L}\right) \cdot (V_{GS} - V_{TN})^2$



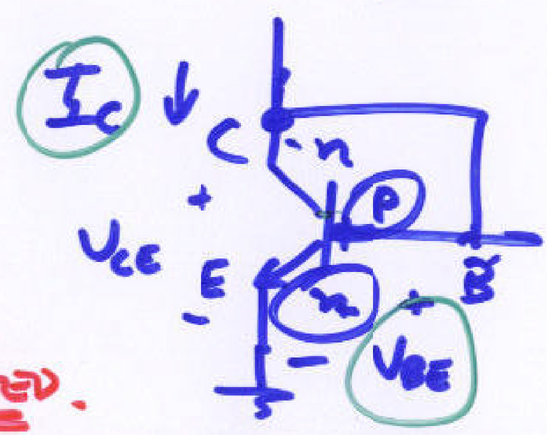
$V_{GS} = V_{DS} < V_T$

$\Rightarrow$ OFF

$I_D = 0$

$V_{DS} \overset{?}{\gtrless} V_{GS} - V_{TN}$ TEST

= $\Rightarrow$ SATURATED.

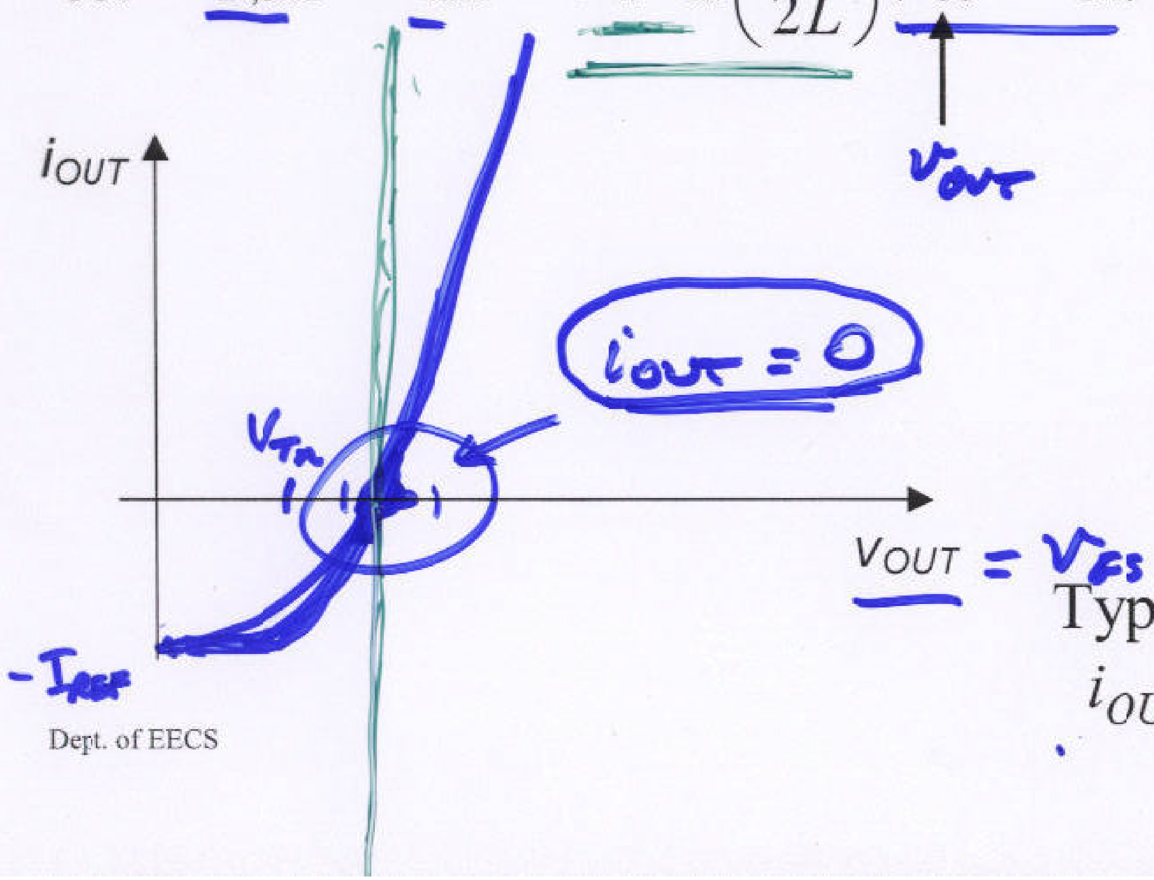


Modeling the Voltage Source

- Find i_{OUT} versus v_{OUT} MOSFET is off or saturated: why?

"(1+ε)"

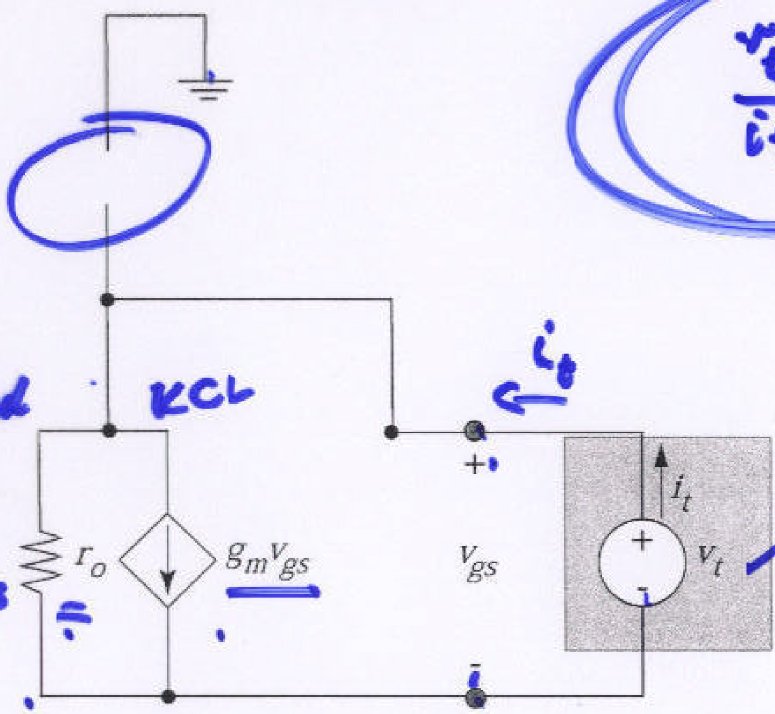
$$i_{OUT} = i_{D,SAT} - I_{REF} = \mu_n C_{ox}\left(\frac{W}{2L}\right)(v_{GS} - V_{Tn})^2(1 + \lambda_n v_{DS}) - I_{REF}$$



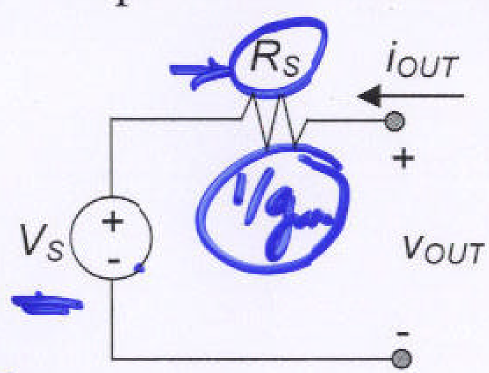
Typical operating point: $i_{OUT} = 0$ A

Small-Signal Source Resistance

$$R_S = \left(\left. \frac{di_{OUT}}{dv_{OUT}} \right|_{I_{OUT}=0} \right)^{-1} = \frac{v_t}{i_t}$$



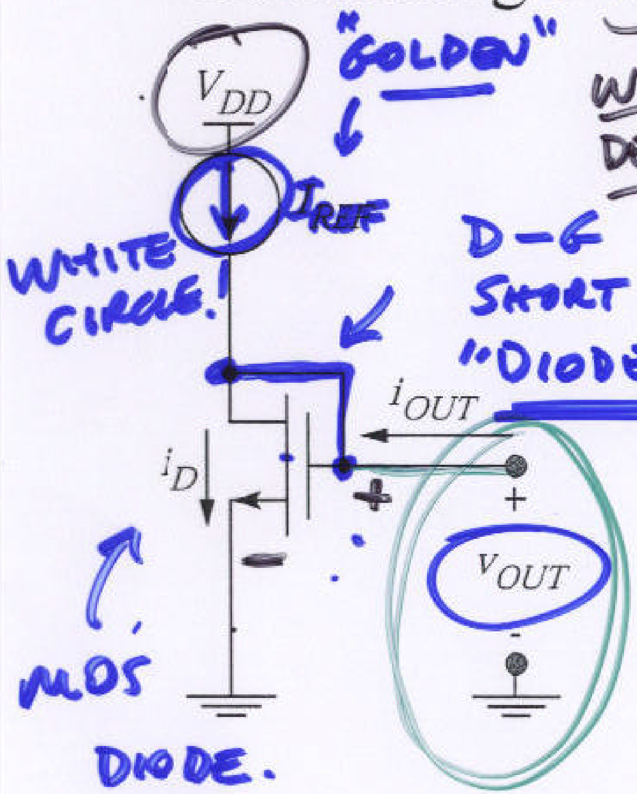
Equivalent Circuit:



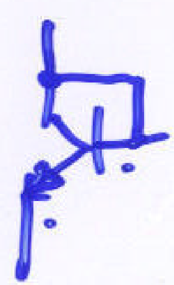
• Multi-Stage Amplifiers: Chap. 9

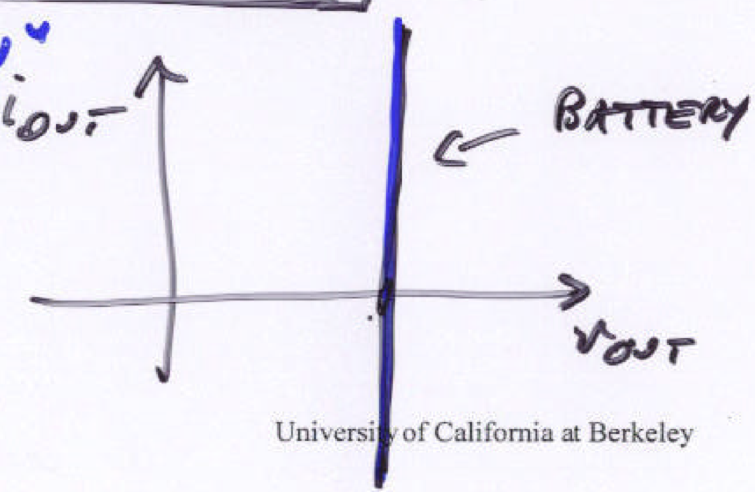
- First topic: voltage and current sources (9.4)
- Generating a voltage: use a current source to set V_{GS} (or V_{BE})

"GOLDEN" WE DEFINE.

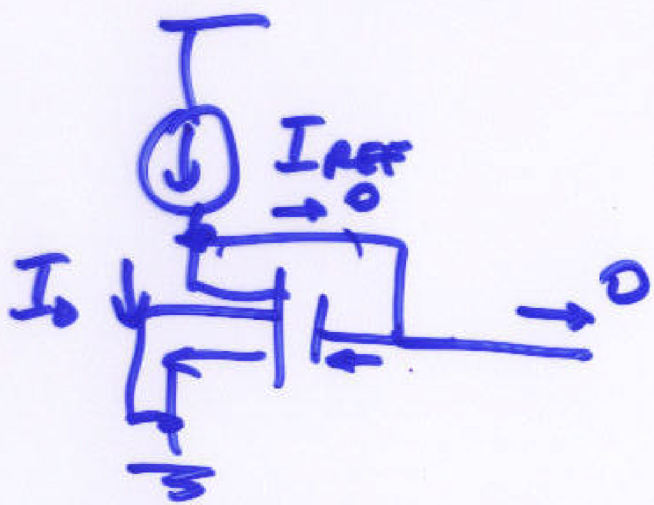


$I_{DSAT} \leftrightarrow V_{GS}.$

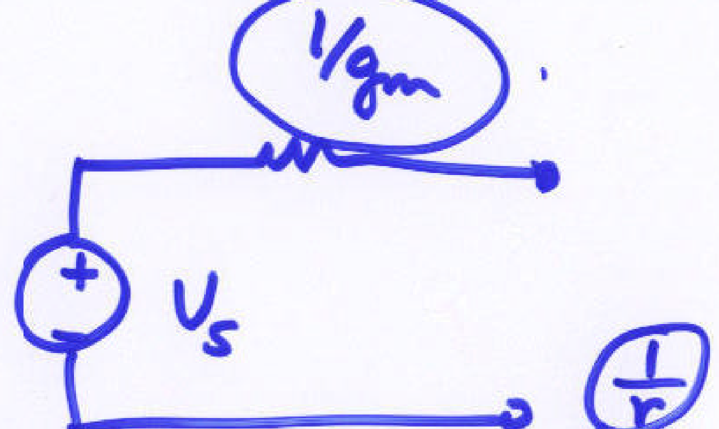


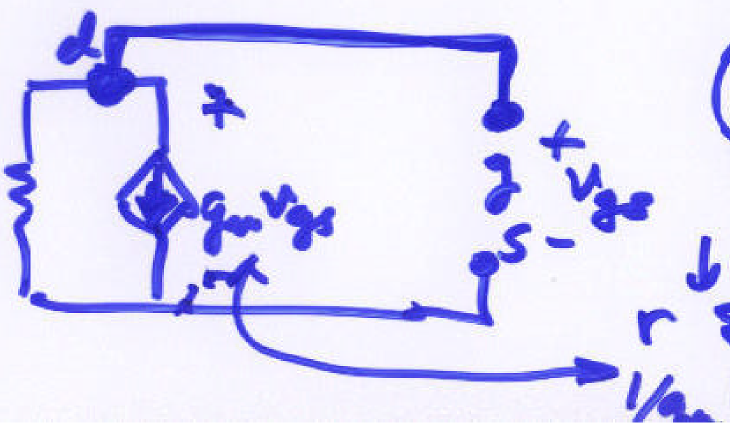


$$\left. V_{OUT} \right|_{I_{OUT}=0} = \underline{V_{Tn}} + \sqrt{\frac{2 I_{REF}}{(W/L)\,\mu_n C_{ox}}} \quad \leftarrow V_S'$$



$I_D = I_{REF}$ FOR $I_{OUT} = 0$.





$\frac{1}{r}$

$v/r = gv$

YES! $\mu_{n1} = \mu_{n2}$, $V_{T1} = V_{T2}$, $C_{ox1} = C_{ox2}$

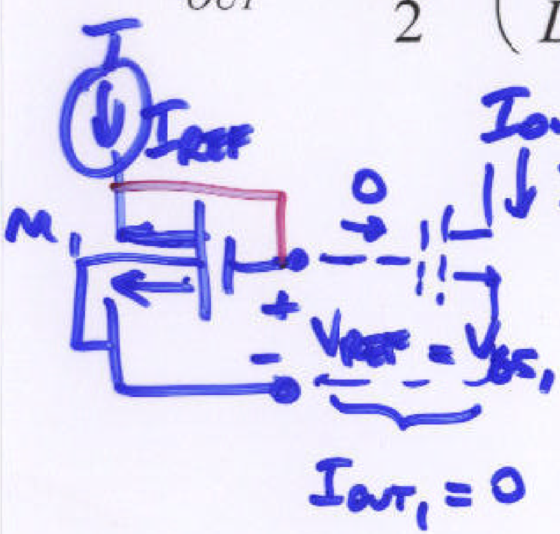
Equivalent Circuit for *I*-Source

Find the DC current for "gray circle" equivalent circuit

- NEGLECT $(1 + \lambda_n V_{DS2})$ HERE.

$$I_{OUT} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_2 (V_{REF} - V_{Tn})^2$$

Substitute for V_{REF}



$$V_{REF} = V_{GS1} = \left(V_{Tn1} + \sqrt{\frac{2 I_{REF}}{(W/L)_1 \mu_n C_{ox}}}\right)$$

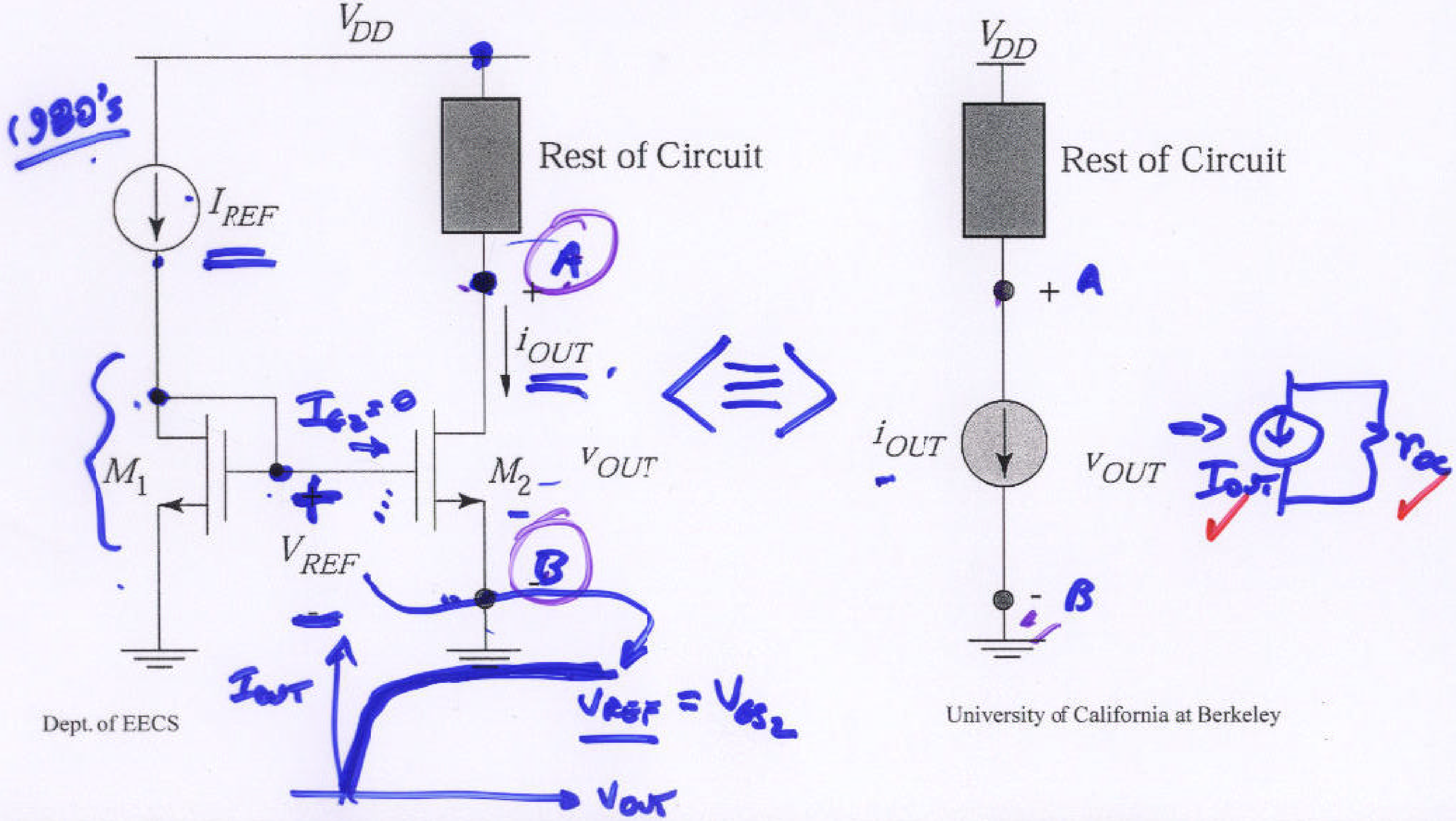
$$I_{OUT} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_2 \left\{V_{Tn1} + \sqrt{(\cdot)} - V_{Tn2}\right\}^2$$

$$= \frac{\mu_n C_{ox2}}{2}\left(\frac{W}{L}\right)_2 \left\{\frac{2 I_{REF}}{(W/L)_1 \mu_n C_{ox1}}\right\}$$

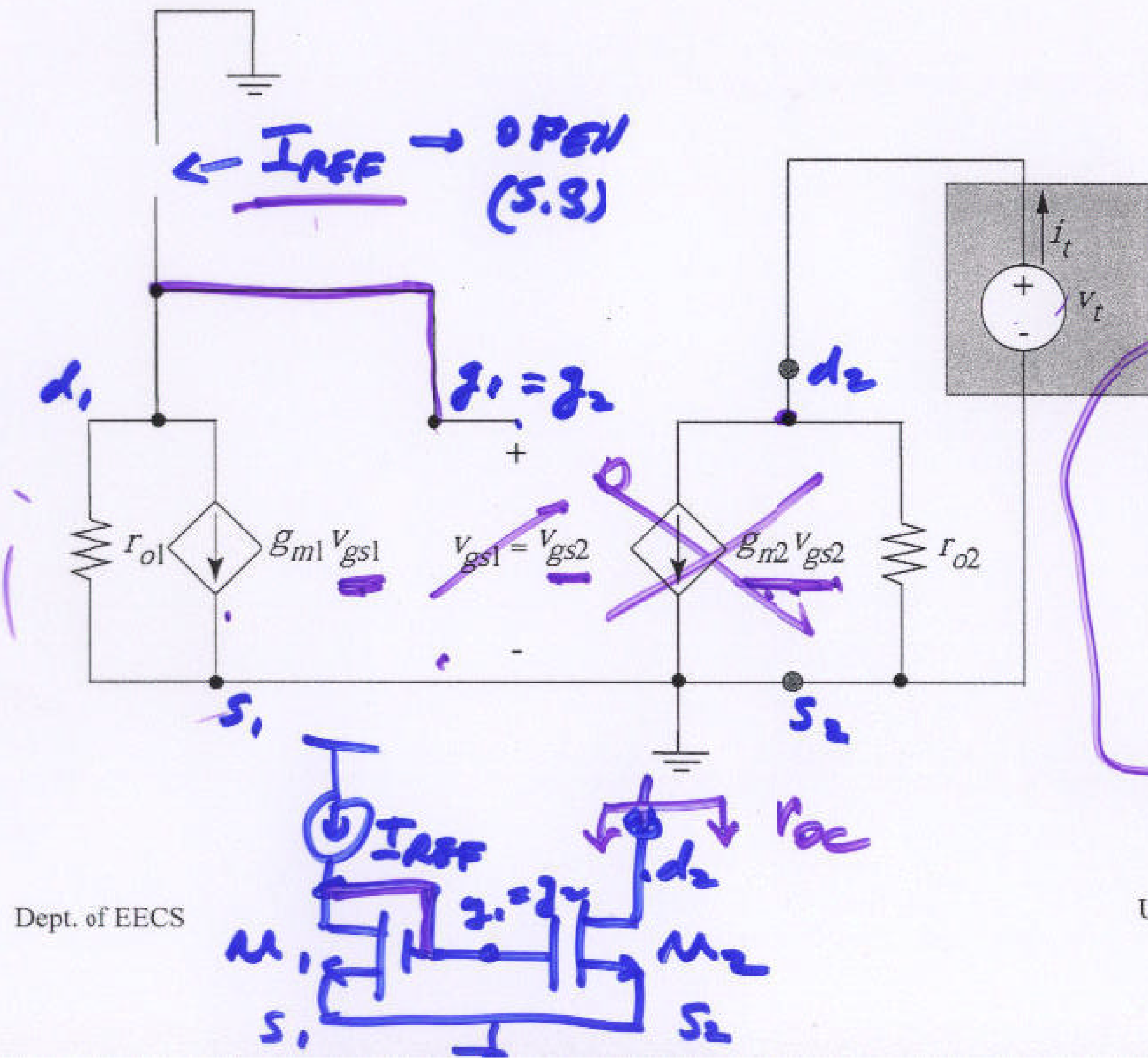
$$I_{OUT} = I_{D2} = I_{REF}\left\{\frac{(W/L)_2}{(W/L)_1}\right\}$$

PICK $L_1 = L_2$

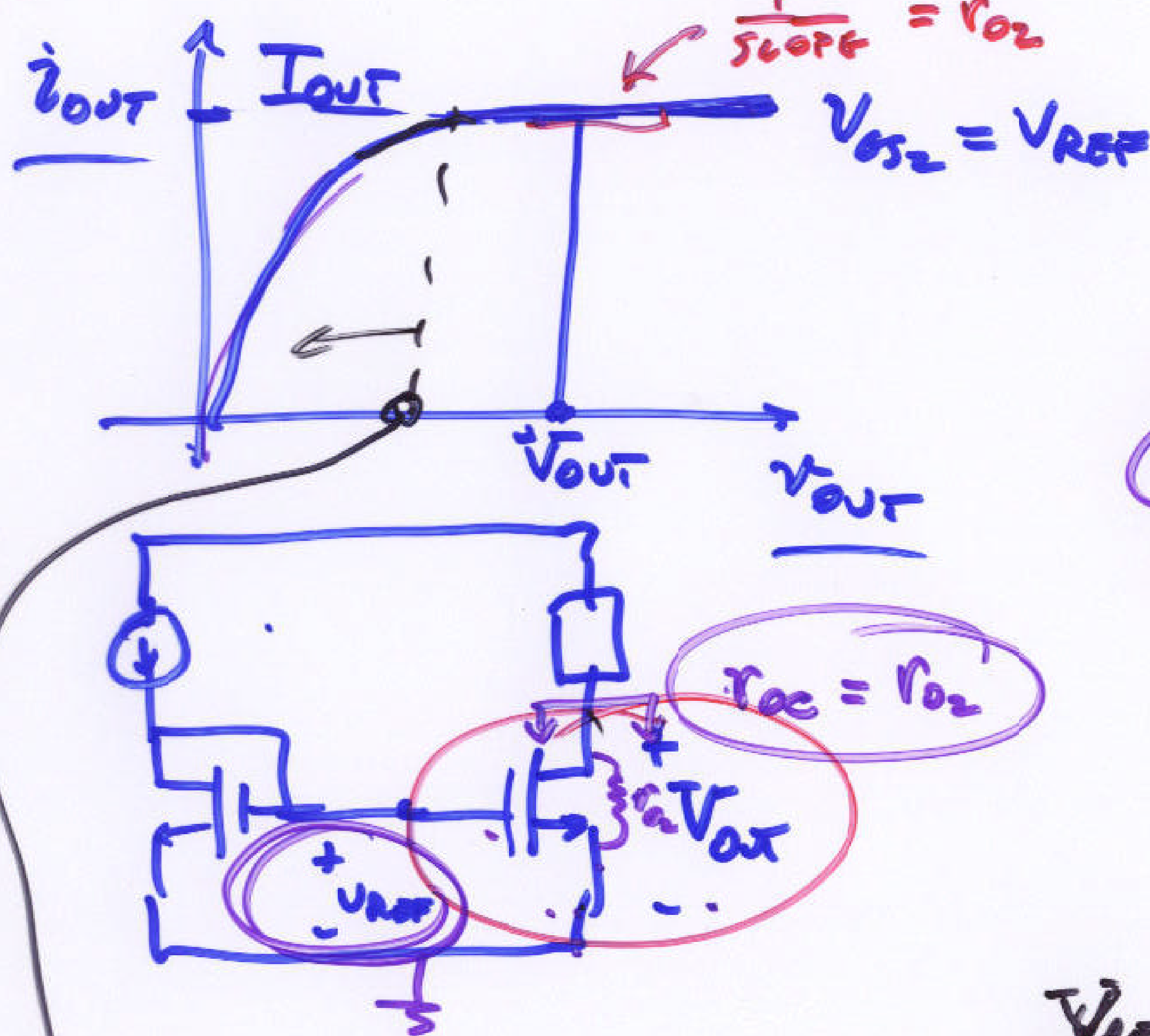
Using a Voltage Source to Make a Current Source

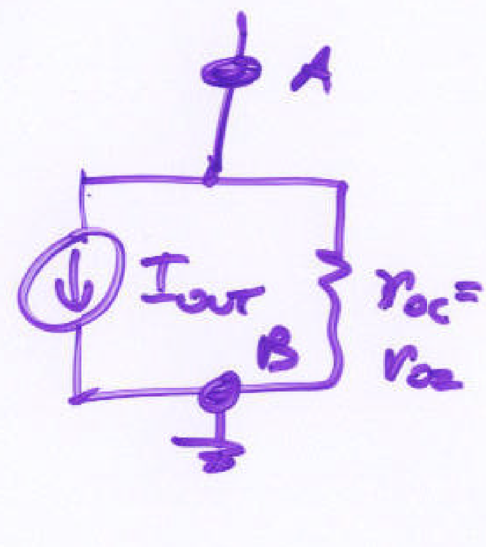


Small-Signal Resistance of *I*-Source (r_{oc})



$$r_{oc} = \frac{v_t}{i_t} = r_{o2}$$





$\underline{\underline{V_{REF}}}$

$$V_{OUT_{min}} = V_{DS_{SAT}} = V_{GS_2} - V_{Tn} \approx 0.5V$$

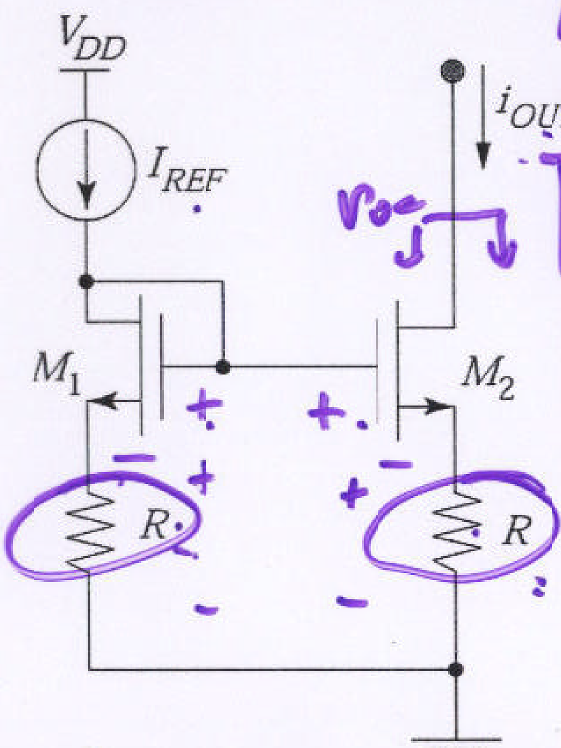
$r_{o2} = \frac{1}{\lambda_n I_{OUT}}$ r_{o2} ... BIG (100's of kΩ) NOT HUGE!

Improved Current Sources

Goal: increase r_{oc} ← 1 MΩ, 5 MΩ, 100 MΩ !!

Approach: look at *amplifier* (?) output resistance results

IDEA ... … to see topologies that boost resistance



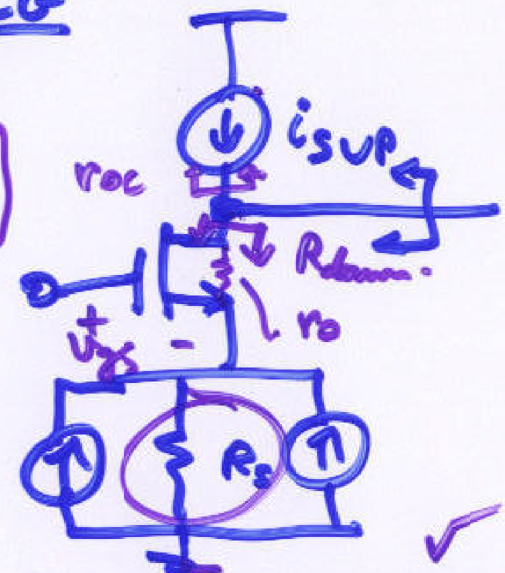
LARGE I_{OUT}
LARGE r_{oc}

$R_{down} = r_{o2}(1 + g_{m2}R)$

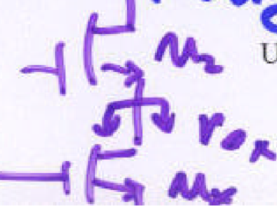
R = 10 kΩ
R = 100 kΩ.
R = 500 kΩ
TOO BIG!

• SYMMETRY ... R ON BOTH SIDES!

CG

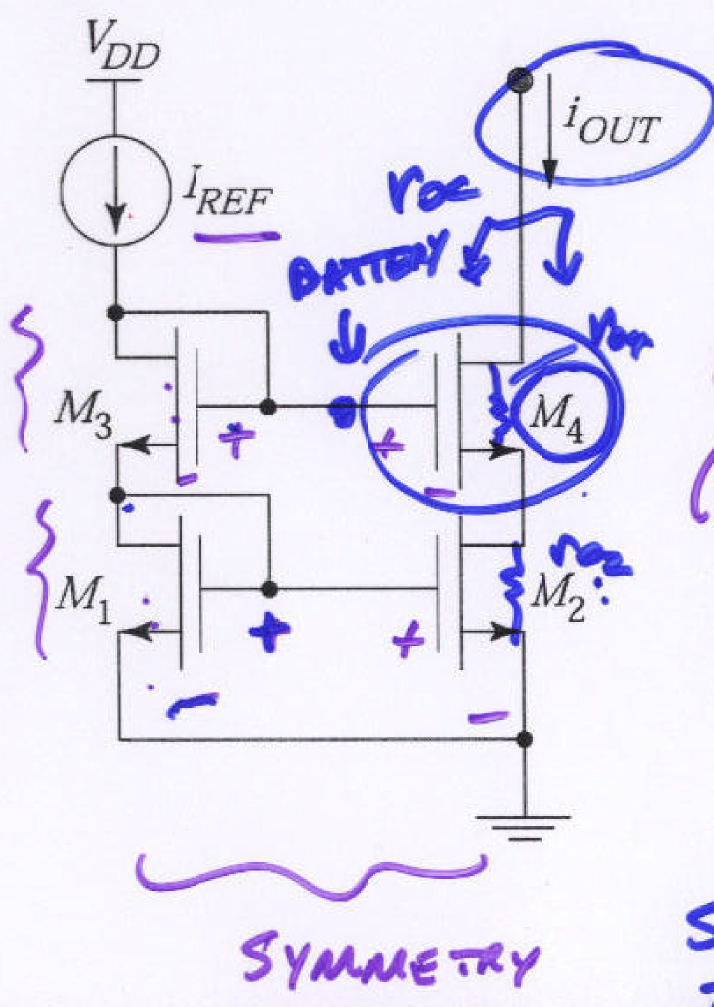


$R_{out_{CG}} = r_{oc} \,||\, r_o(1 + g_m R_S)$



$R_{up} \,||\, R_{down}$

"Cascode" (or Stacked) Current Source



Insight: V_{GS2} = constant AND
V_{DS2} = constant

Small-Signal Resistance r_{oc}:

$(W/L)_2 / (W/L)_1 =$
$(W/L)_4 / (W/L)_3$

100...

$r_{oc} = \frac{v_t}{i_t} \cong r_{o4}(1 + g_{m4} \cdot r_{o2})$

"R_{down}" from C.G. TABLE (R_{out})

SIMPLE I-SOURCE