Lecture 26

ANNOUNCEMENTS

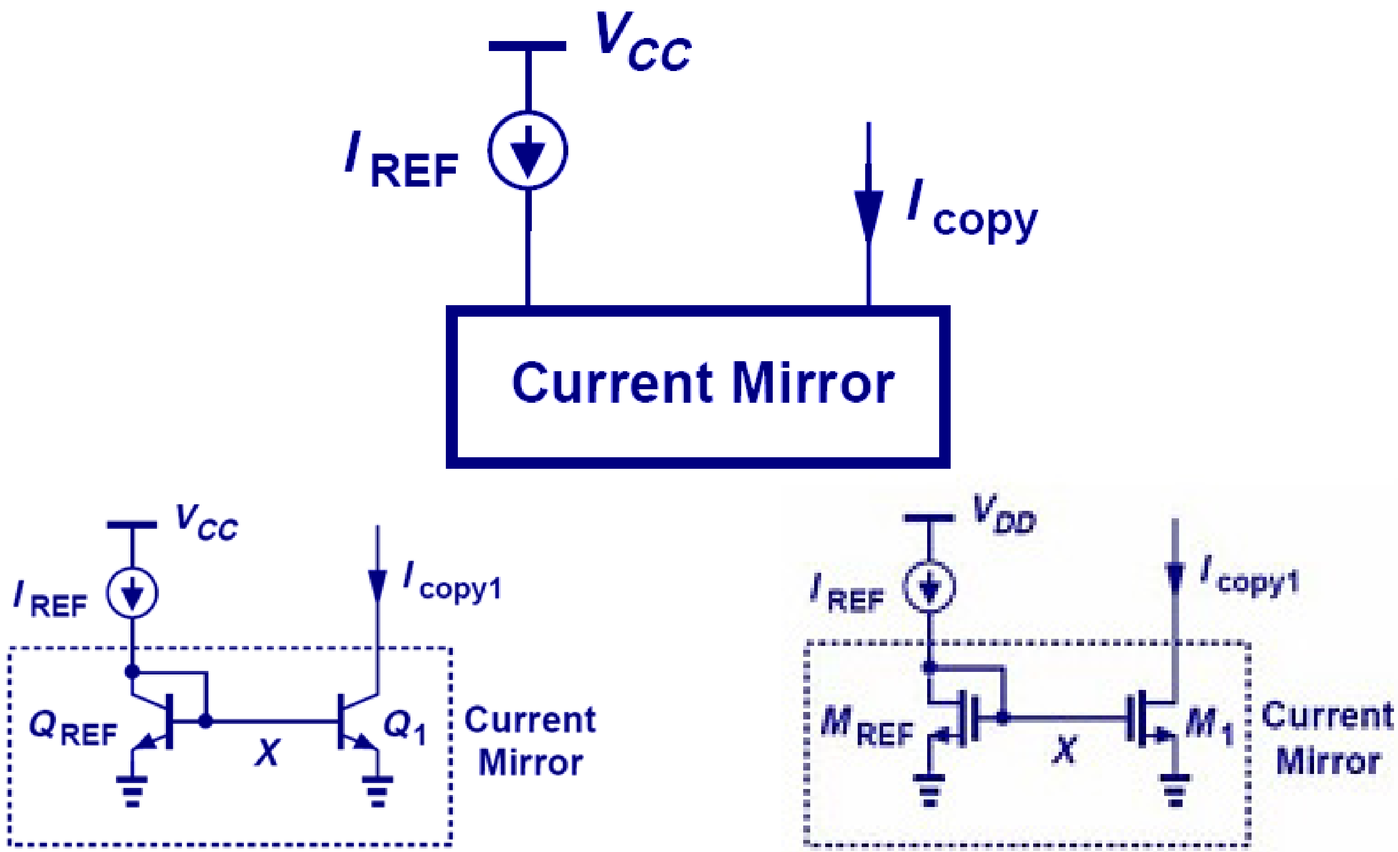
- Homework 12 due Thursday, 12/6

OUTLINE

- Self-biased current sources
  - BJT
  - MOSFET
- Guest lecturer Prof. Niknejad

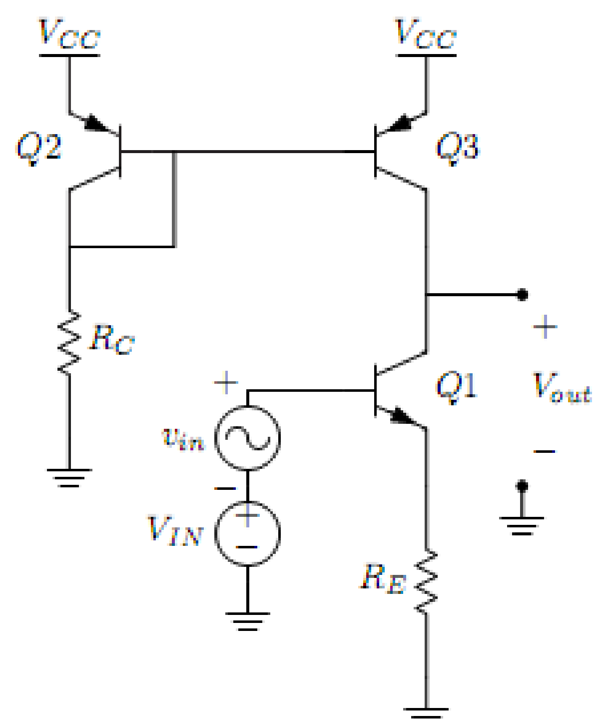
Review: Current Mirrors

- The current mirrors we discussed require a "golden" current source, I_{REF}, to copy.



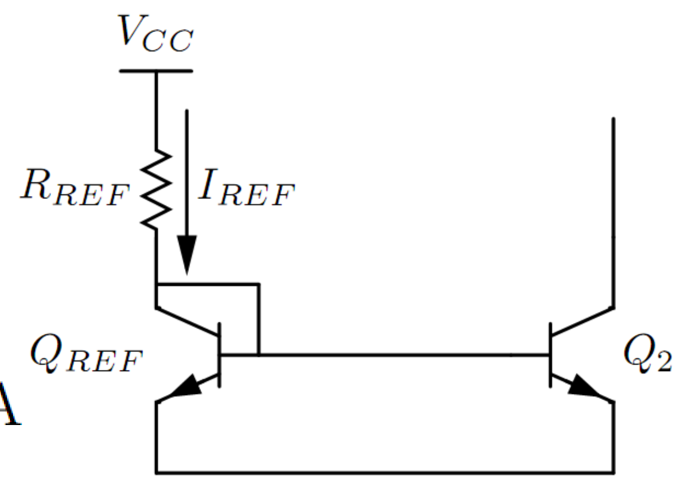
Review: Current Mirrors (cont'd)

- In lab 6 and lab 10, you used a resistor as your current source.
- Q: What are some problems associated with this method?



Review: Current Mirrors (cont'd)

- A: Variations in V_{CC} and temperature cause significant variations in I_{REF}. Consider the following analysis (ignoring base currents and the Early effect):



$$I_{REF} = I_S e^{V_{BE}/V_T}$$

$$V_{BE} = V_{CC} - I_{REF} R_{REF}$$

$$I_{REF} = I_S e^{(V_{CC} - I_{REF} R_{REF})/V_T}$$

$$V_{CC} = 5\ \text{V}, R_{REF} = 5\ \text{k}\Omega, I_S = 1\ \text{fA}$$

$$\Rightarrow I_{REF} = 857\ \mu\text{A}$$

$$V'_{CC} = 4.5\ \text{V}$$

$$\Rightarrow I'_{REF} = 758\ \mu\text{A}$$

- Thus, a 10 % change in V_{CC} results in a 11.6 % change in I_{REF}.

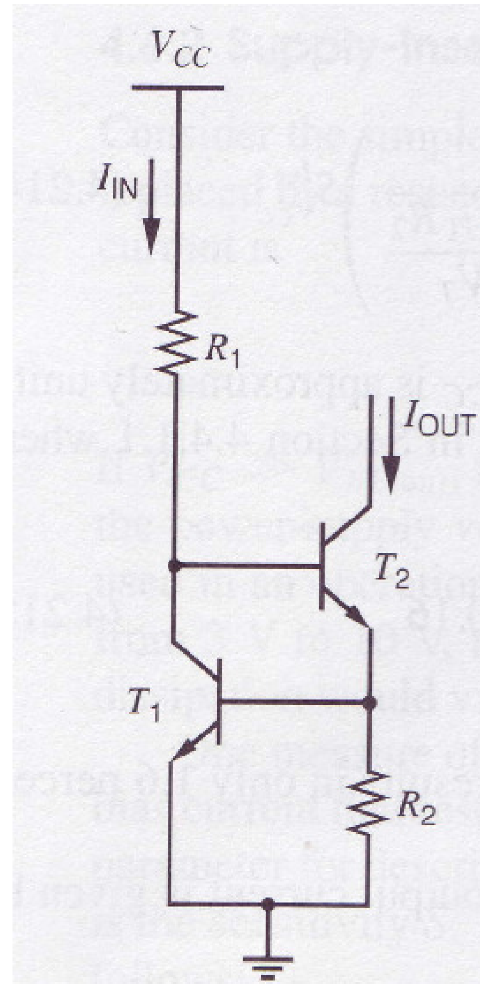
Base-emitter Reference

- Rather than having a source dependent on V_{CC}, why not use some other reference?
- For example, a V_{BE} referenced current source.
- Ignoring base currents, we have:

$$V_{BE1} = V_T \ln \frac{I_{IN}}{I_{S1}}$$

$$I_{OUT} = \frac{V_{BE1}}{R_2}$$

- Q: Why is this less supply dependent?



Base-emitter Reference (cont'd)

- A: Although I_{IN} varies almost directly with V_{CC}, V_{BE1} won't vary nearly as much, since the device is exponential. Since I_{OUT} depends only on V_{BE1}, the output won't vary much with V_{CC}.
- Example:

$$V_{CC} = 5\ \text{V}, R_1 = 5\ \text{k}\Omega, R_2 = 1\ \text{k}\Omega, I_S = 1\ \text{fA}$$

$$I_{IN} = 857\ \mu\text{A}, V_{BE1} = 715\ \text{mV} \Rightarrow I_{OUT} = 715\ \mu\text{A}$$

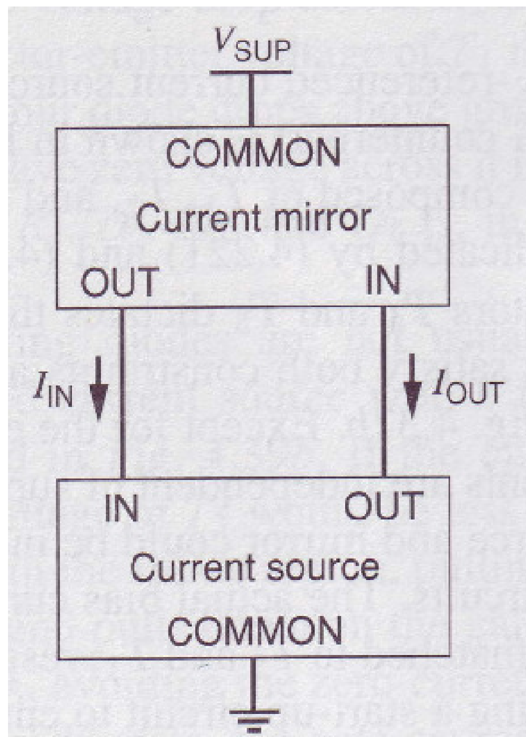
$$V'_{CC} = 4.5\ \text{V}$$

$$I'_{IN} = 758\ \mu\text{A}, V'_{BE1} = 710\ \text{mV} \Rightarrow I'_{OUT} = 710\ \mu\text{A}$$

- Thus, a 10 % change in V_{CC} results in a 0.7 % change in I_{OUT}.

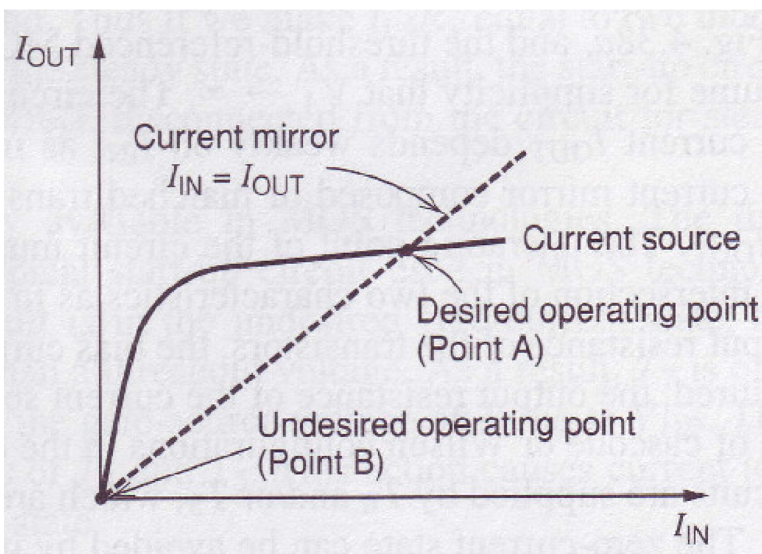
Self Biasing

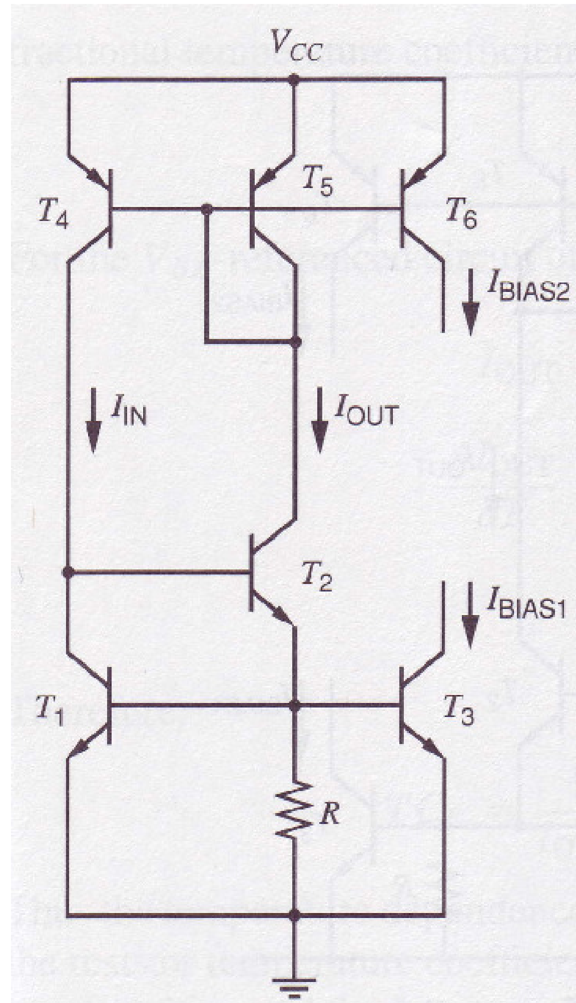
- We can do better than the V_{BE} referenced source using feedback. What if our source had a current mirror attached that fed back the output current to act as the input current?



Self Biasing (cont'd)

- Here, we've attached a *pnp* current mirror to force I_{OUT} and I_{IN} to match.
- There are two stable operating points:
  - $I_{IN} = I_{OUT} = 0$ A
  - Desired operating point

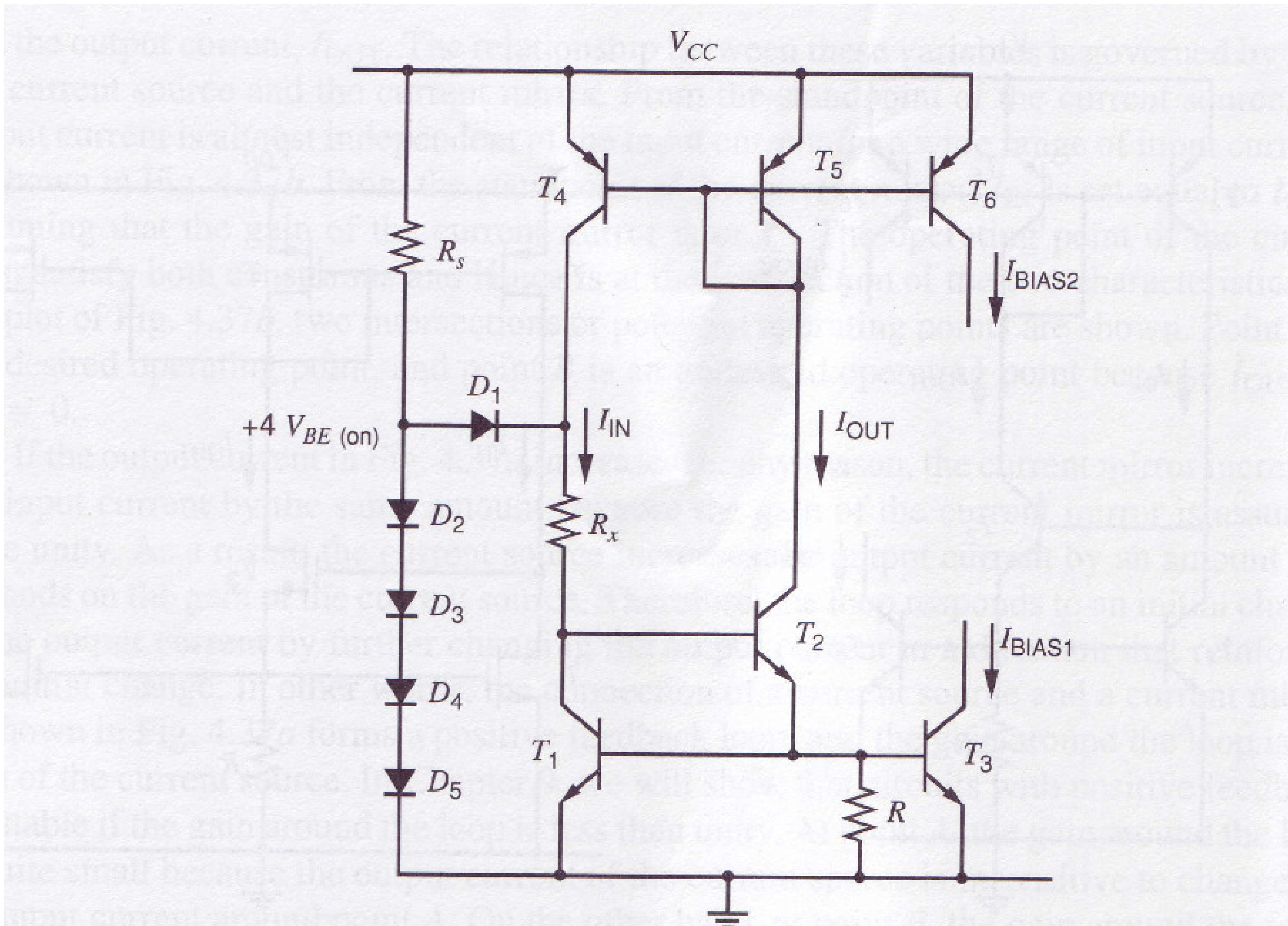




Start-up Circuit

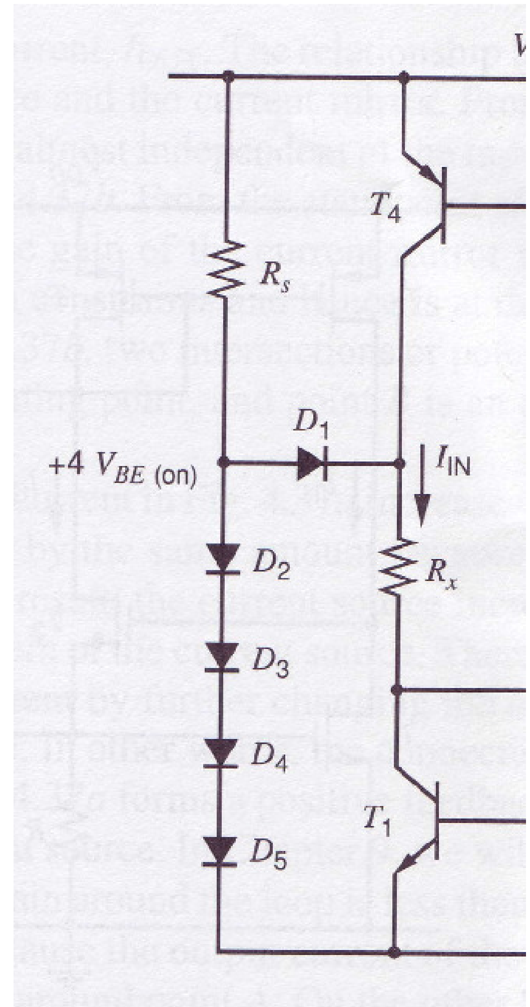
- Need a way to "start-up" the circuit, like a car starter starts up your car.
- Requirements:
  - Must keep the circuit out of the undesired operating point
  - Must not interfere with the circuit once it reaches the desired operating point

Start-up Circuit (cont'd)



Start-up Circuit (cont'd)

- Let's ensure this works:
  - Assume $I_{IN} = I_{OUT} = 0$. This means approximately that $V_{BE1} = V_{BE2} = 0$. However, note that the left side of D_1 is four diode drops from ground, meaning D_1 is on. This drops some voltage across R_x, forcing current to flow into T_1 and T_2, starting up the circuit.
  - After the circuit is at the desired operating point, turn D_1 off by ensuring $R_x I_{IN}$ (the drop across R_x) is sufficiently large.

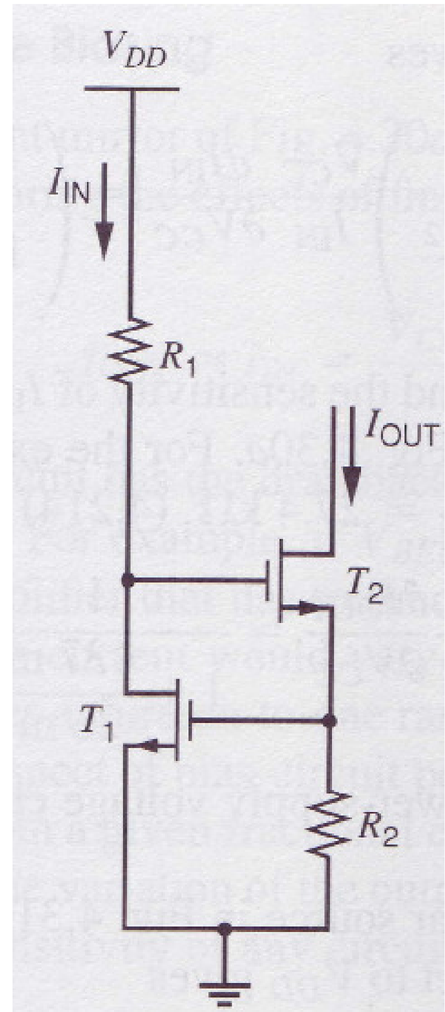


MOSFET Current Source

- We can build an analogous circuit from MOSFETs as well. Let's start with a V_{TH} referenced current source.

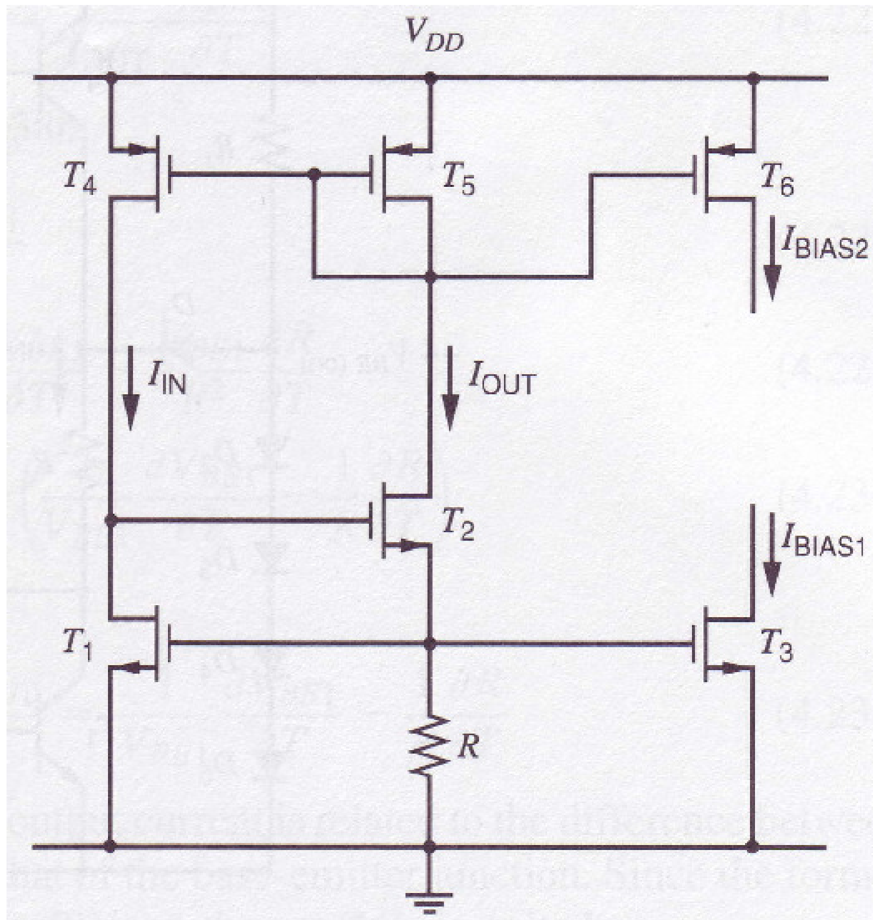
$$I_{OUT} = \frac{V_{GS1}}{R_2} = \frac{V_{TH} + V_{ov1}}{R_2} = \frac{V_{TH} + \sqrt{\frac{2I_{IN}}{\mu_n C_{ox}(W/L)}}}{R_2}$$

- If we make V_{ov1} small (by sizing up T_1 or using small currents), I_{OUT} is controlled primarily by V_{TH} and R_2.



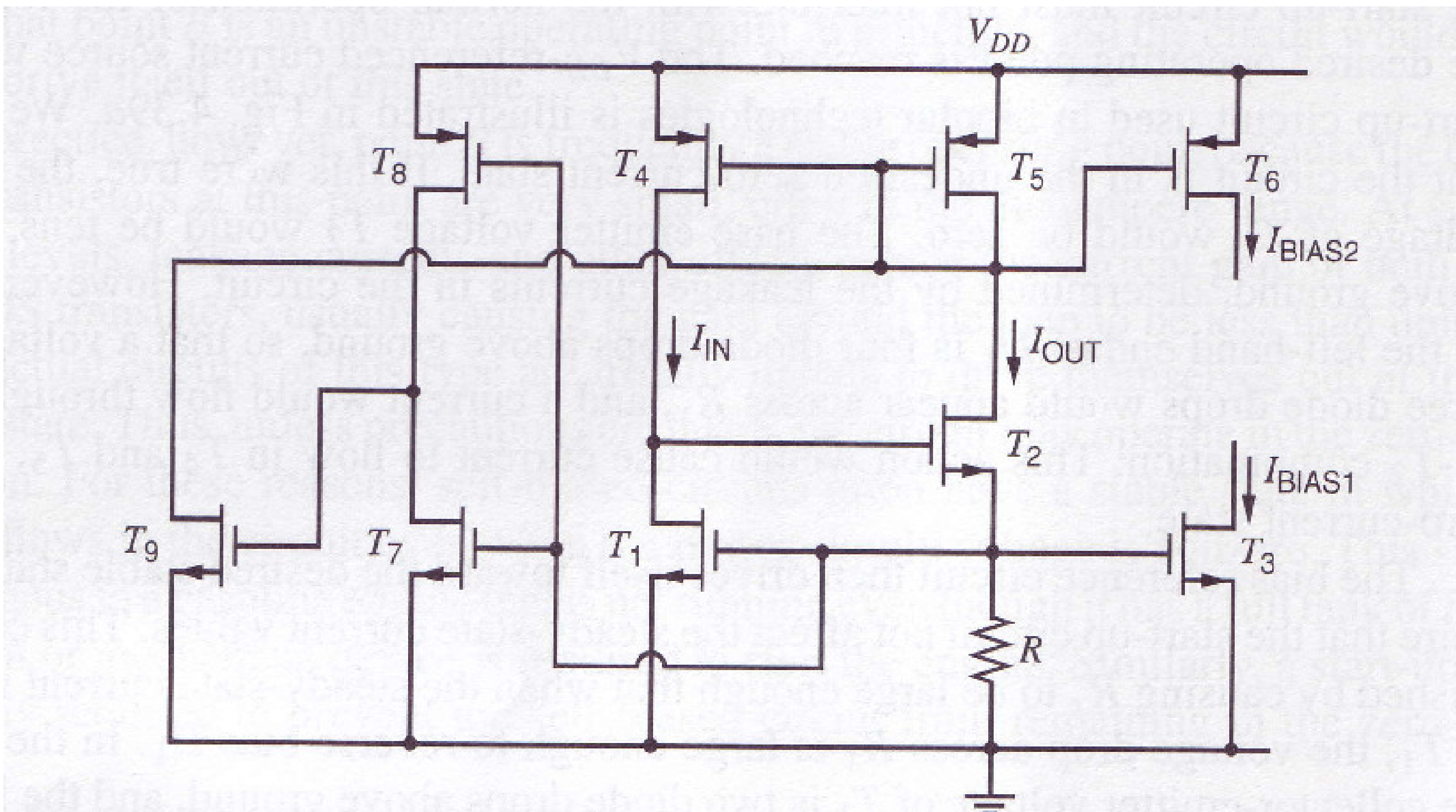
MOSFET Current Source (cont'd)

- Let's add the current mirror feedback.



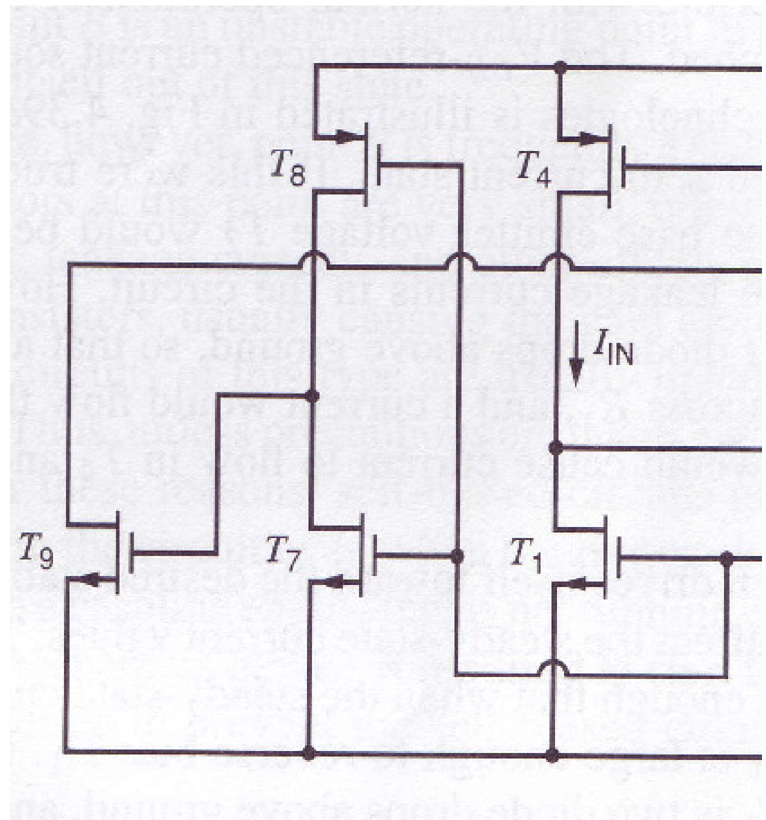
MOSFET Current Source (cont'd)

- Finally, the start-up circuitry. It's more typical to use more MOSFETs in MOS technologies rather than diodes.



MOSFET Current Source (cont'd)

- Assume $I_{IN} = I_{OUT} = 0$. This means $V_{GS1} = 0$, meaning T_8 is in triode. This turns on T_9 and forces current to flow into T_4 and T_5.
- Once in steady state, we can size T_7 to ensure that T_9 turns off. T_7 and T_8 don't directly affect the circuit themselves, so the start-up circuit has done its job.



References

- Material and figures largely from *Analysis and Design of Analog Integrated Circuits, Fourth Edition* by Gray, Hurst, Lewis, and Meyer.

Guest Lecturer: Prof. Ali Niknejad

- Faculty director of the Berkeley Wireless Research Center (BWRC). Primary research interests include analog integrated circuits, mm-wave CMOS, RF and microwave circuits, device modeling (BSIM), electromagnetics (ASITIC), communication systems, and scientific computing.