EEE 51: Second Semester 2017 - 2018

Lecture 14

Compound Amplifiers; Review

Today

- Compound Amplifiers
  - Cascode Amplifiers
  - Operational Amplifiers

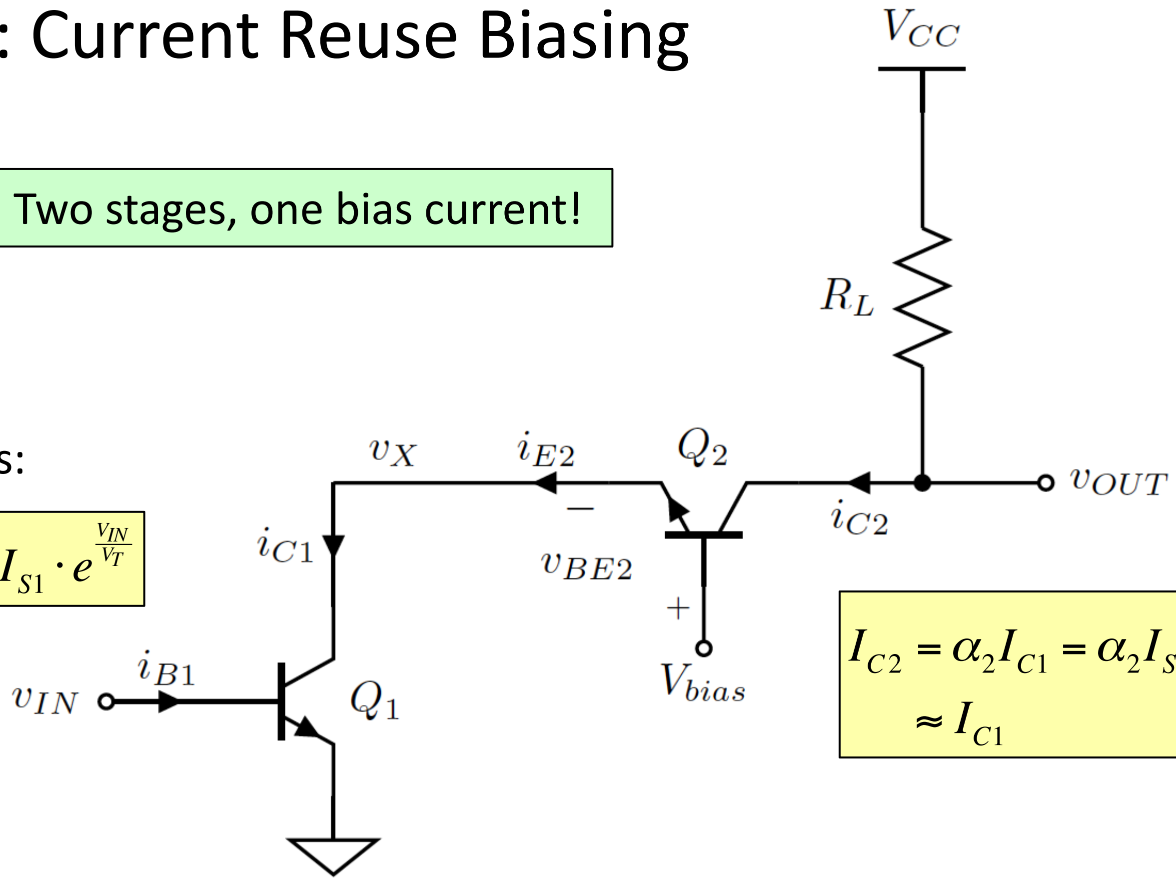
The CE-CB Amplifier (Cascode Amplifier)

- Idea: Current Reuse Biasing

→ Two stages, one bias current!

DC Analysis:

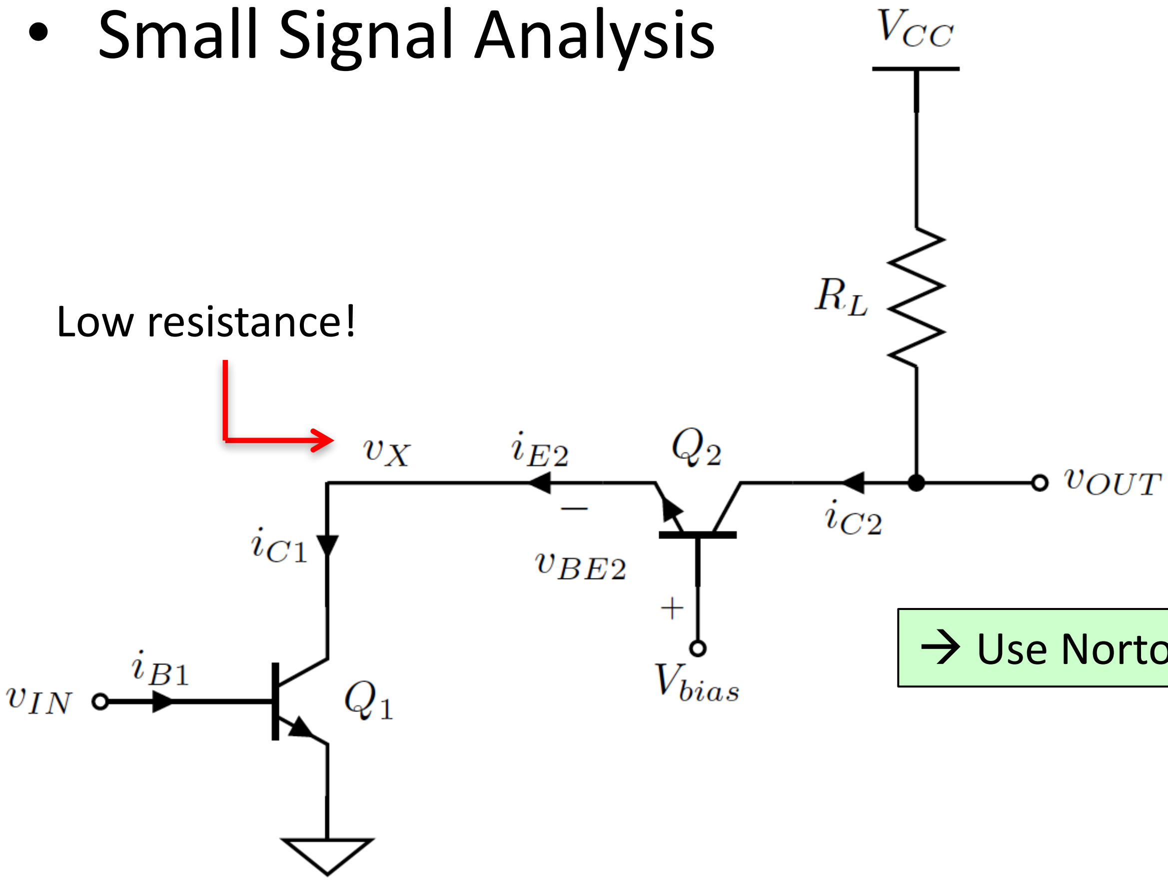
$$I_{C1} = I_{S1} \cdot e^{\frac{V_{IN}}{V_T}}$$



$$I_{C2} = \alpha_2 I_{C1} = \alpha_2 I_{S1} \cdot e^{\frac{V_{IN}}{V_T}}$$
$$\approx I_{C1}$$

The CE-CB Amplifier (Cascode Amplifier)

- Small Signal Analysis



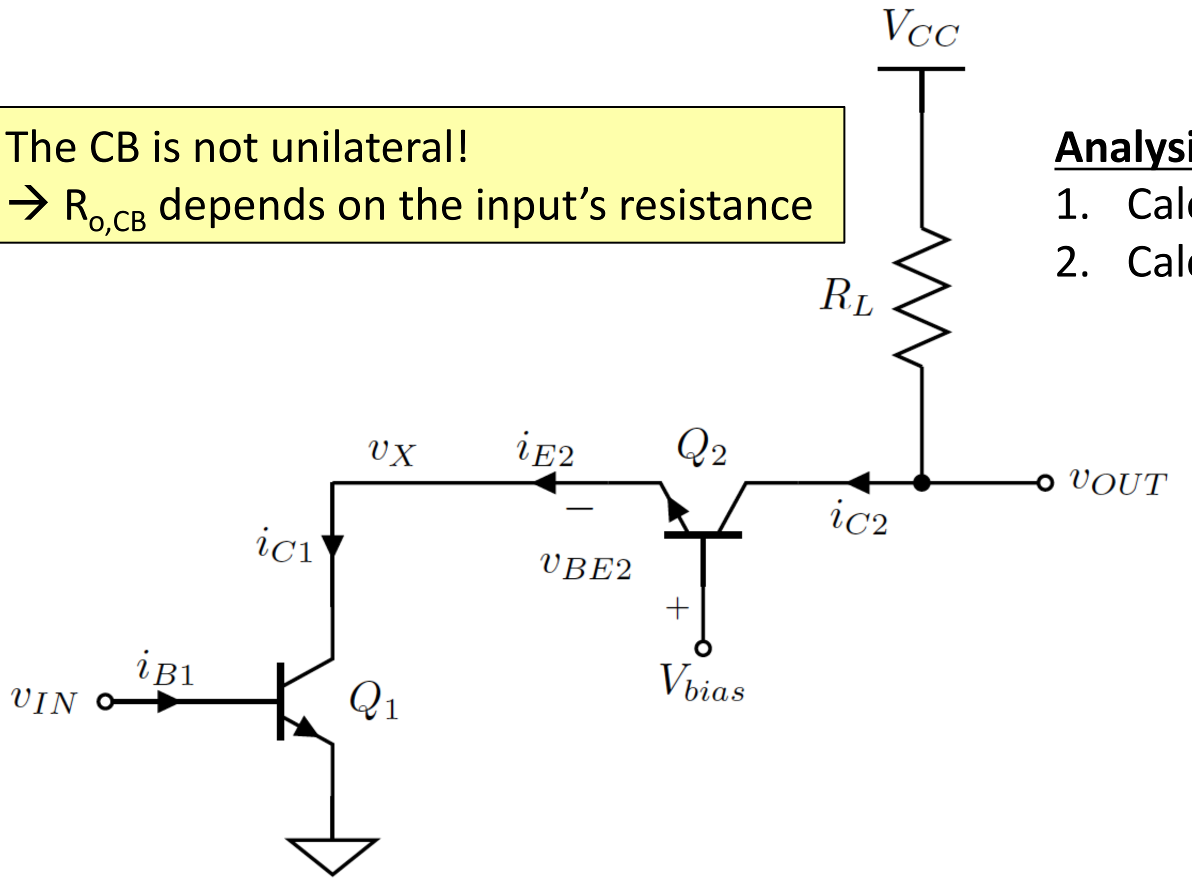
<u>Expect:</u>

- small voltage changes at node X
- large current flowing into the CB stage

→ Use Norton model for the CE stage

Small Signal Analysis

The CB is not unilateral!
→ $R_{o,CB}$ depends on the input's resistance

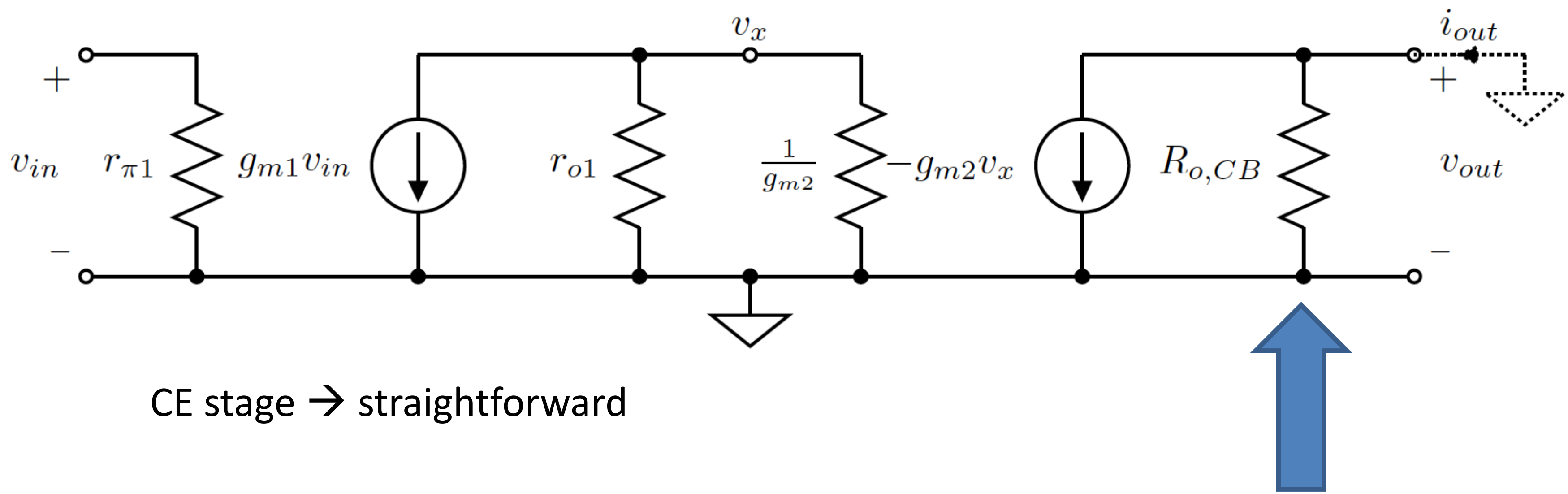


Analysis steps:

1. Calculate CB output resistance
2. Calculate overall transconductance

Small Signal Equivalent Circuit (1)

- Cascaded CE-CB

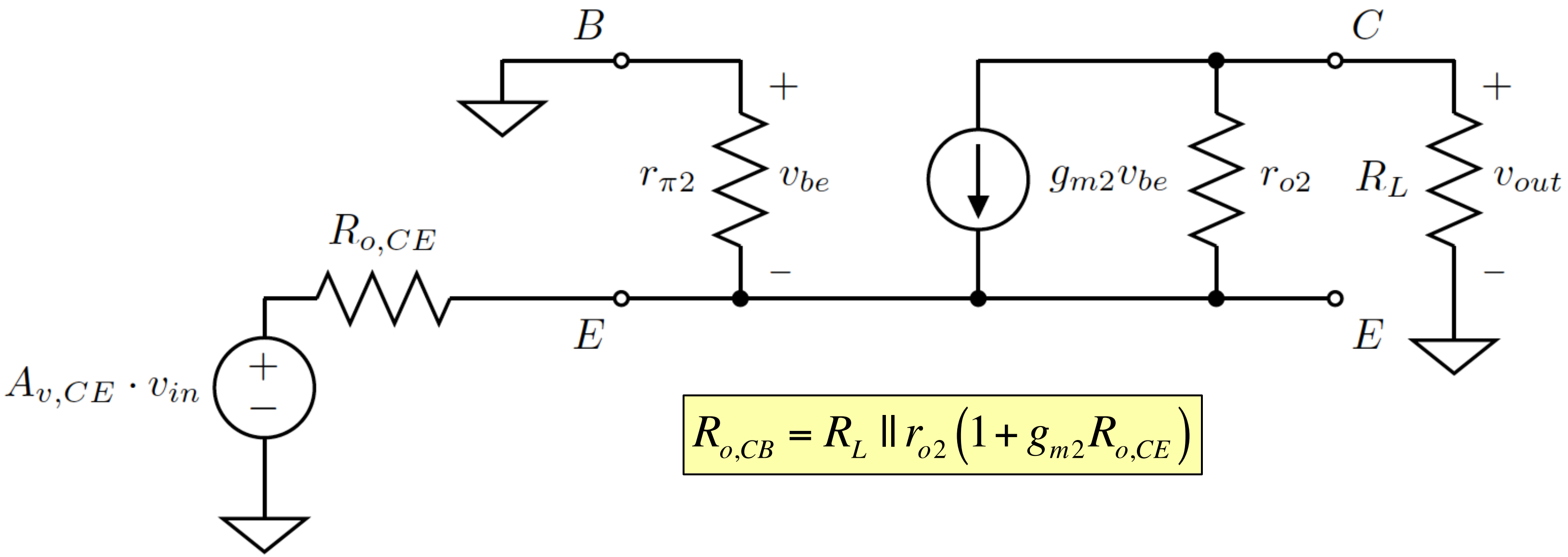


CE stage → straightforward

We need to calculate this!

The CB Amplifier driven by a CE Amplifier

- Small signal equivalent circuit

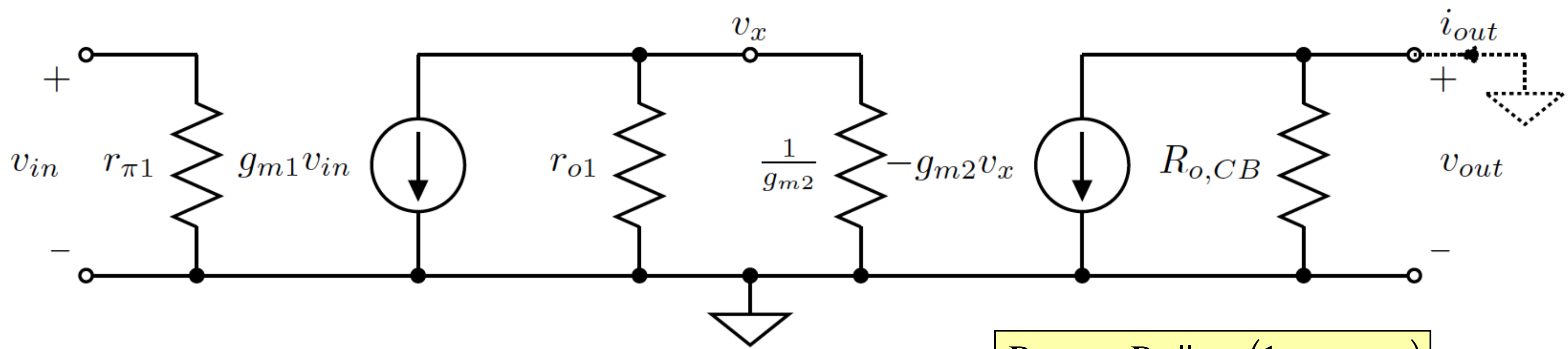


$$\boxed{R_{o,CB} = R_L \parallel r_{o2}\left(1 + g_{m2}R_{o,CE}\right)}$$

Zero out the input → same as the emitter-degenerated circuit!

Small Signal Equivalent Circuit (2)

- Cascaded CE-CB



$$R_{o,CB} = R_L \parallel r_{o2}\left(1 + g_{m2}r_{o1}\right)$$

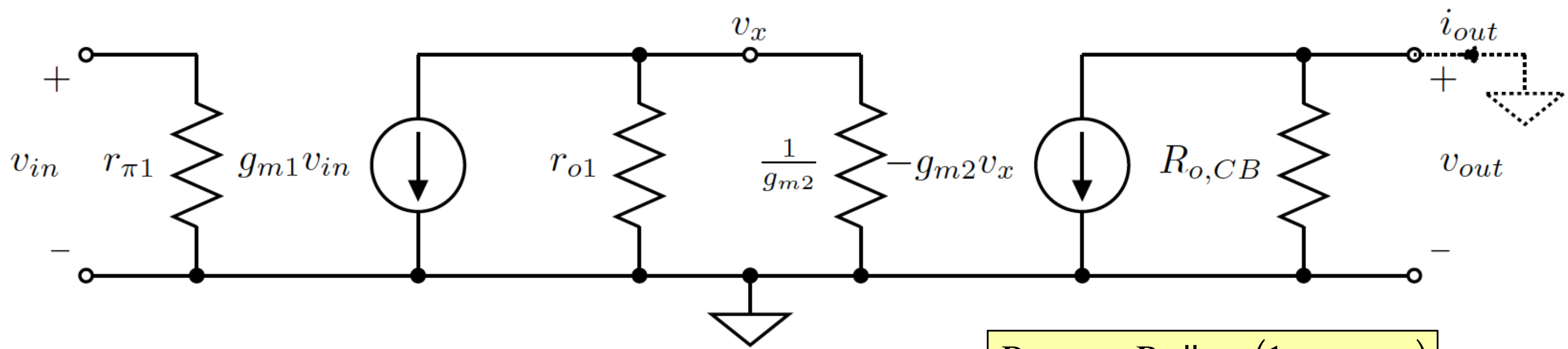
Transconductance:

$$G_{m,casc} = \frac{i_{out}}{v_{in}} = \left(-g_{m1} \cdot \left(r_{o1} \parallel \frac{1}{g_{m2}}\right)\right) \cdot \left(-g_{m2}\right) \approx g_{m1}\frac{g_{m2}}{g_{m2}} \approx g_{m1}$$

Small Signal Equivalent Circuit (3)

- Cascaded CE-CB

$$G_{m,casc} \approx g_{m1}$$



$$R_{o,casc} = R_L \parallel r_{o2}\left(1 + g_{m2}r_{o1}\right)$$

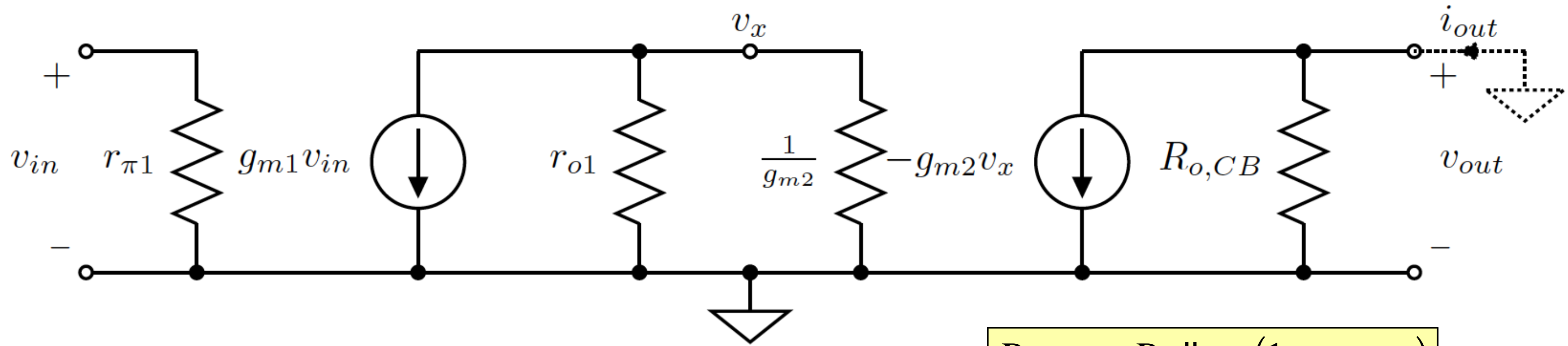
Voltage gain:

$$A_{v,casc} = -G_{m,casc}R_{o,casc} = -g_{m1}\cdot\left(R_L \parallel r_{o2}\left(1 + g_{m2}r_{o1}\right)\right)$$

Small Signal Equivalent Circuit (4)

- Cascaded CE-CB

$$G_{m,casc} \approx g_{m1}$$



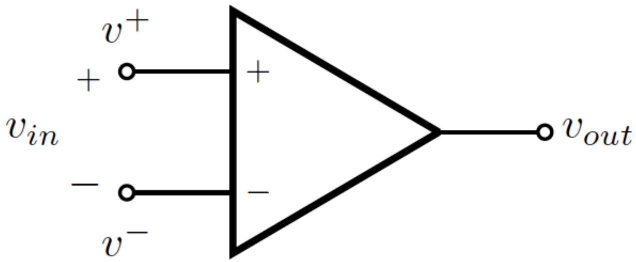
$$R_{o,casc} = R_L \parallel r_{o2}\left(1 + g_{m2} r_{o1}\right)$$

Maximum voltage gain: $R_L \rightarrow \infty$

$$a_{o,casc} = -g_{m1} \cdot r_{o2}\left(1 + g_{m2} r_{o1}\right) \approx -g_{m1} r_{o1} g_{m2} r_{o2} \approx -g_m^2 r_o^2$$

Operational Amplifiers (1)

- The ideal op-amp



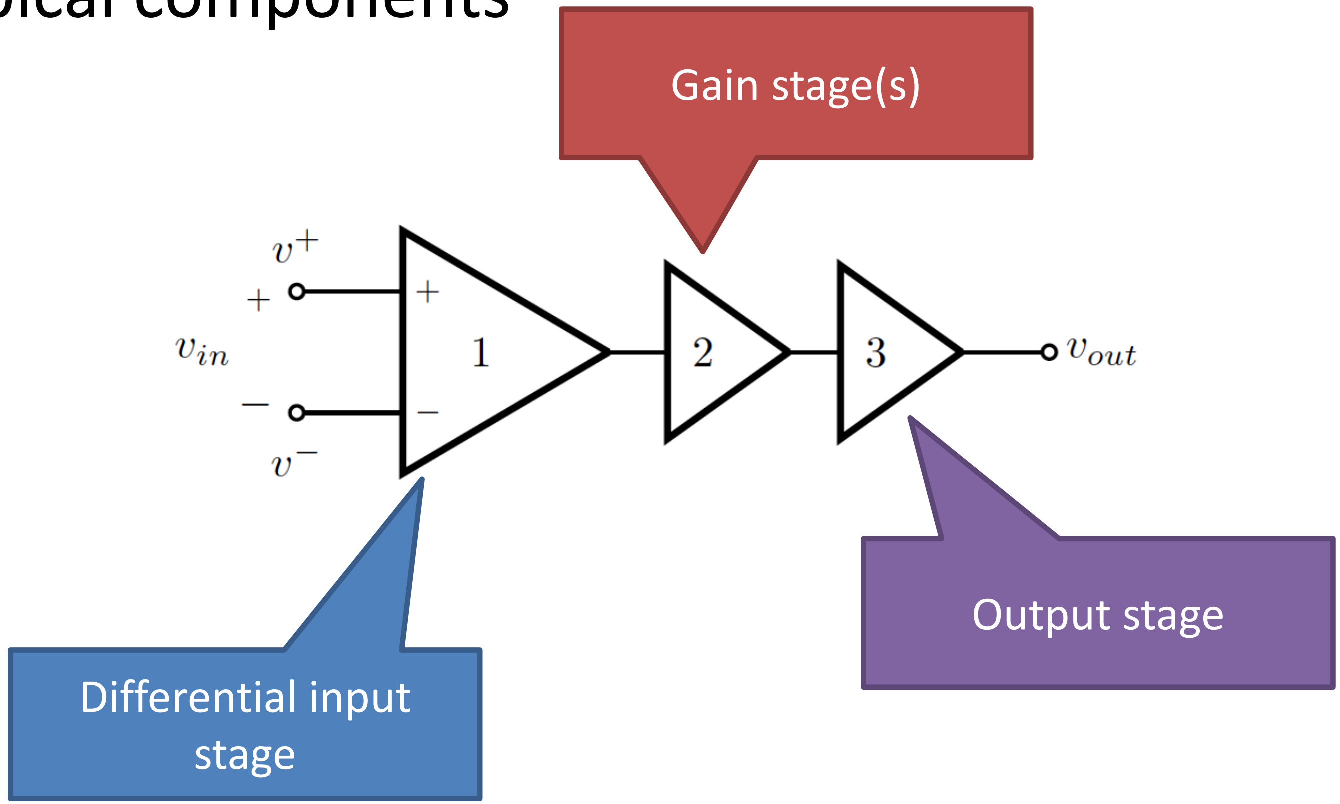
Characteristics:

1. Differential inputs
2. Single-ended output
3. Infinite gain
4. Infinite input resistance
5. Zero output resistance

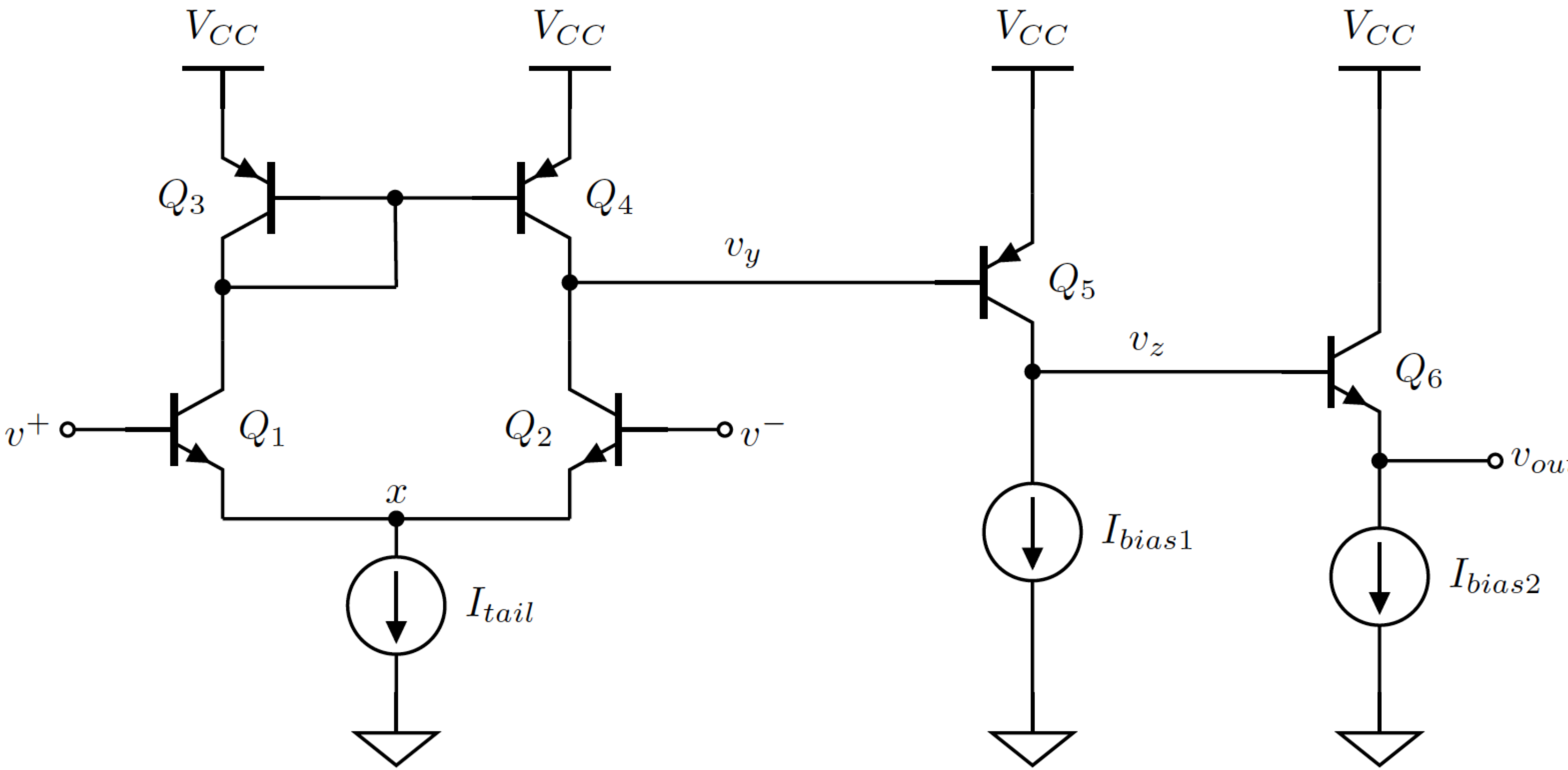
Can we build an ideal op-amp?

Operational Amplifiers (2)

- Typical components



A Simple BJT Operational Amplifier



Midterm Review

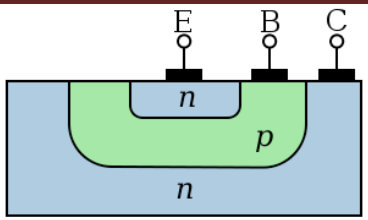
Exam Coverage

- Transistor Models
  - Large signal
  - Small signal
- Amplifiers
  - Single-stage
  - Differential amplifiers
  - Compound amplifiers
- Current Sources

Midterm Exam:

- March 24, 2018
- 1pm – 4pm
- Bring a pen and calculator

Transistor Models



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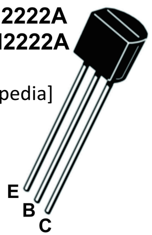
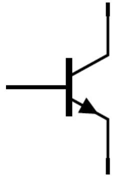
[wikipedia]





transistor operation

device characterization

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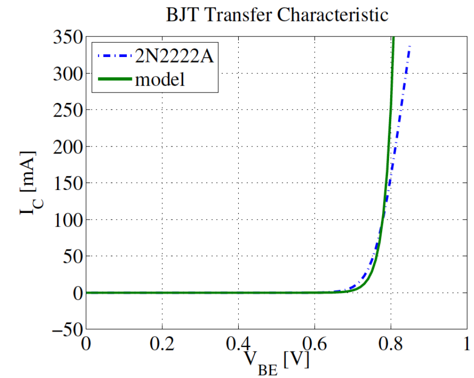

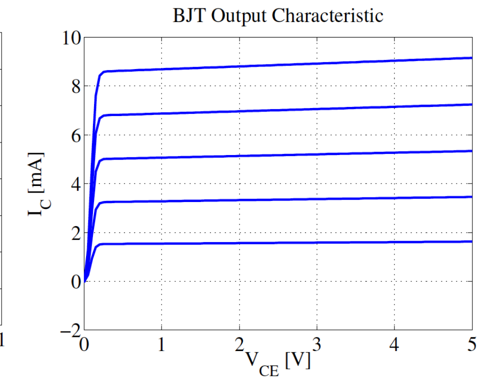

large signal terminal behavior (I-V curves)

device models

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I-V models (**large signal** approximation)

$$I_C = I_S\left(e^{\frac{V_{BE}}{V_T}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right) \qquad I_B = \frac{1}{\beta} I_C$$

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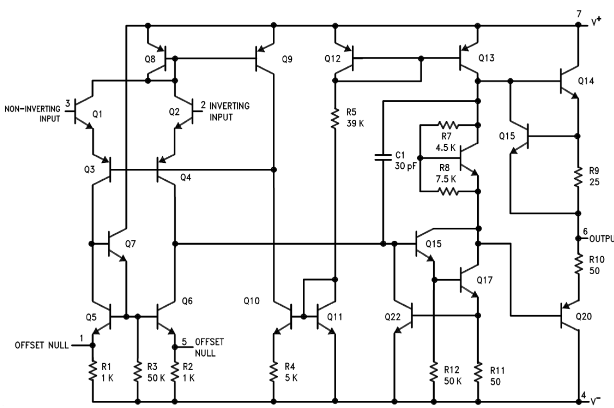
?



transistor circuits

Two Ways to Bridge the Gap

The complex, non-intuitive, non-extendable way…

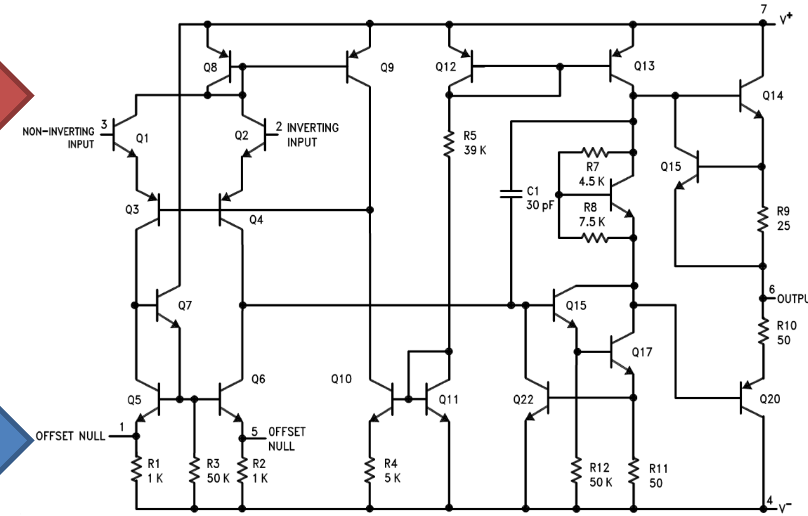
I-V models
(**large signal** transfer,
input and output
characteristics)

$$I_C = I_S\left(e^{\frac{V_{BE}}{V_T}} - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$I_B = \frac{1}{\beta} I_C$$

direct application
of KCL and KVL

linearization +
two-port network
reduction

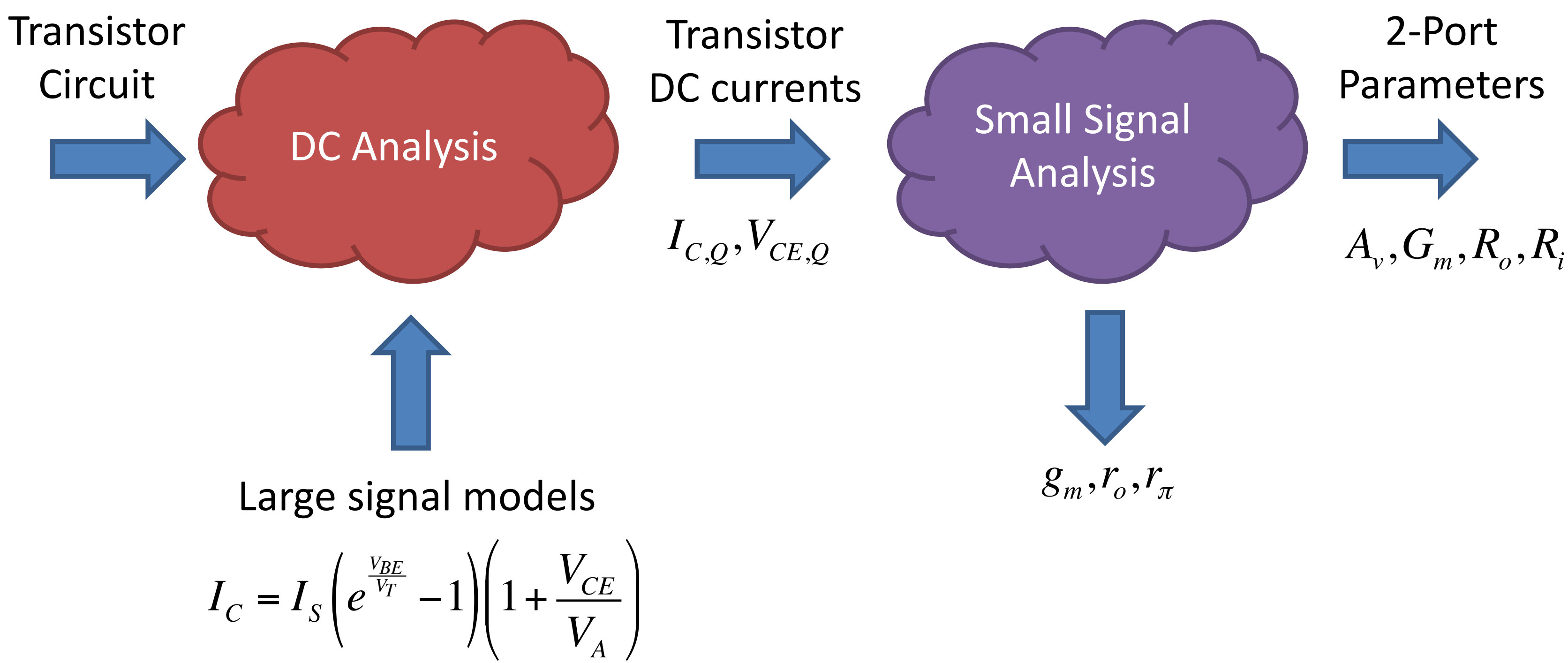


transistor circuits

EEE 51 way (aka the fun way ☺)

- Allows us to use our EEE 31, 33 skills
- Allows us to break up large circuits into smaller ones
- Gives us more intuition in terms of circuit operation

Transistor Amplifier Analysis

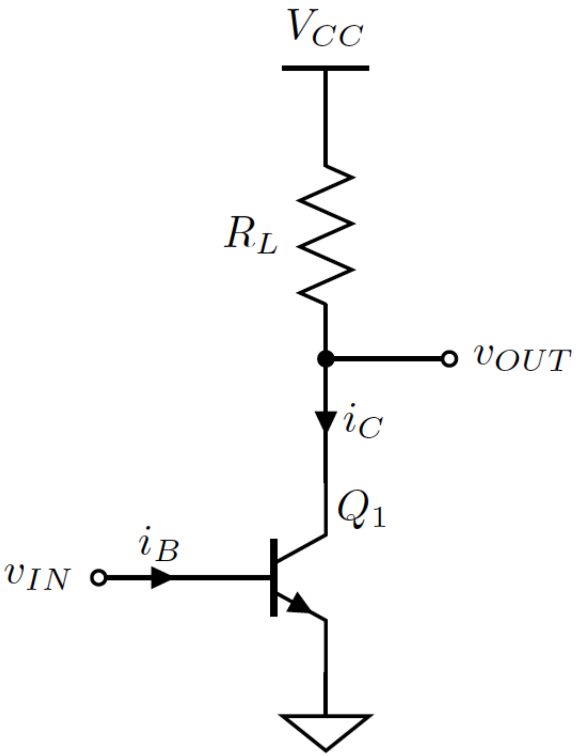


Single-Stage Amplifiers

	CE/CS	CB/CG	CC/CD
G_m	g_m	$-g_m$	$-g_m$
R_o	$r_o \parallel R_L$	$r_o \parallel R_L$	$\frac{R_L}{1+g_m R_L}$
R_i	r_π	$\frac{1}{g_m}$	r_π
A_v	$-g_m\left(r_o \parallel R_L\right)$	$g_m\left(r_o \parallel R_L\right)$	$\frac{g_m R_L}{1+g_m R_L}$

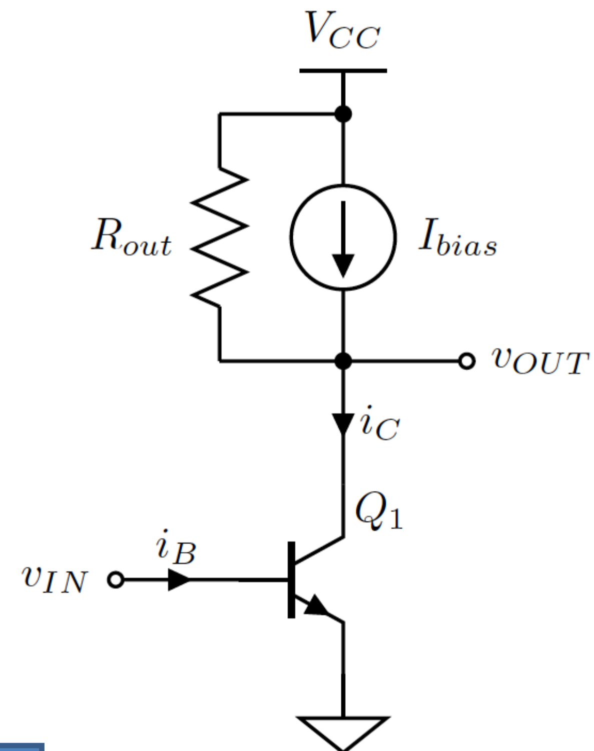
Can we use this diverse set of characteristics to create better amplifiers?

Implications of Using Current Source for Biasing



Spot the difference?

vs.

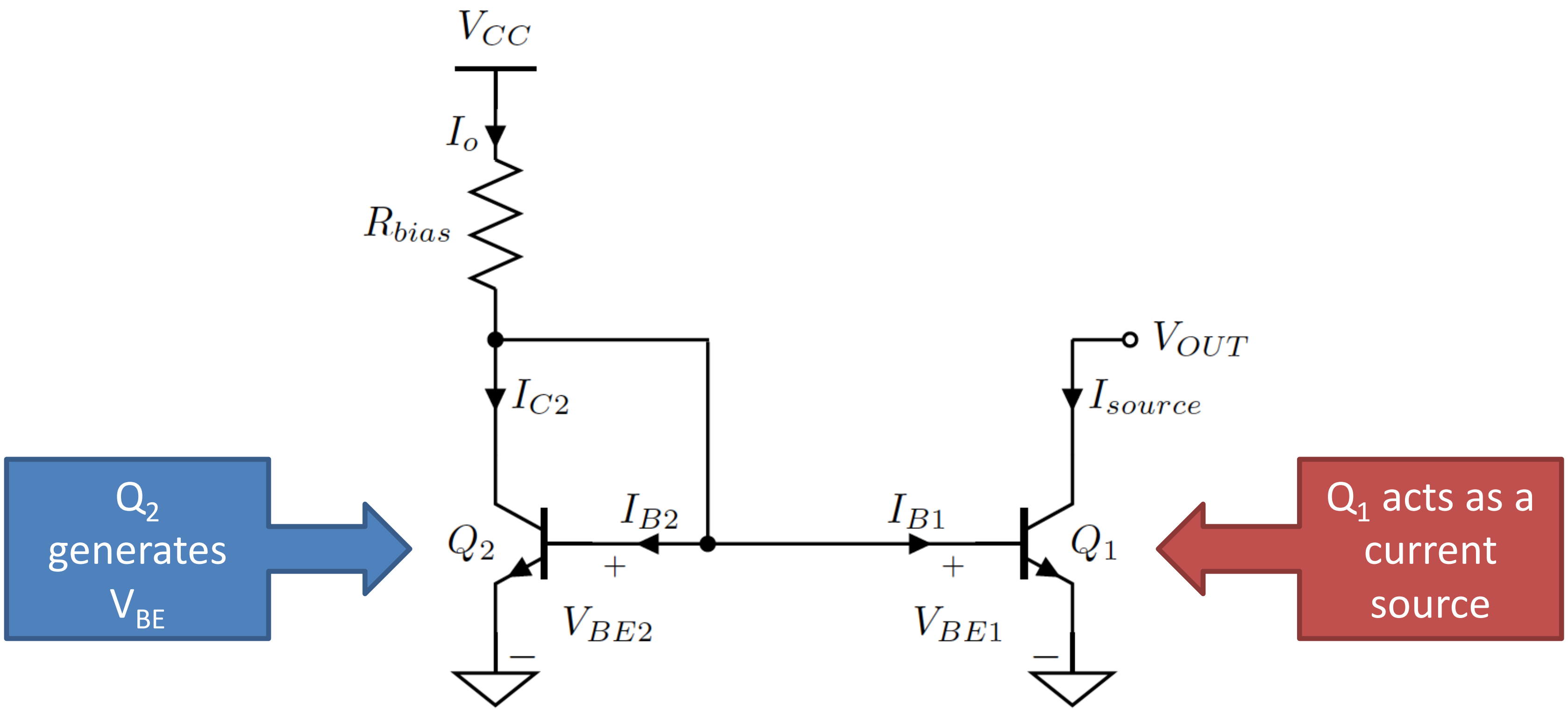


$$A_v = -g_m\left(r_o \parallel R_L\right)$$

To increase A_v, increase R_L and R_{out}

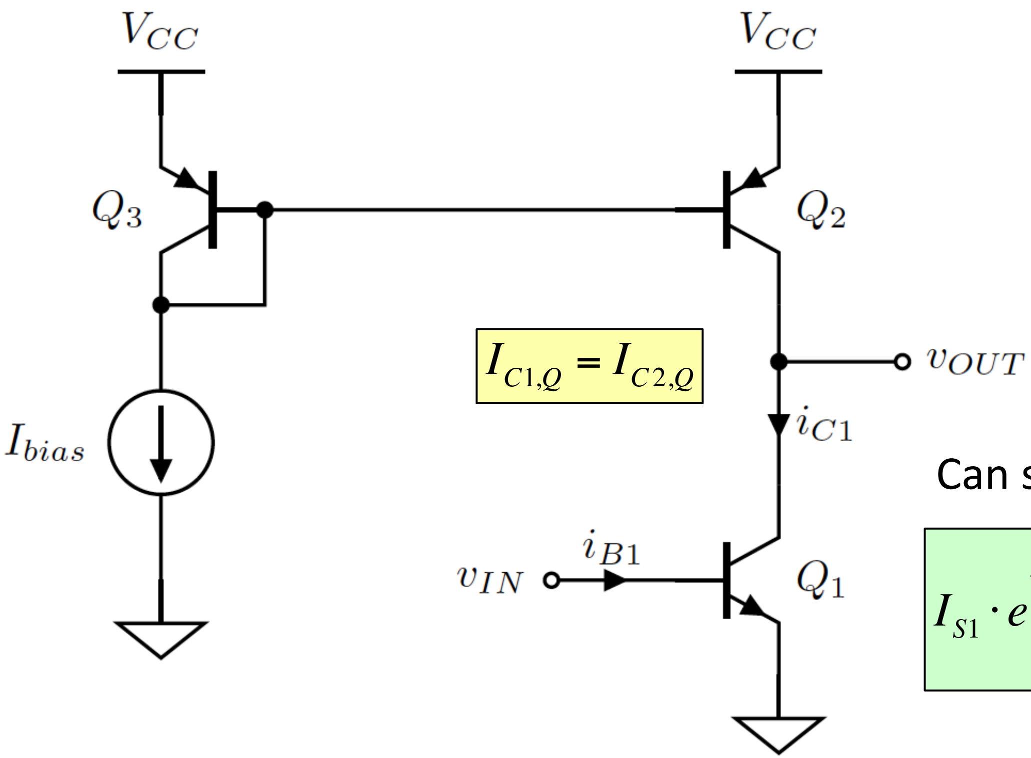
$$A_v = -g_m\left(r_o \parallel R_{out}\right)$$

A Simple BJT Current Mirror (1)



Biasing the Common-Emitter Amplifier (2)

- DC Analysis



$$\boxed{I_{C1,Q} = I_{C2,Q}}$$

For $V_A \rightarrow \infty$:

$$\boxed{I_{C,Q} \approx I_{bias}}$$

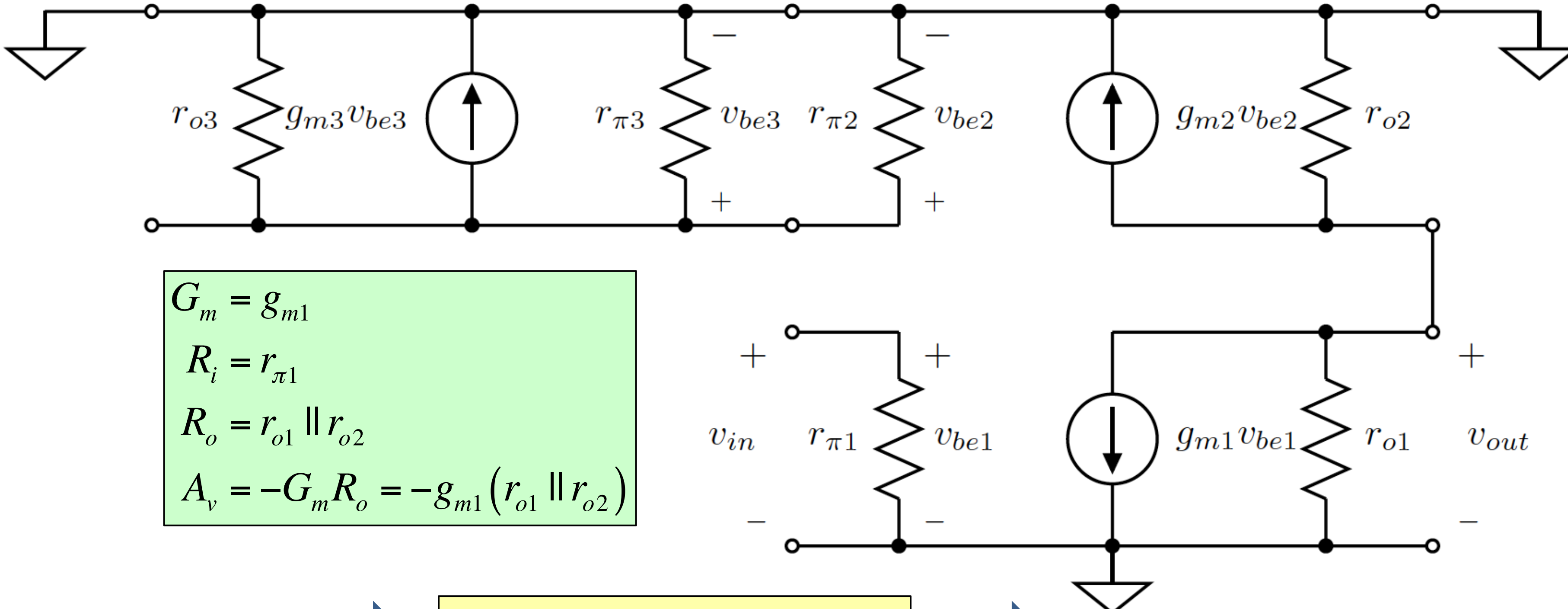
What about V_{OUT}?
→ Need finite V_A!
→ Why?

Can solve for V_{OUT}:

$$\boxed{I_{S1} \cdot e^{\frac{V_{IN}}{V_T}} \cdot \left(1 + \frac{V_{OUT}}{V_{A1}}\right) = I_{S2} \cdot e^{\frac{|V_{BE2}|}{V_T}} \cdot \left(1 + \frac{|V_{CC} - V_{OUT}|}{V_{A2}}\right)}$$

Biasing the Common-Emitter Amplifier (3)

- Small Signal Model

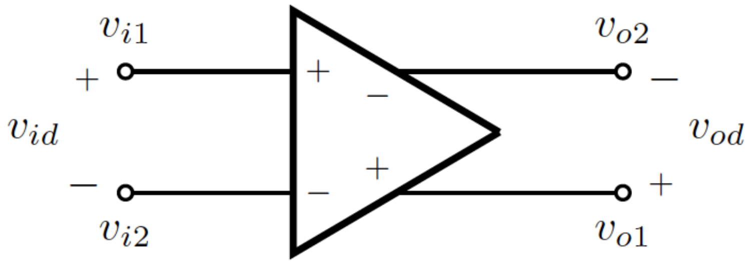


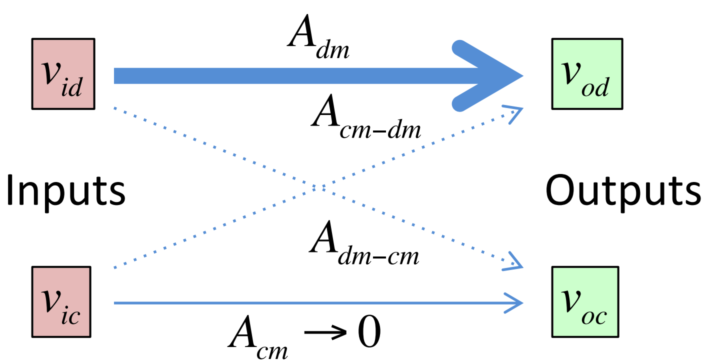
$$G_m = g_{m1}$$
$$R_i = r_{\pi 1}$$
$$R_o = r_{o1} \parallel r_{o2}$$
$$A_v = -G_m R_o = -g_{m1}\left(r_{o1} \parallel r_{o2}\right)$$

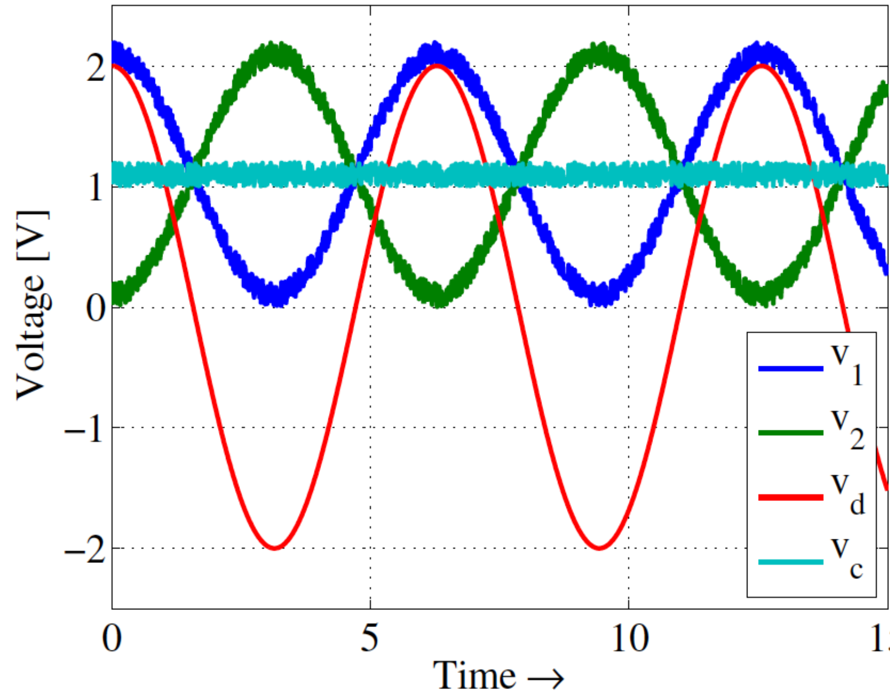
If $r_{o1} \approx r_{o2}$ → $A_v = -g_{m1}\left(r_{o1} \parallel r_{o2}\right) \approx -\dfrac{g_{m1} r_{o1}}{2}$ → Already half a_o!

Why Use Differential Signaling? (3)

- Amplify v_{id}, reject v_{ic}





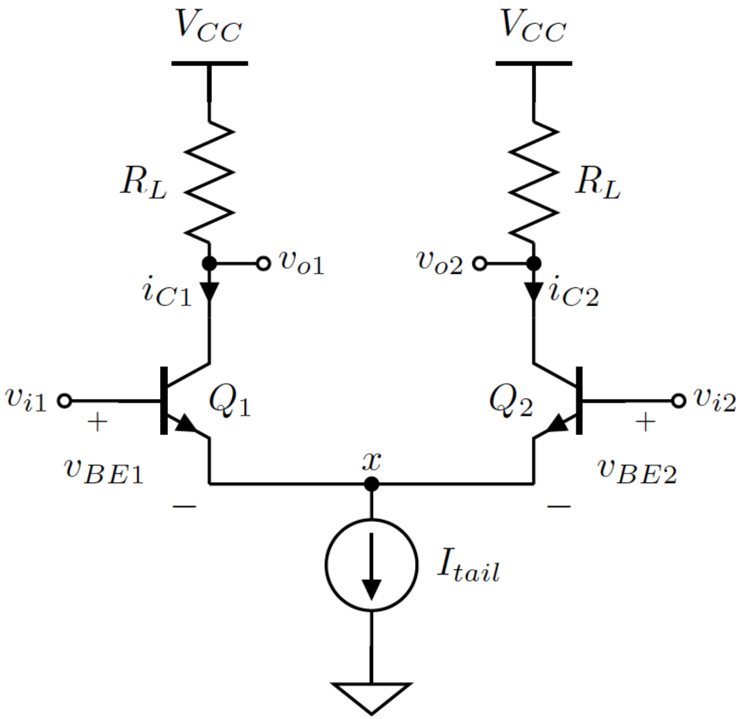


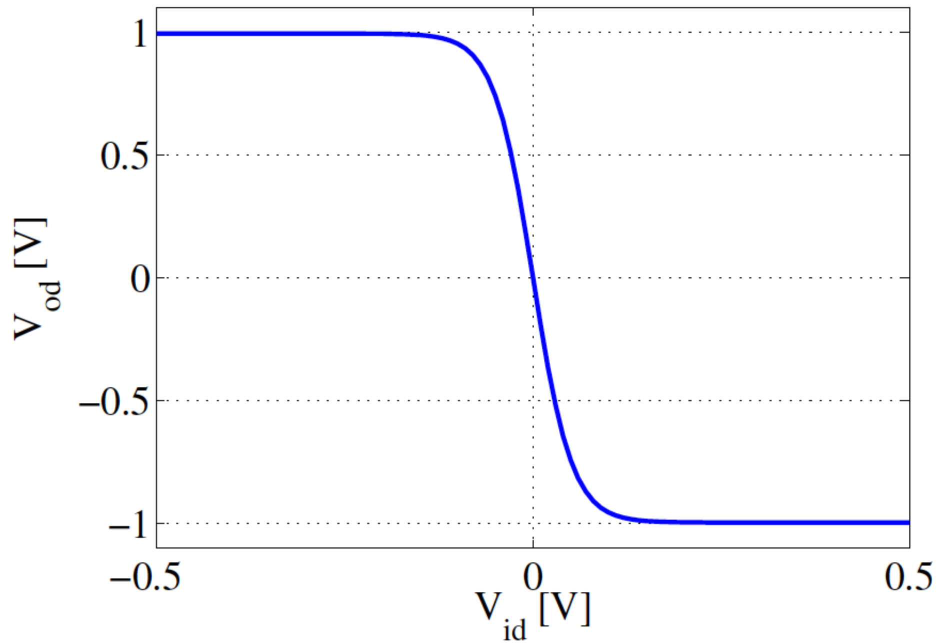
Metric:
Common-Mode Rejection Ratio

$$CMRR = \left| \frac{A_{dm}}{A_{cm}} \right|$$

Basic Building Block: The Differential Pair (5)

- Transfer Characteristic

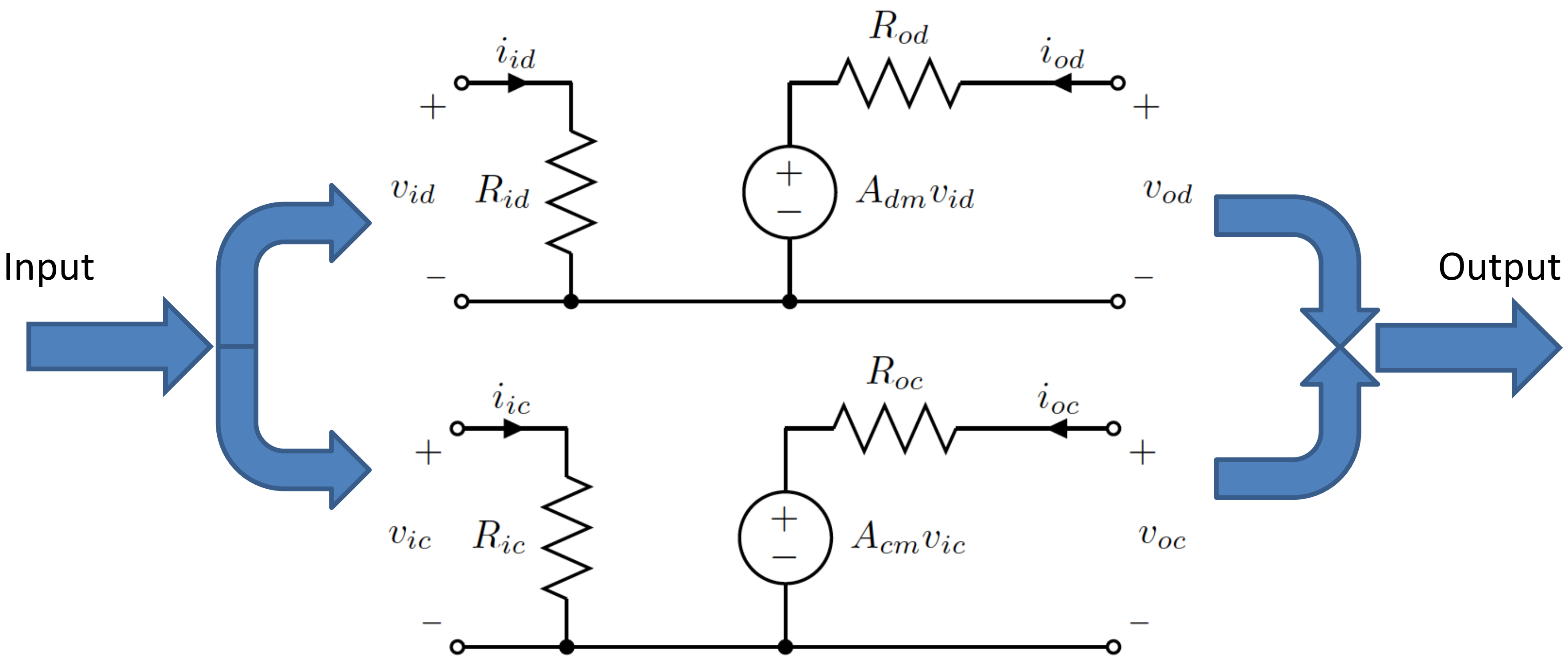




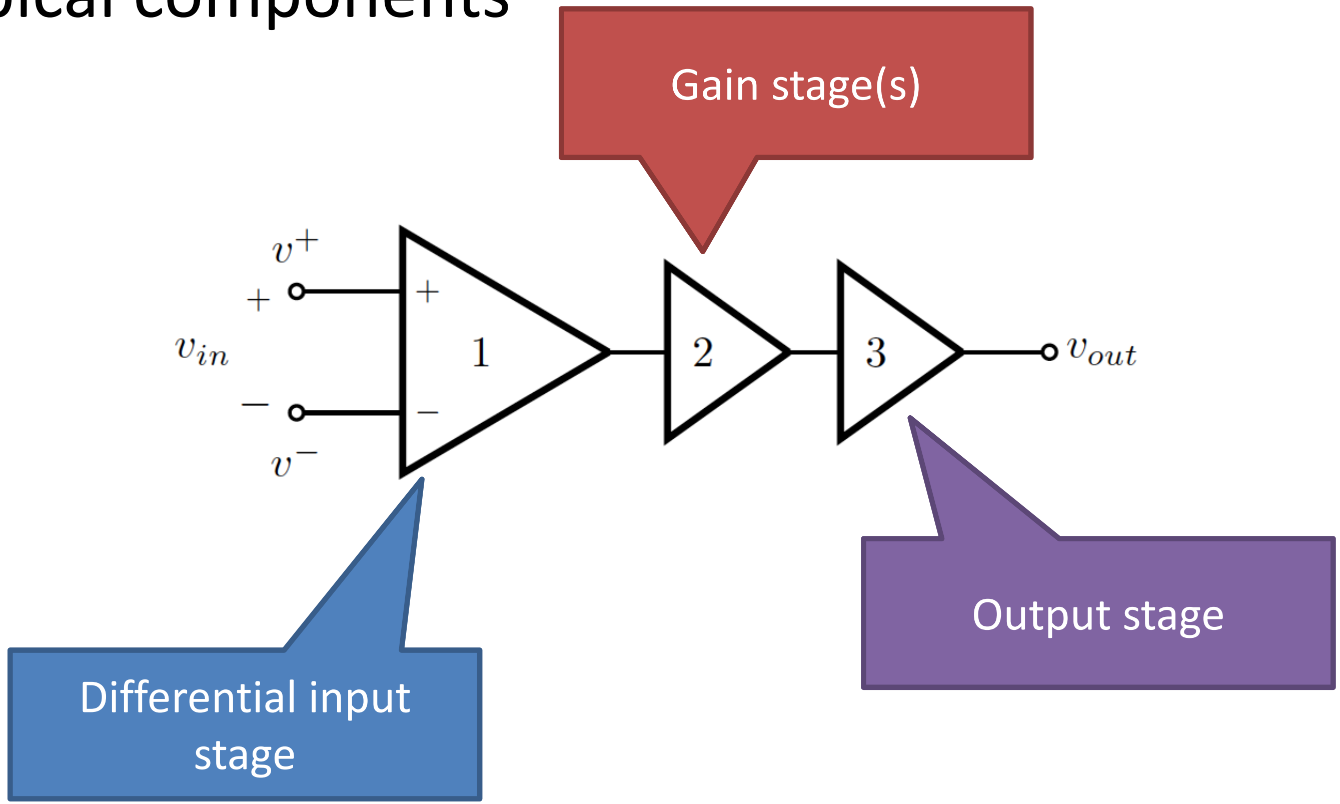
$$V_{od} = \alpha \cdot I_{tail} \cdot R_L \cdot \tanh\left(-\frac{V_{id}}{2 \cdot V_T}\right)$$

Differential vs. Common-Mode

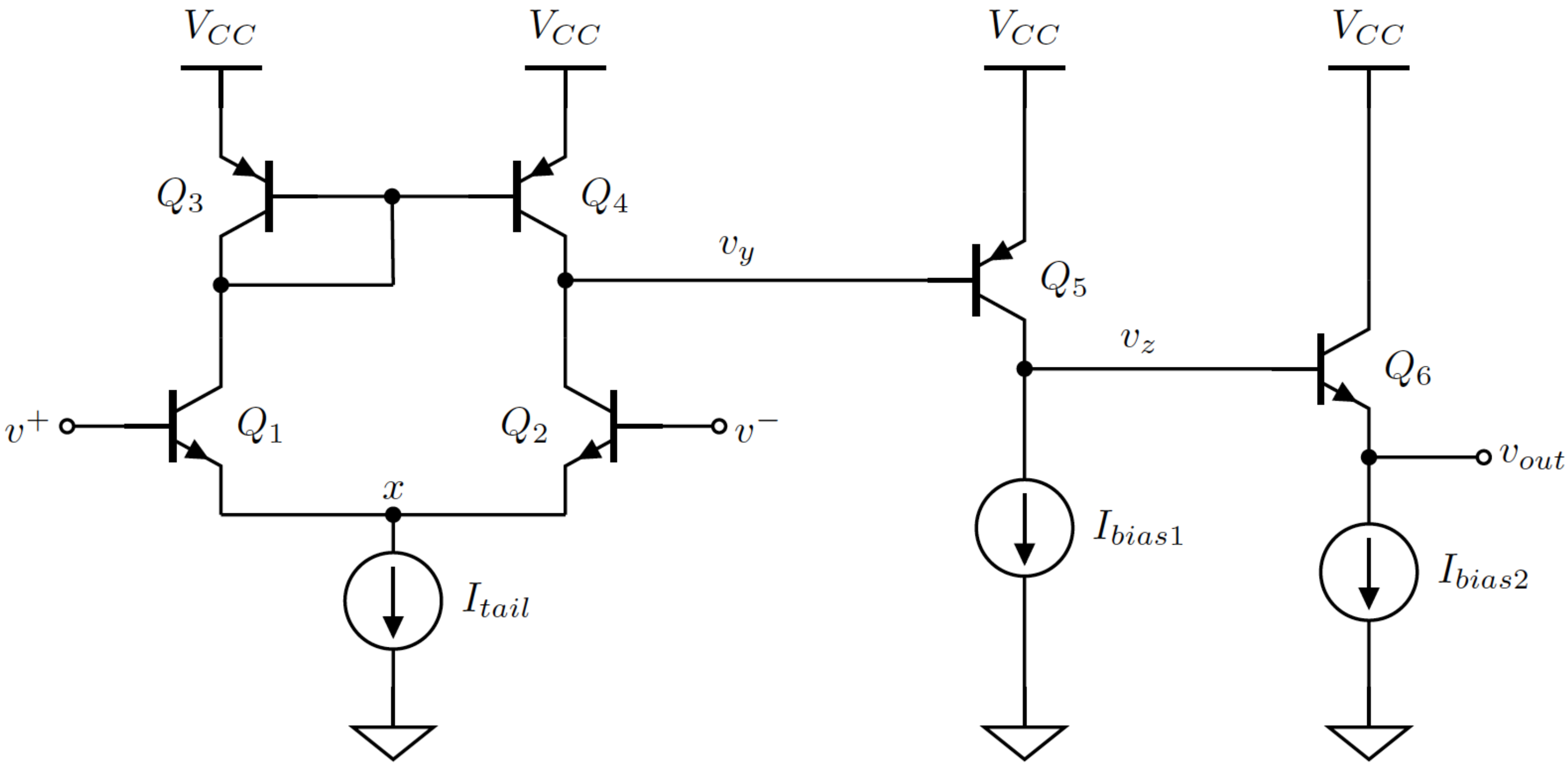
- The amplifier processes the two signals differently!



- Typical components



A Simple BJT Operational Amplifier



Next Meeting

- Frequency Response of Amplifiers
  - You will need to remember your EEE 35 concepts