Lecture 34

- Last time:
  - Improved current sources and current mirrors
  - Start multistage amplifiers
- Today :
  - More examples of cascades
  - DC coupling issues

"STACKED"

Drawback of Cascode *I*-Source

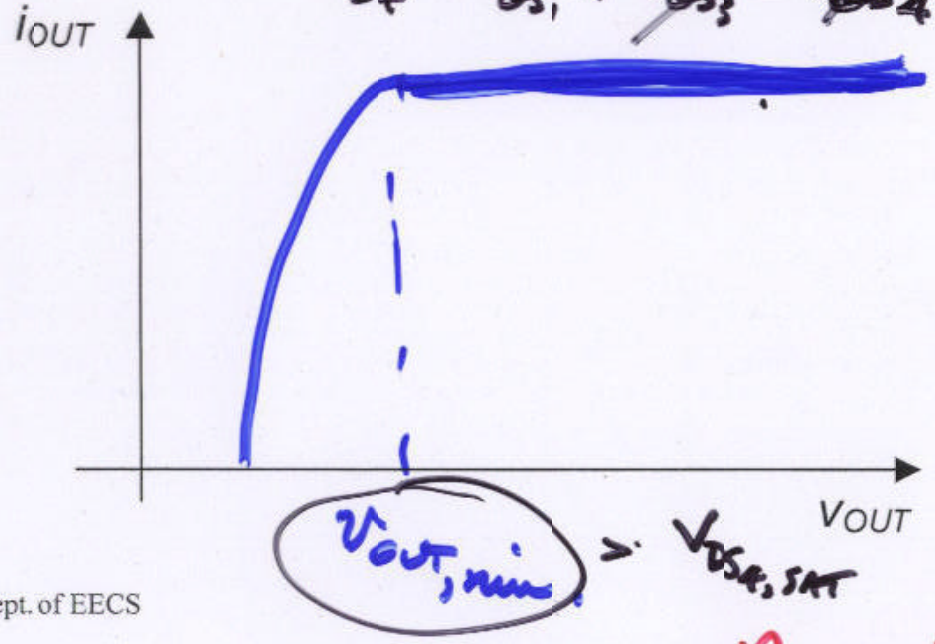
Minimum output voltage for all transistors saturated:

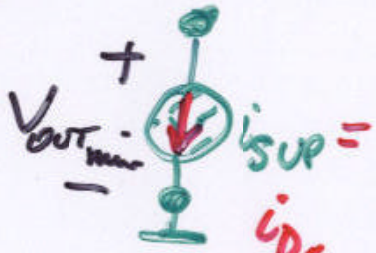
SET BY "BATTERIES"

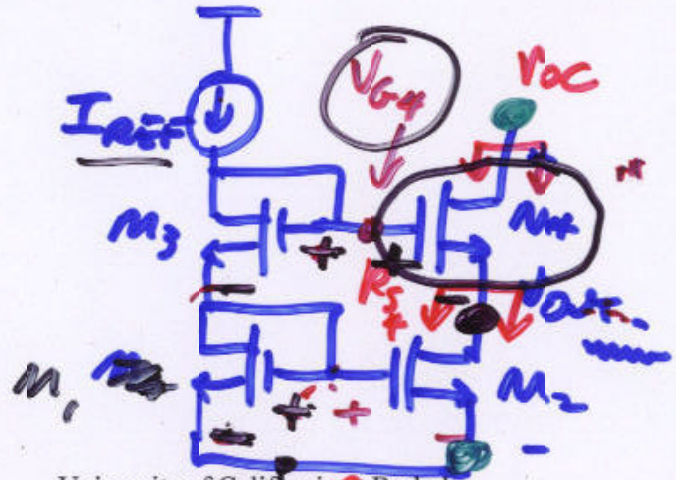
$$V_{OUT,MIN} = V_{DS4,SAT} + V_{S4} = V_{DS4,SAT} + V_{GS1}$$

$$V_{S4} = V_{GS1} + V_{GS3} - V_{GS4} = V_{GS1}$$

$$= V_{T1} + \sqrt{(\cdot)}\,V_{4}$$

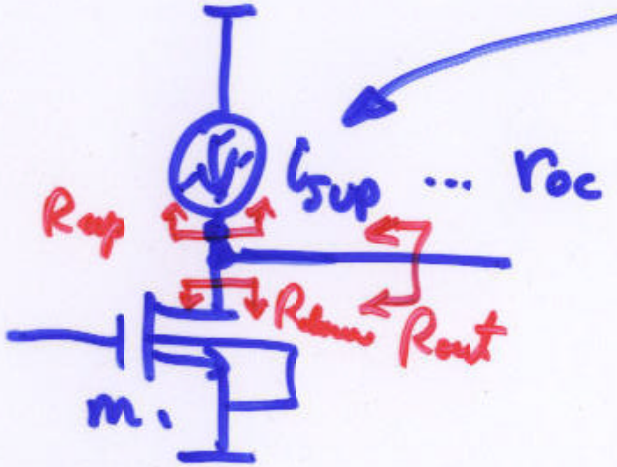




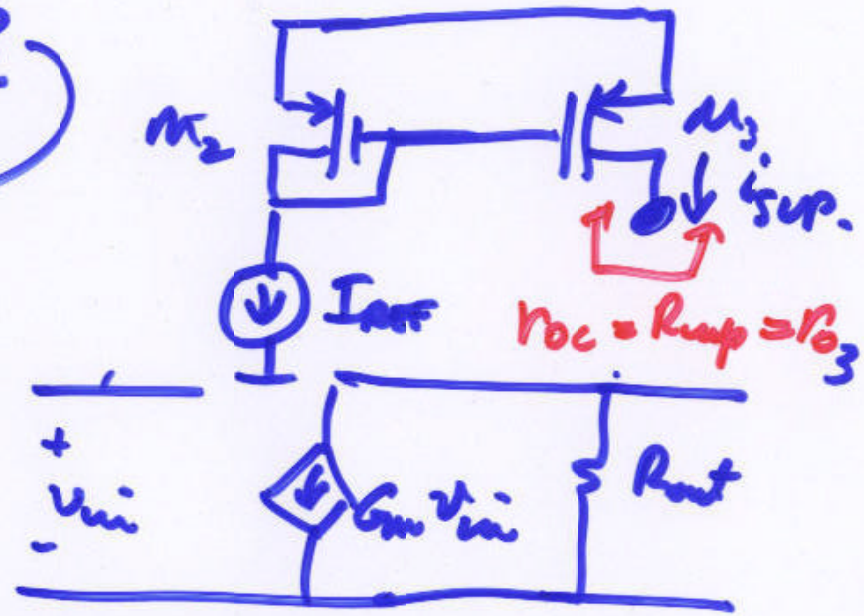


$$r_{oc} = r_{o4}(1 + g_{m4}R_{S4}) = r_{o4}(1 + g_{m4}r_{o2})$$

• WHAT'S GOOD ENOUGH ?



CS



$R_{out} = r_o \| r_{oc}$ $r_{oc} >> r_o$ ... $R_{out} \approx r_o$.

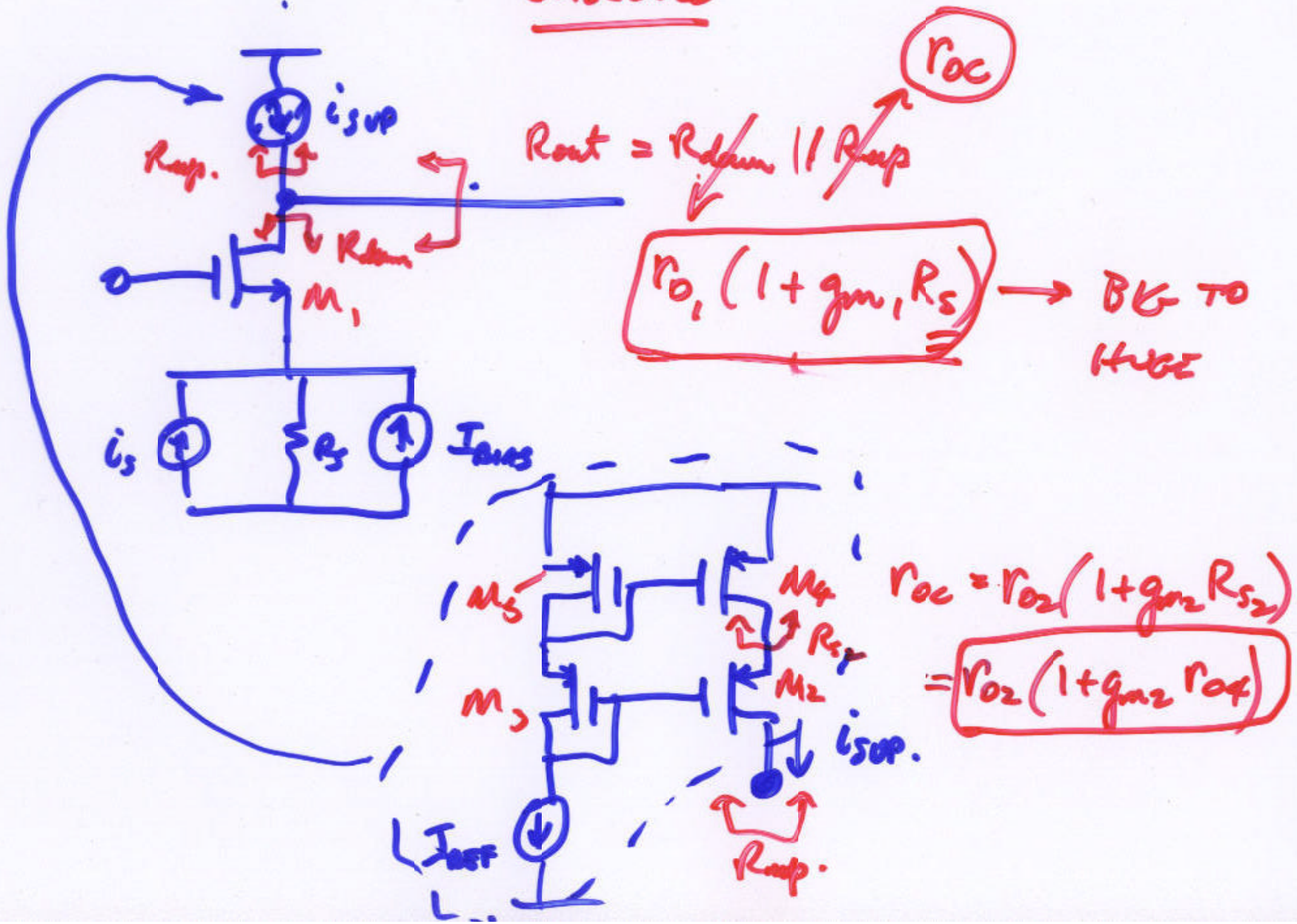
$= R_{down} \| R_{up}$.

$$r_o = \frac{1}{\lambda_n I_D}$$

$$= \frac{1}{\lambda_n I_{sup}} \approx 100\text{'s of } k\Omega. \text{ (MODERATELY LARGE)}$$

USE SIMPLE/ BASIC I-SUPPLY.

CG STAGE ... NEED CASCODE



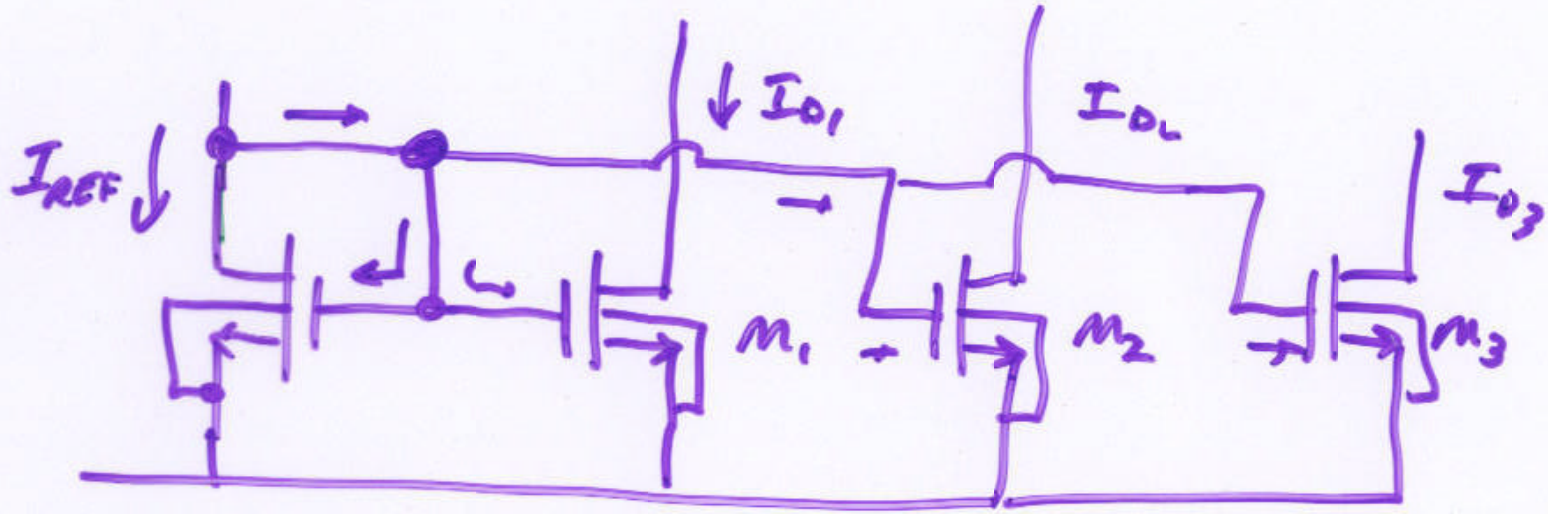
$R_{out} = R_{down} \parallel R_{up}$

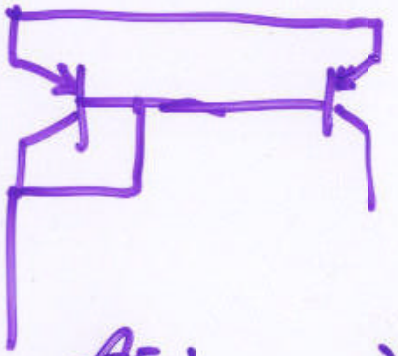
r_{OC}

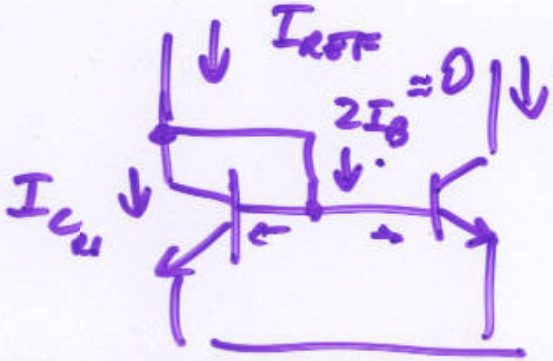
$r_{O_1}(1 + g_{m_1} R_S)$ → BIG TO HUGE

$r_{OC} = r_{O2}(1 + g_{m2} R_{S2})$

$= r_{O2}(1 + g_{m2} r_{O4})$





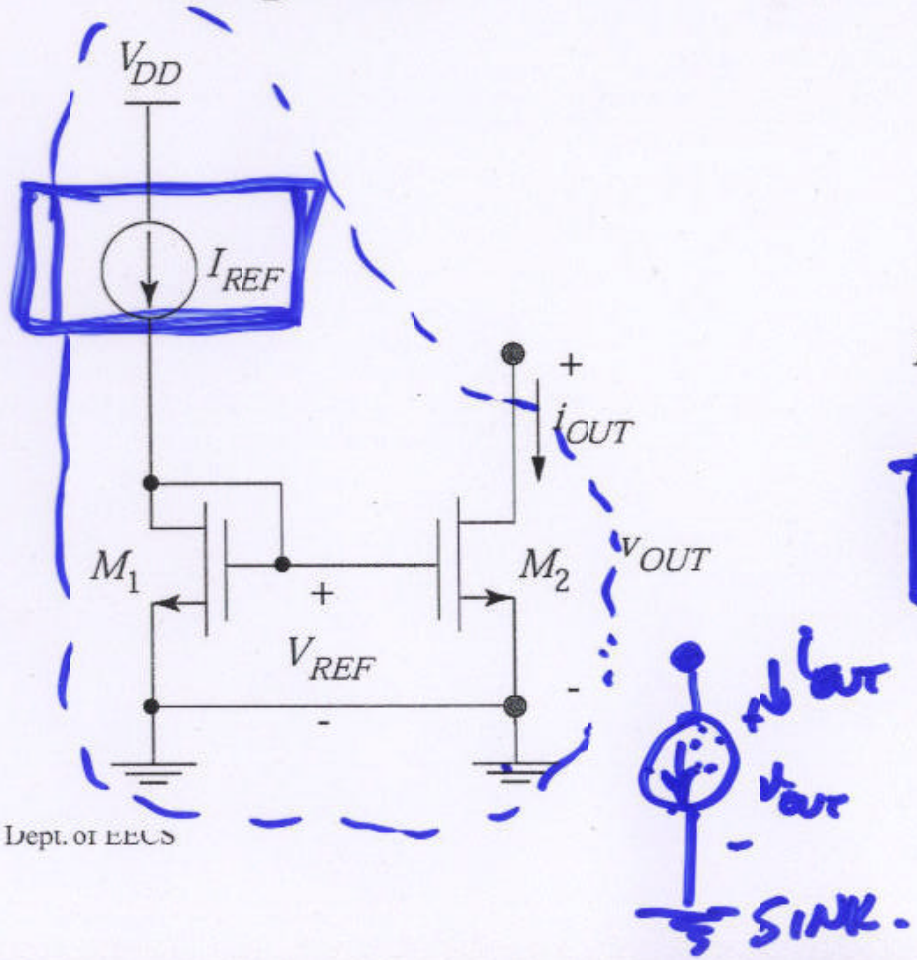


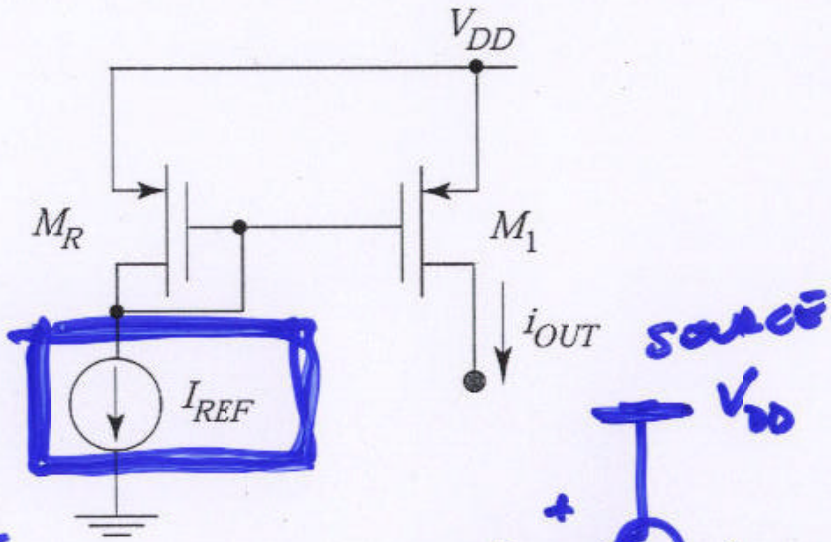
$$I_{C1} = I_{C2}\left(\frac{A_{E1}}{A_{E2}}\right)\cdot(1 - \cancel{\frac{2}{\beta}})$$

Current Sinks and Sources

Sink: output current goes to ground

Source: output current comes from voltage supply





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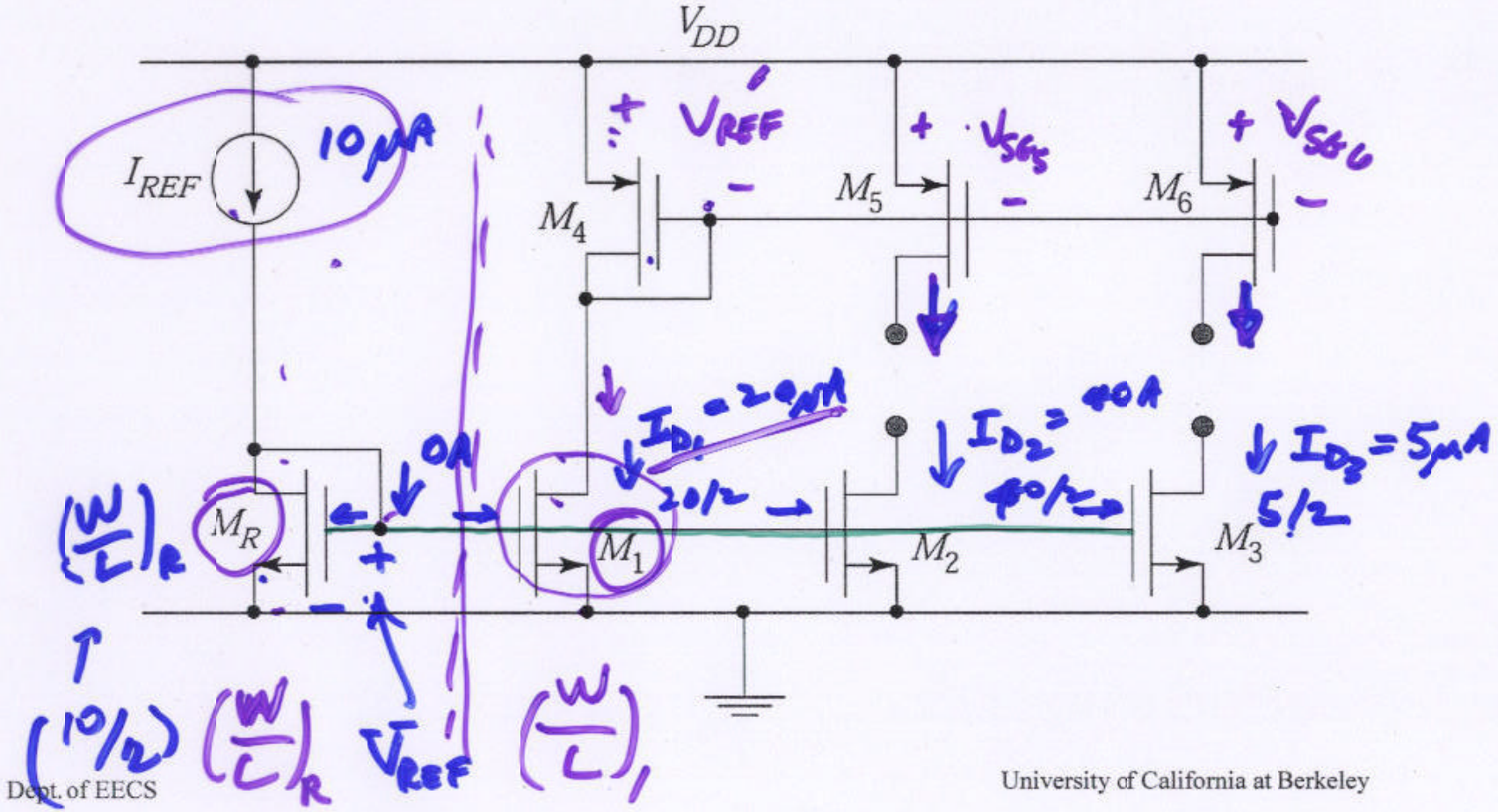
Current Mirrors

Idea: we only need one reference current to set up all the current sources and sinks needed for a multistage amplifier.



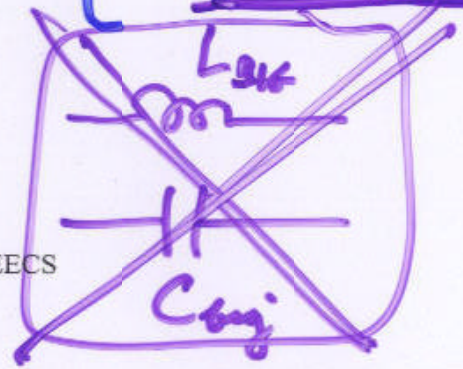
Multistage Amplifiers

- Necessary to meet typical specifications for any of the 4 types

We have 2 flavors (NMOS, PMOS) of CS, CG, and CD and the npn versions of CE, CB, and CC (for a BiCMOS process)

What are the constraints?

1. Input/output resistance matching
2. DC coupling (no passive elements to block the signal)



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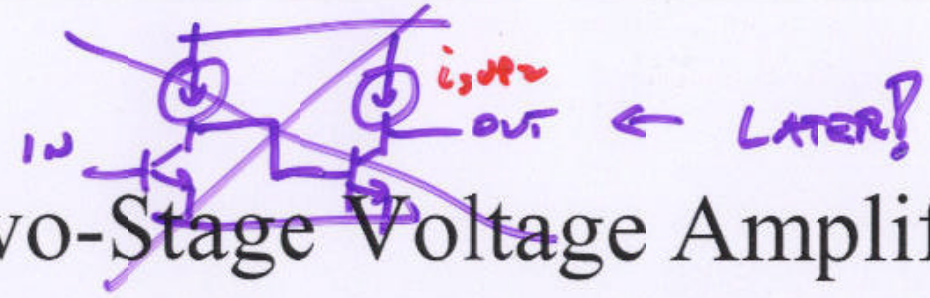
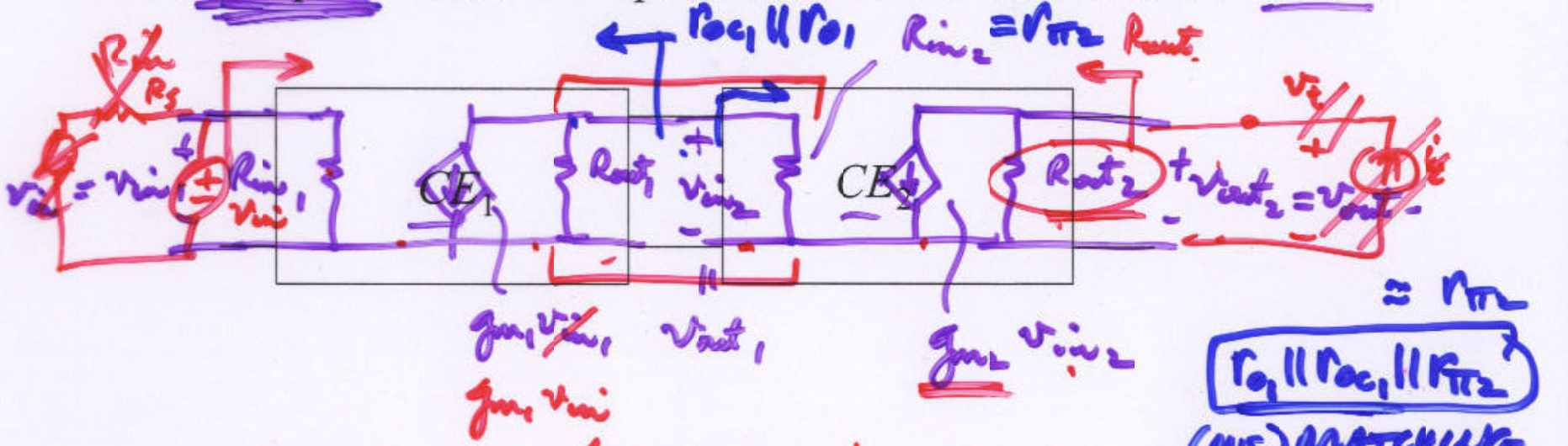


Start: Two-Stage Voltage Amplifier

- Use two-port models to explore whether the combination "works"



$v_{in2} = -g_{m1} v_{in} (R_{out1} \| R_{in2})$

$= r_{o2} \| r_{oc2}$

$\simeq r_{TT2}$

$r_{o1} \| r_{oc1} \| r_{TT2}$

(MIS) MATCHING LOADING

Results: $R_{in} = R_{in1}$, $R_{out} = R_{out2}$, $A_v = \frac{v_{out}}{v_{in}} = g_{m1} g_{m2} (R_{out1} \| R_{in2}) R_{out2}$

$R_s = 0$

$R_s = \infty$

$R_{in} = r_{TT1}$

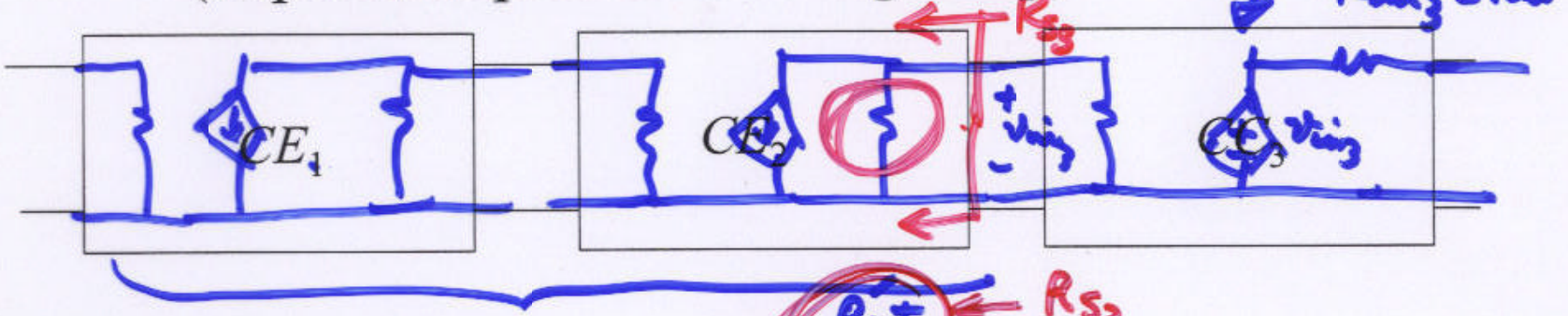
$R_{out} = \frac{v_t}{i_t}\Big|_{R_L \to \infty,\ R_S \to \text{short/off}}$

TOO SMALL R_{in} TO LARGE R_{out} LOADING.

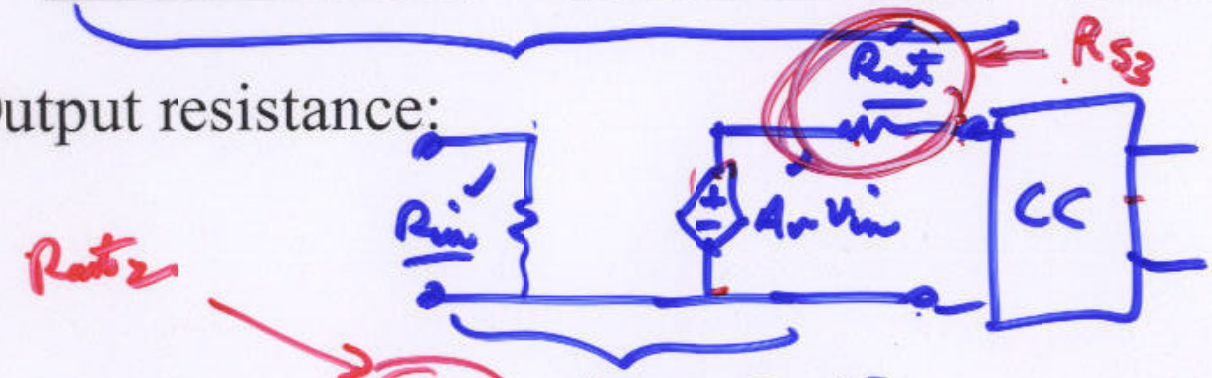
Add a Third Stage: CC

Goal: reduce the output resistance (important spec. for a voltage amp)

R_{out} SMALL



Output resistance:



LAST SLIDE: CE_1 / CE_2

$$R_{out} = \left(\frac{1}{g_{m3}}\right) + \frac{R_{S3}}{\beta_0}$$

$$R_{S3} = r_{o2} \| r_{oc2}$$

$$= \left(\frac{1}{g_{m3}}\right) + \frac{r_{o2} \| r_{oc2}}{\beta_0}$$

← IMPROVEMENT!!