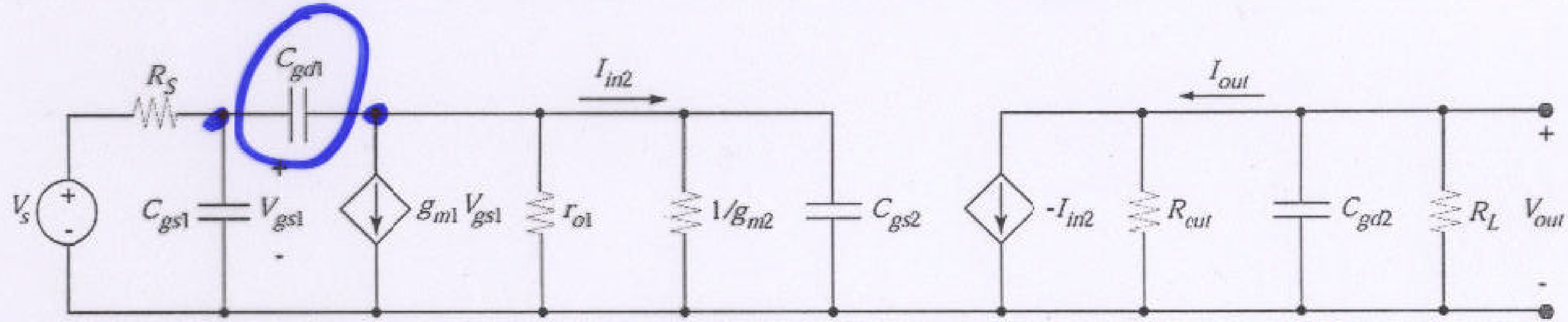
Lecture 36

- Last time:
  - Cascode amplifiers, totem pole voltage supplies
  - Start: two-stage CMOS transconductance amp
- Today :
  - Complete "lecture design" of two-stage CMOS transconductance amplifier

3 EXAMPLES

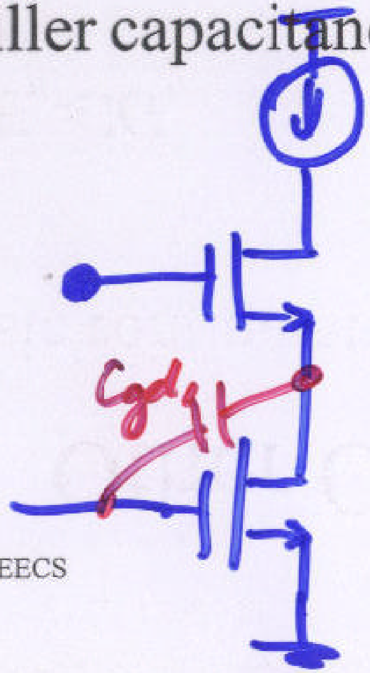
- PS DUE AT 4PM TODAY
- PS 12 OUT FRIDAY
  SOLNS TO 11 FRIDAY
- PROBLEM 1(f)...
- OH 5/7 TUESDAY 9:30 – 11:00

Two-Port Model with Capacitors



Miller capacitance: $C_M = (1 - A_{vC_{gs1}})C_{gd1}$

$(1 - A_{v C_{gd1}}) C_{gd1}$



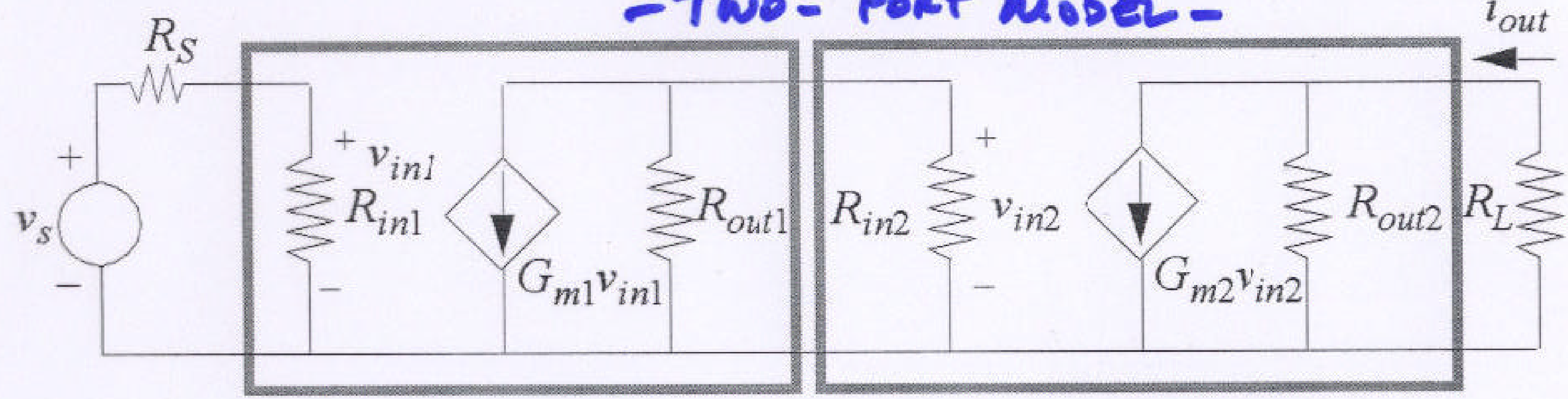
← $A_{v C_{gd1}} \cong -g_{m1}/g_{m2}$ ....

Small.

Multistage Amplifier Design Examples

Start with basic two-stage transconductance amplifier:

–TWO– PORT MODEL–



CS (NMOS) CS (PMOS)

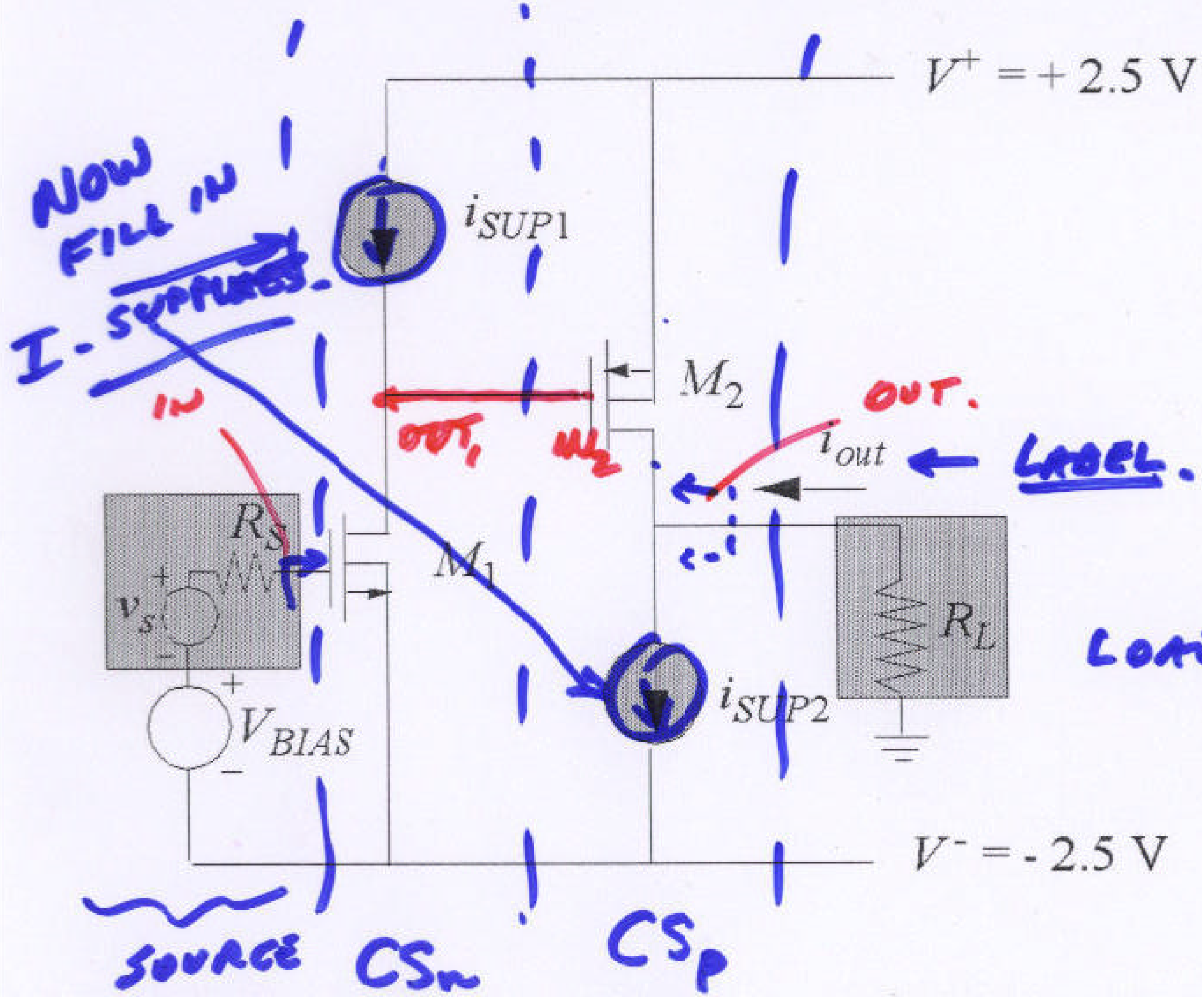
Why do this combination? TEACH EE 105!

$CS_n - CS_p$ ... 1ST STEP IN MULTISTAGE DESIGN

WHY? DC LEVEL SHIFTING...

Two-Stage Amplifier Topology.

Direct DC connection: use NMOS then PMOS



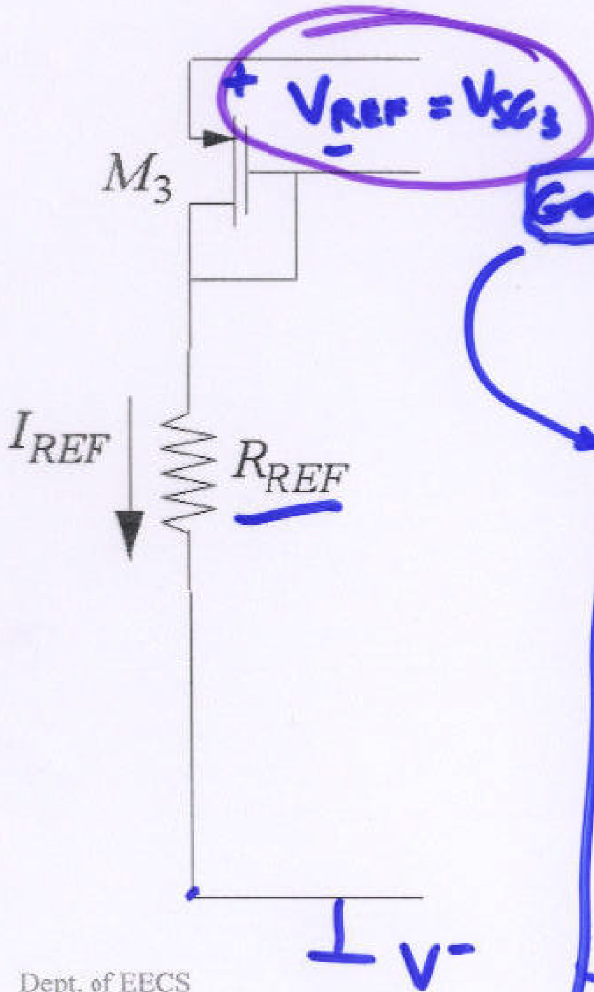
MORE LIKE TRANS-COND. ✓ THAN VOLTAGE.

↑

R_{OUT} = TOO BIG.

• SETTING (W/L)'s ...

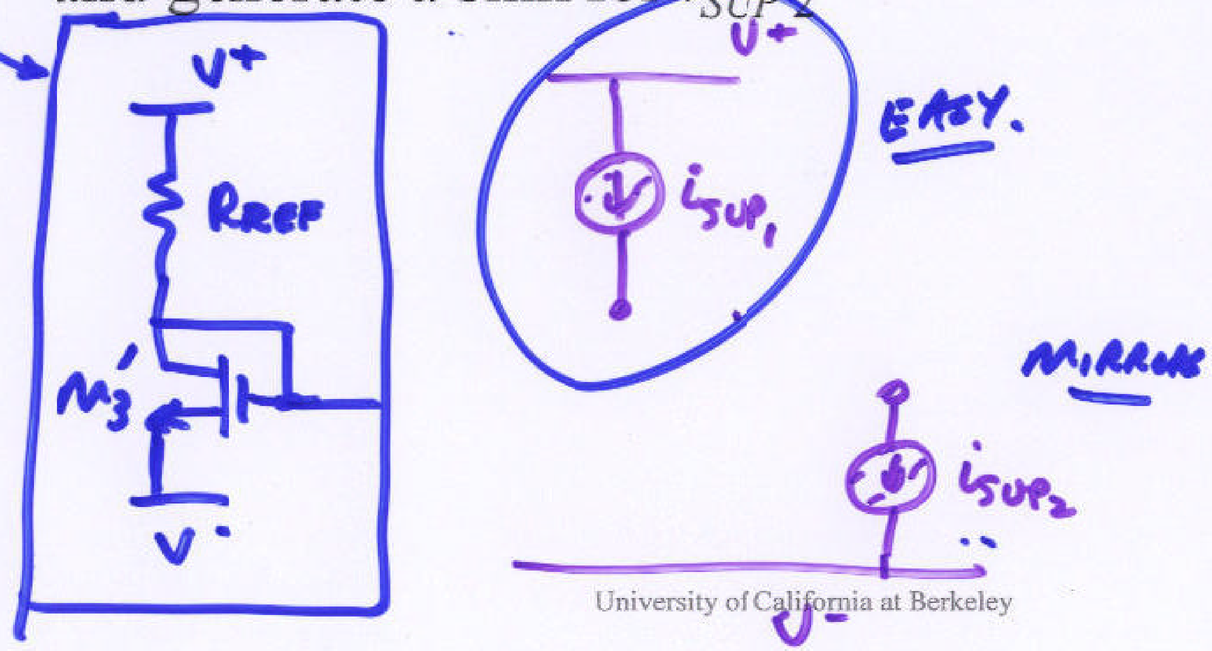
Current Supply Design

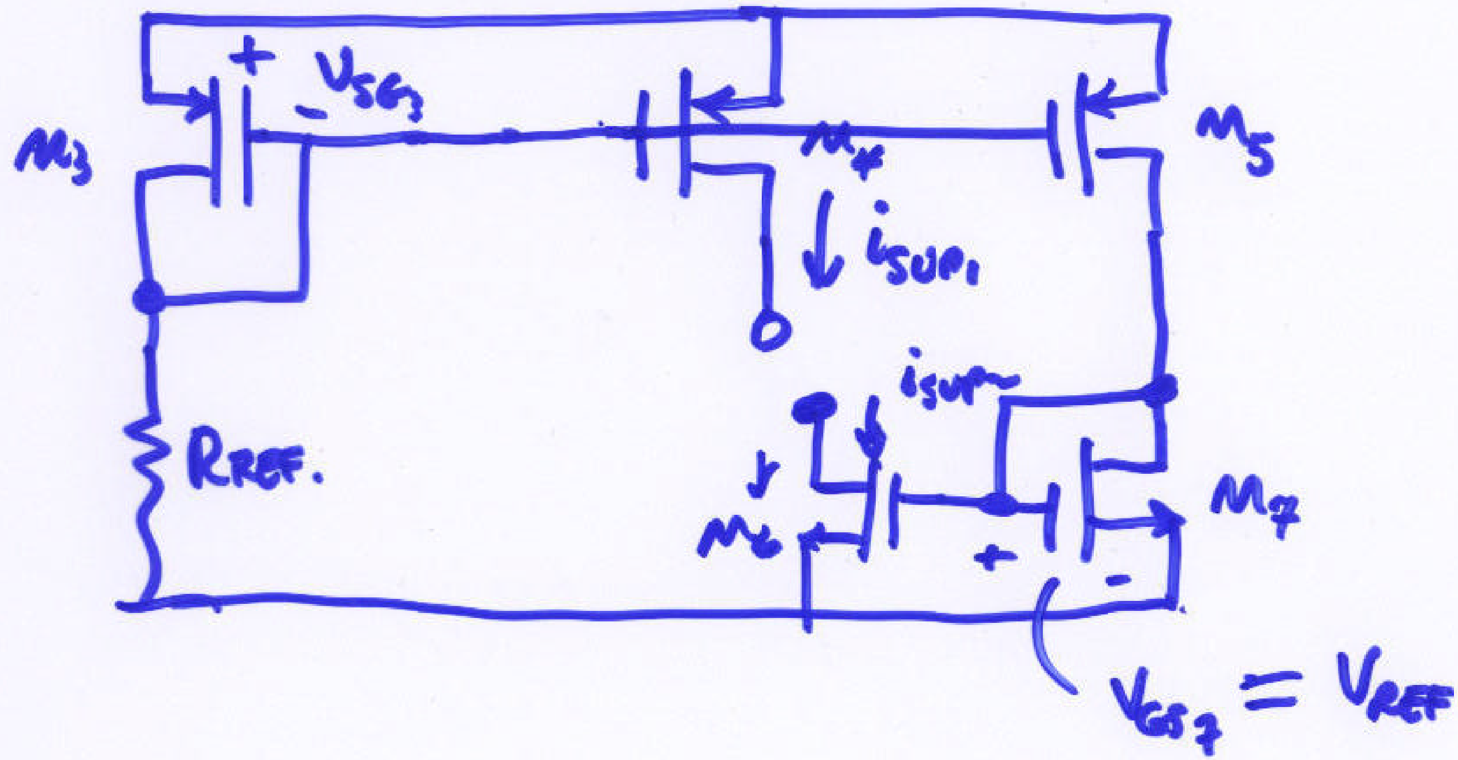


Assume that the reference is a "sink" set by a resistor [UNUSUAL... ACADEMIC EXERCISE.]

GOOD DESIGN EX.

Must mirror the reference current and generate a sink for i_{SUP2}

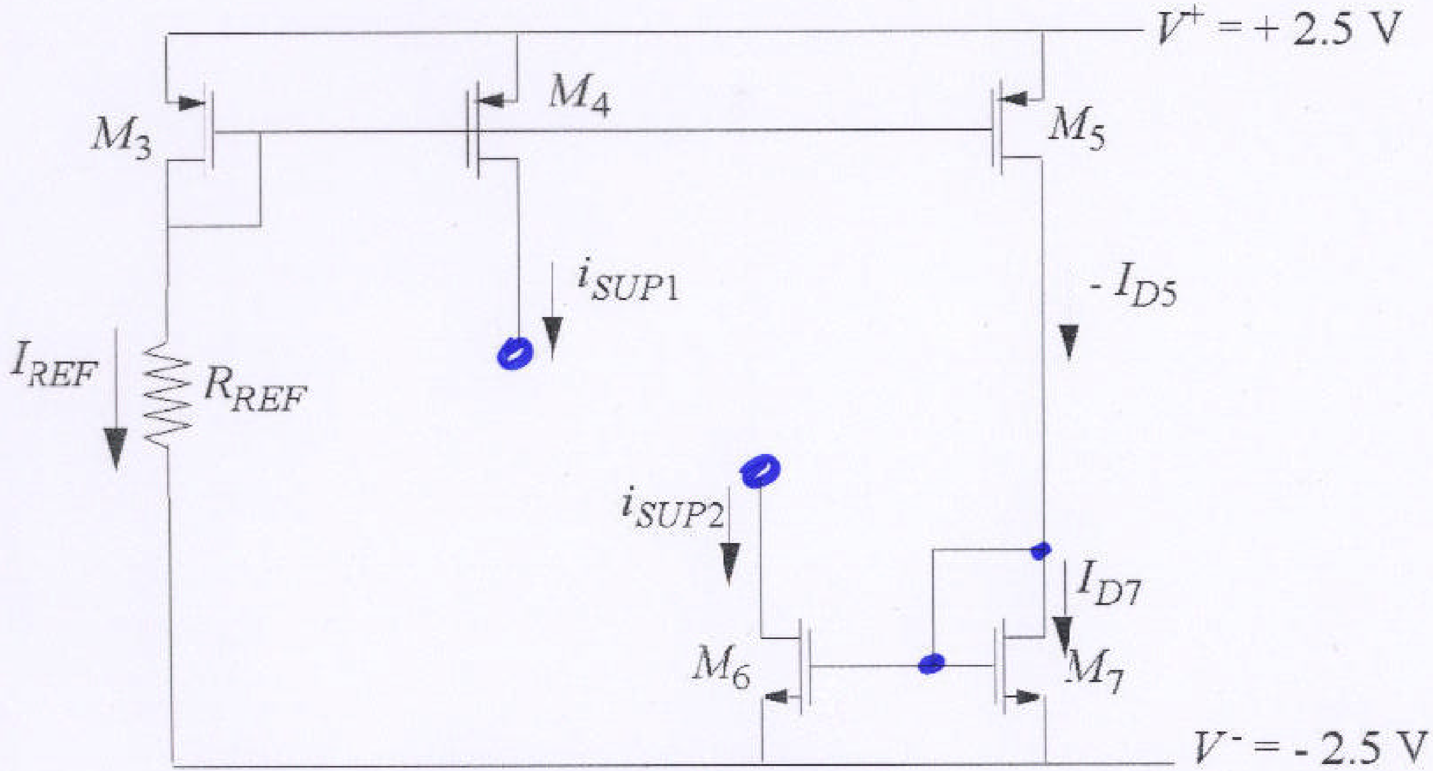




M3
+
V_{SG_3}
–
M4
i_{SUP_1}
M5
i_{SUP_2}
M6
M7
+
–
R_{REF}.
$V_{GS_7} = V_{REF}$

SIMPLE

Use Basic Current Supplies



NOTE: 5 MOSFETs, 1 RESISTOR ≡ 2 "GRAY CIRCLES" I SUPPLIES.

DC Bias: Find Operating Points

- Find V_{BIAS} such that $V_{OUT} = 0$ V

  NEGLECT λ's.

  APPROX. ... PSPICE.

  Device parameters:

$\mu_n C_{ox} = 50\ \mu A/V^2$	$\mu_p C_{ox} = 25\ \mu A/V^2$
$V_{Tn} = 1$ V	$V_{Tp} = -1$ V
$\lambda_n = 0.05\ V^{-1}$	$\lambda_p = 0.05\ V^{-1}$

- Device dimensions (for "lecture" design):

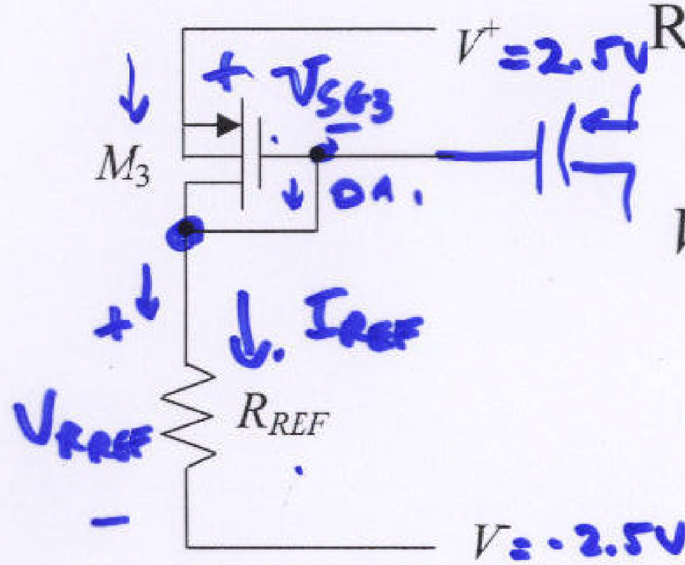
  HIGHLY CONSTRAIN ... SO MATH WORKS.

$(W/L)_n = 50/2$ $\quad\quad$ $(W/L)_p = 80/2$

$\mu_p / \mu_n \approx 1/2$

Finding R_{REF}

TOO LARGE ... WASTES POWER.



Require $I_{REF} = -I_{D3} = 50\ \mu A$ ✓

$$V_{SG3} = -V_{Tp} + \sqrt{\frac{-2I_{D3}}{\mu_p C_{ox}(W/L)_3}}$$

$$= -(-1)V + \sqrt{\frac{2(50\mu A)}{25\mu A(80/2)}}$$

$$= 1 + \sqrt{\frac{4}{40}} = 1 + \frac{1}{\sqrt{10}} = 1.32\ V$$

$I_{REF} =$ 50μA.

$$= \frac{[V^+ - V_{SG3}] - [V^-]}{R_{REF}}$$

($[V^+ - V_{SG3}] - [V^-] = V_{REF}$)

$$I_{REF} = \frac{2.5 - (1.32) - (-2.5)}{R_{REF}}$$

$$R_{REF} = \frac{(5 - 1.32)V}{50\mu A}$$

$$\boxed{R_{REF} = 74\ k\Omega}$$

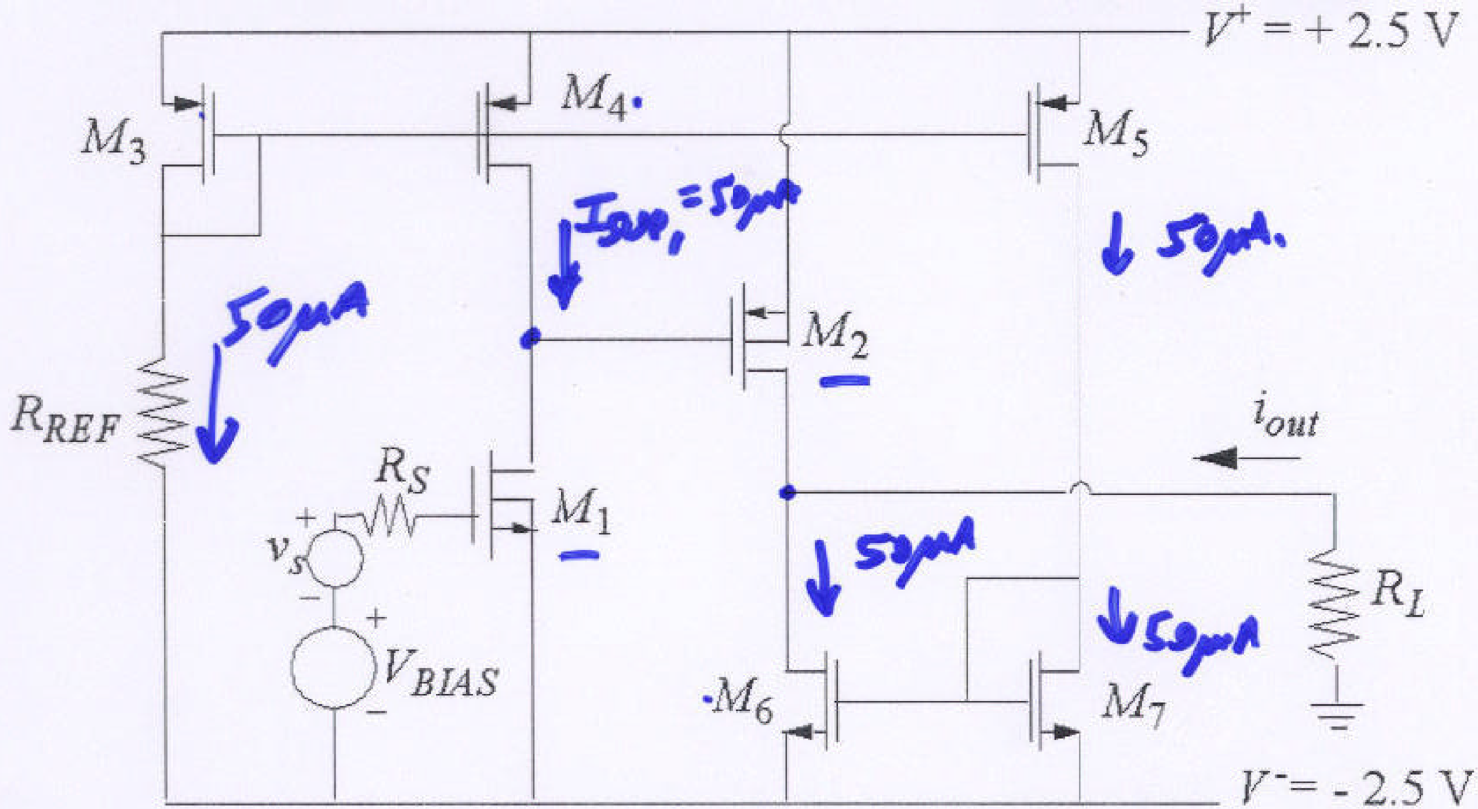
$$\bullet\ V_{BIAS} = V_{GS_1} = V_{Tn} + \sqrt{\frac{2 I_{D1}}{\mu_n C_{ox} (W/L)_1}}$$

$$= 1 + \sqrt{\frac{2 \cdot 100 \mu A}{(50 \mu A/V^2) \cdot (50/2)}}$$

$$= 1 + \sqrt{\frac{4}{50}}\ V$$

$$= 1 + \frac{2}{\sqrt{50}}\ V \cong \frac{9}{7}\ V.$$

Complete Amplifier Topology



What's missing? The device dimensions and the bias voltage and reference resistor

KNOW ALL DC CURRENTS ...

R. T. Howe

Small-Signal Device Parameters

Transistors M_1 and M_2

$g_{m1} = 350\ \mu S \qquad r_{o1} = 400\ k\Omega = \frac{1}{\lambda_n I_{D1}} = \frac{1}{(\frac{1}{20}) \cdot 50\times10^{-6}}$

$g_{m2} = 315\ \mu S \qquad r_{o2} = 400\ k\Omega$

$\lambda_n = 0.05$, $I_{D1} = 50\ \mu A$

Current supplies i_{SUP1} and i_{SUP2}

$r_{oc1} = r_{o4} = 400\ k\Omega$ ← λ's same ... L's same [WHY?]

$r_{oc2} = r_{o6} = 400\ k\Omega$ ←

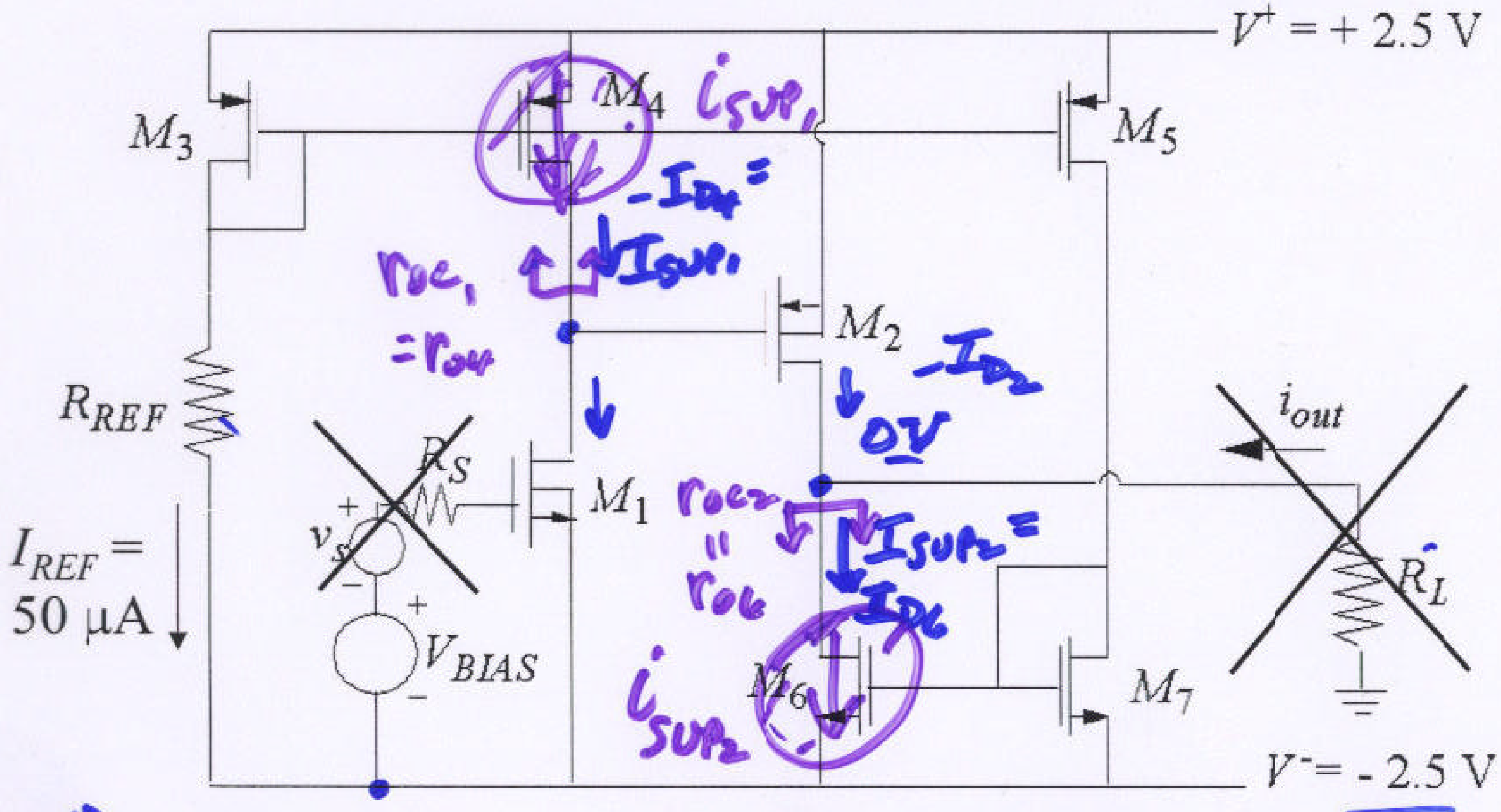
$g_{m1} \cong \mu_n C_{ox} \left(\frac{W}{L}\right) (V_{GS1} - V_{Tn})$ — BOOST (W/L).

$g_{m1} = \frac{2 I_{D1}}{(V_{GS} - V_{Tn})} \propto \sqrt{I_{D1}}$

BOOST I_{D1} → 50 μA TOO SMALL.

SET V_{BIAS} SO THAT V_{OUT} OR I_{OUT} = 0

DC Operating Point



HAND CALC... $V_{BIAS} =$? STARTING POINT FOR PSPICE

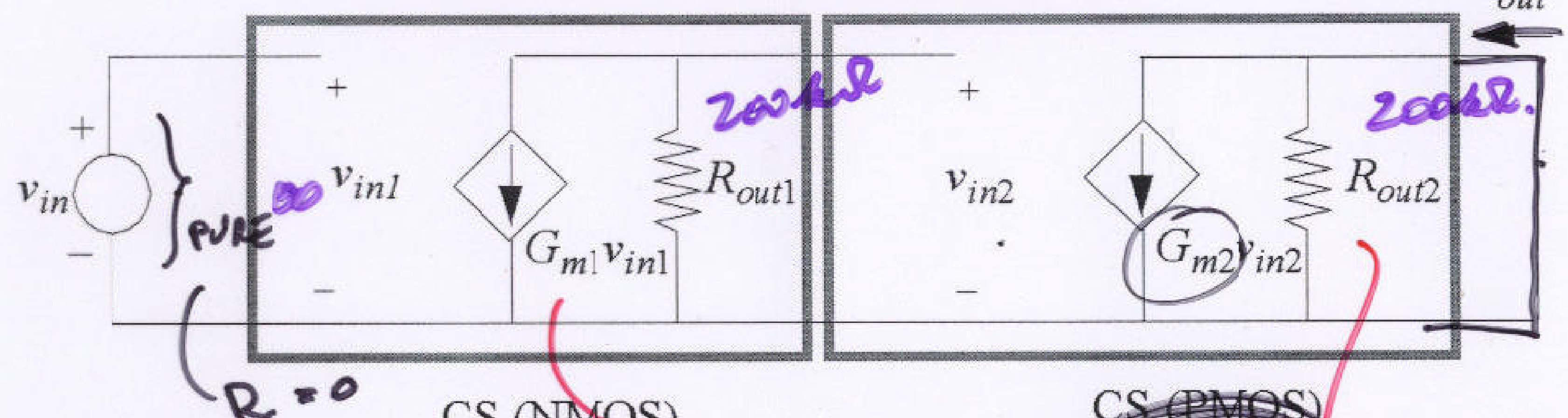
$= I_{SUP1} = 50\mu A$.

$I_{D1}' = \frac{\mu_n C_{ox}}{2} (W/L)_1 (V_{GS1} - V_{Tn})^2 (1 + 0)$ ← NEGLECTING λ_n

$g_{m1} = 0.35\,mS$; $R_{out1} = 200\,k\Omega$.

Two-Port Model

$g_{m2} = 0.315\,mS$.



CS (NMOS) CS (PMOS)

Find $G_m = i_{out} / v_{in} \Big|_{R_S=0,\ R_L=0} = -g_{m1} g_{m2} R_{out1} = -22\,mS$

$G_{m1} = g_{m1}$

$R_{out1} = r_{o1} \| r_{oc1}$ (r_{o4})

$R_{out} = R_{out2} = r_{o2} \| r_{oc2}$ (r_{o6})

$v_{in2} = -g_{m1} \cdot R_{out1} v_{in}$

$i_{out} = g_{m2} \cdot v_{in2}$ (70)

$i_{out} = g_{m2} [-g_{m1} \cdot R_{out1}] \cdot v_{in}$

KNOW WHY!!