EEE 51: Second Semester 2017 - 2018

Lecture 13

Compound Amplifiers

Today

- Compound Amplifiers
  - CE-CC
  - CB-CE
  - CE-CB (Cascode)

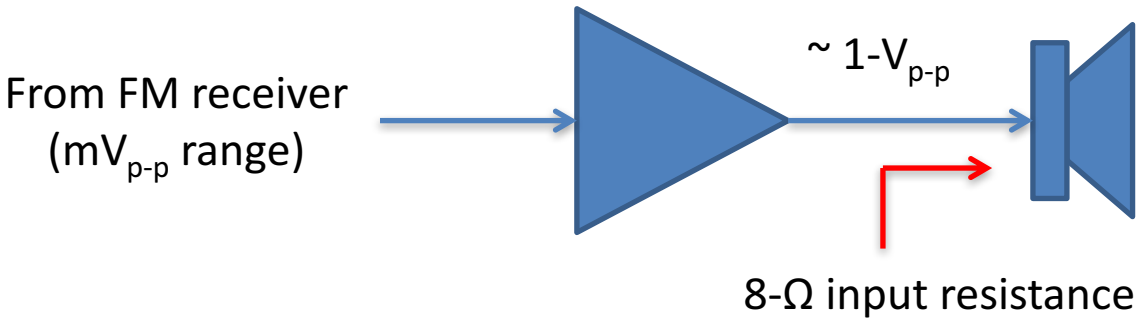
Limitations of Using Single-Stage Amplifiers

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

Can we “mix-and-match” these parameters?

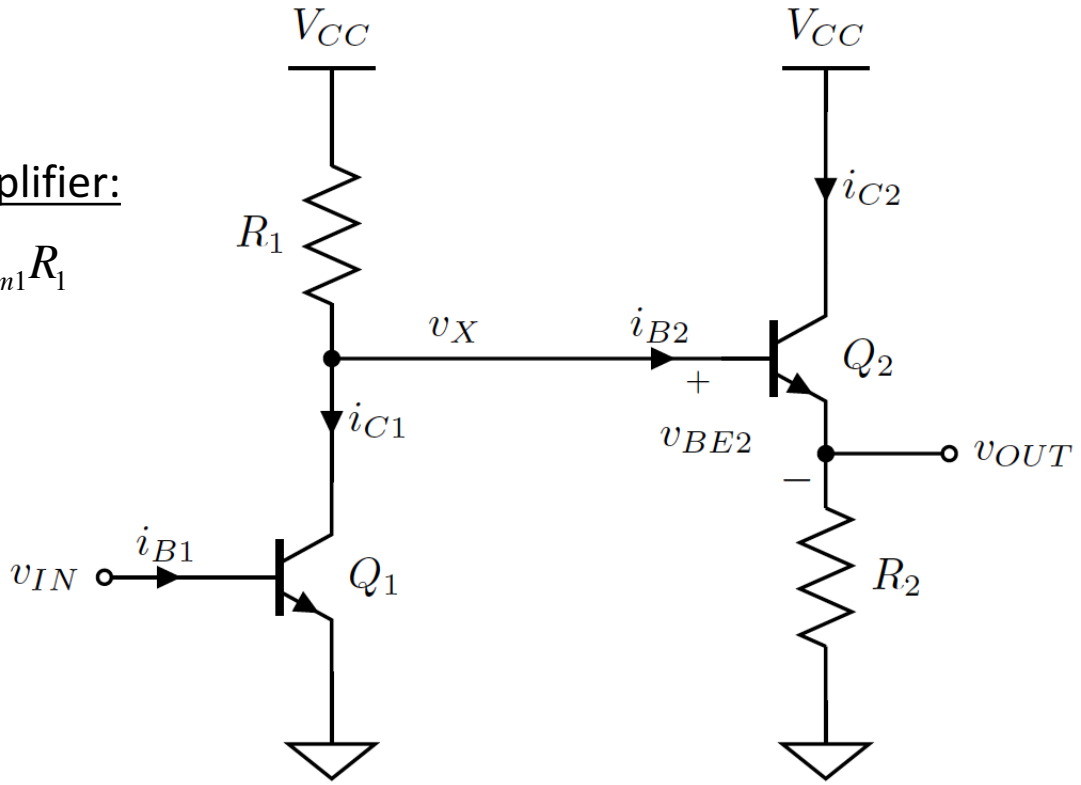
Example: Audio Amplifiers

- Basic Idea:
  - Need large gain
  - Need to drive small resistances



Which amplifier topology can we use?

One Option: The CE-CC Amplifier



The CE amplifier:

$$A_{v,CE} = -g_{m1}R_1$$

$$R_{o,CE} = R_1$$

$$R_{i,CE} = r_{\pi 1}$$

The CC amplifier:

$$A_{v,CC} = \frac{g_{m2}R_2}{1+g_{m2}R_2} \approx 1$$

$$R_{o,CC} = \frac{R_2}{1+g_{m2}R_2} \approx \frac{1}{g_{m2}}$$

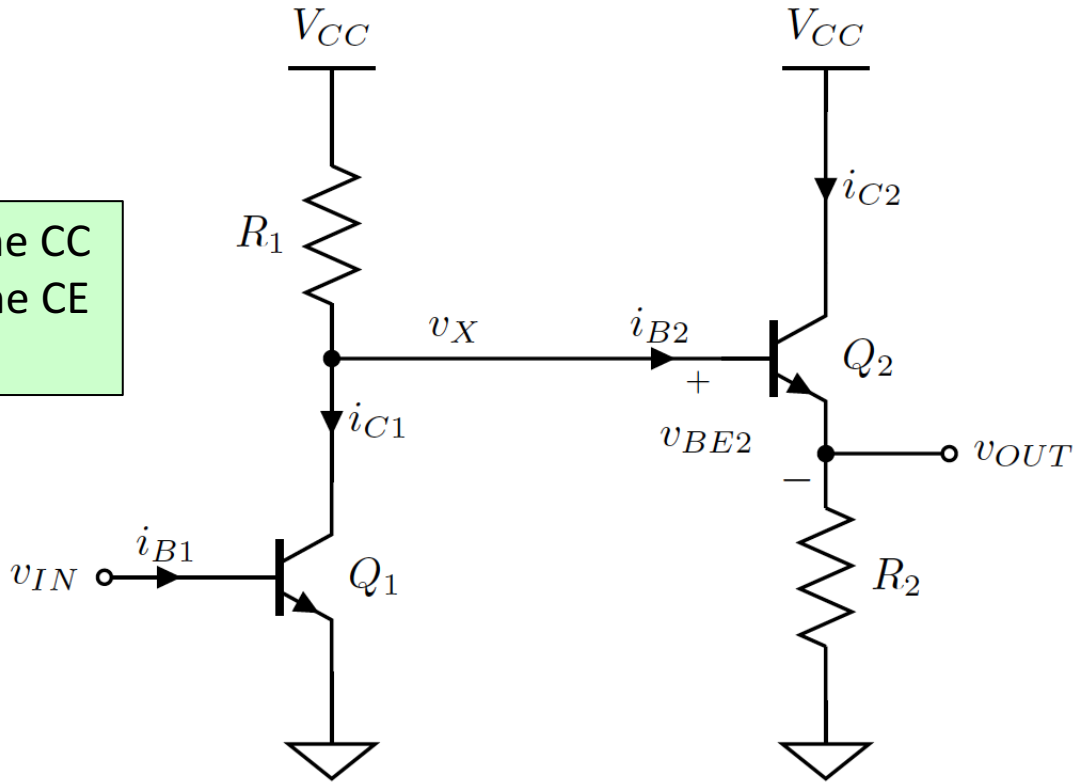
$$R_{i,CC} = r_{\pi 2}\left(1+g_{m2}R_2\right)$$

Possibly a good match! What about the DC voltages and currents?

The CE-CC Amplifier

- DC Analysis:

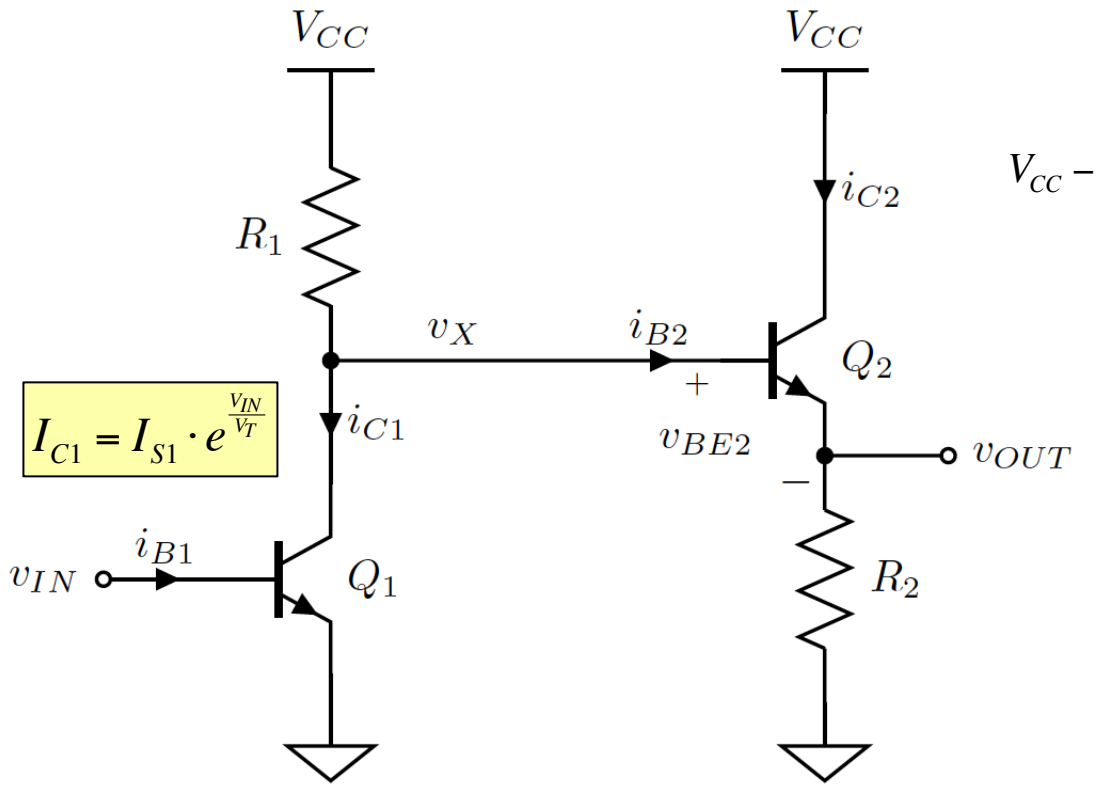
The DC input voltage of the CC amplifier is provided by the CE amplifier…



The two collector currents are NOT independent of each other!

The CE-CC Amplifier

- DC Analysis:



KVL at the interface loop to get I_{C2}:

$$V_{CC} - (I_{C1} + I_{B2})R_1 - V_{BE2} - I_{E2}R_2 = 0$$

$$V_{CC} - I_{S1} \cdot e^{\frac{V_{IN}}{V_T}} \cdot R_1 - \frac{I_{C2}}{\beta_2}R_1 - V_T \ln\left(\frac{I_{C2}}{I_{S2}}\right) - \frac{I_{C2}}{\alpha_2}R_2 = 0$$

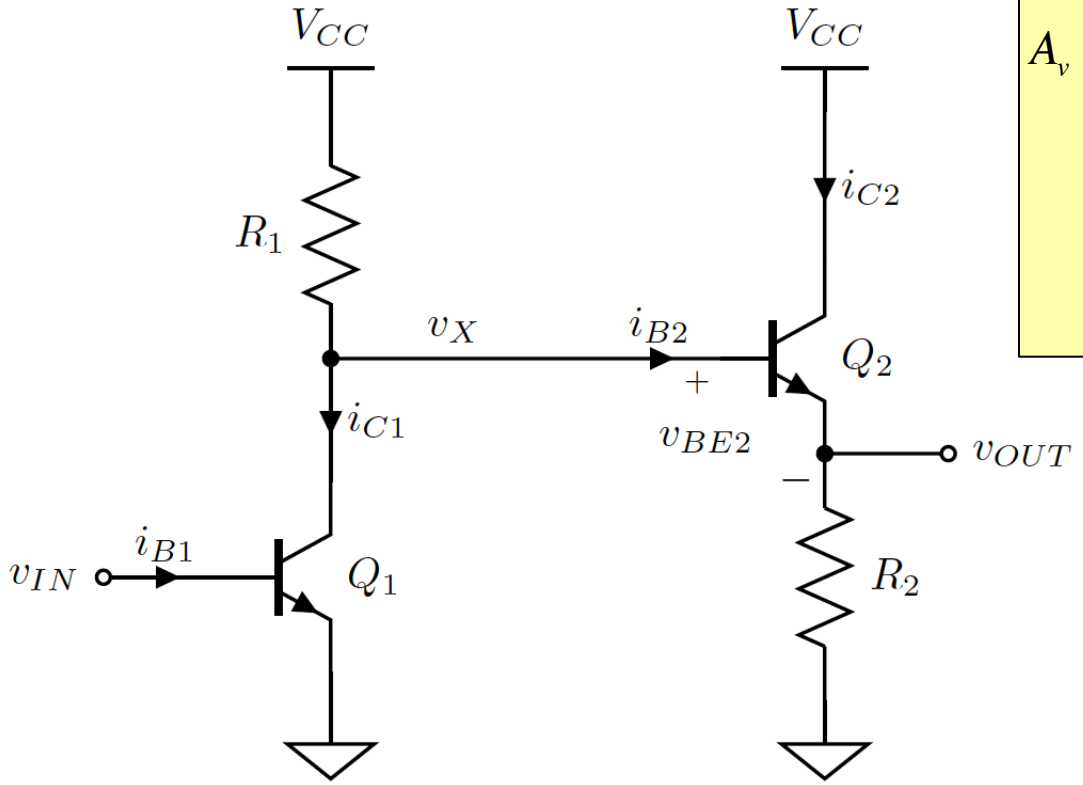
Estimate using relative values

$$V_{CC} - I_{S1} \cdot e^{\frac{V_{IN}}{V_T}} \cdot R_1 - 0.7\text{V} - I_{C2}R_2 = 0$$

$$I_{C2} \approx \frac{V_{CC} - I_{S1} \cdot e^{\frac{V_{IN}}{V_T}} \cdot R_1 - 0.7\text{V}}{R_2}$$

The CE-CC Amplifier

- Small Signal Analysis:



$$A_v = A_{v,CE} \cdot \frac{R_{i,CC}}{R_{i,CC} + R_{o,CE}} \cdot A_{v,CC}$$

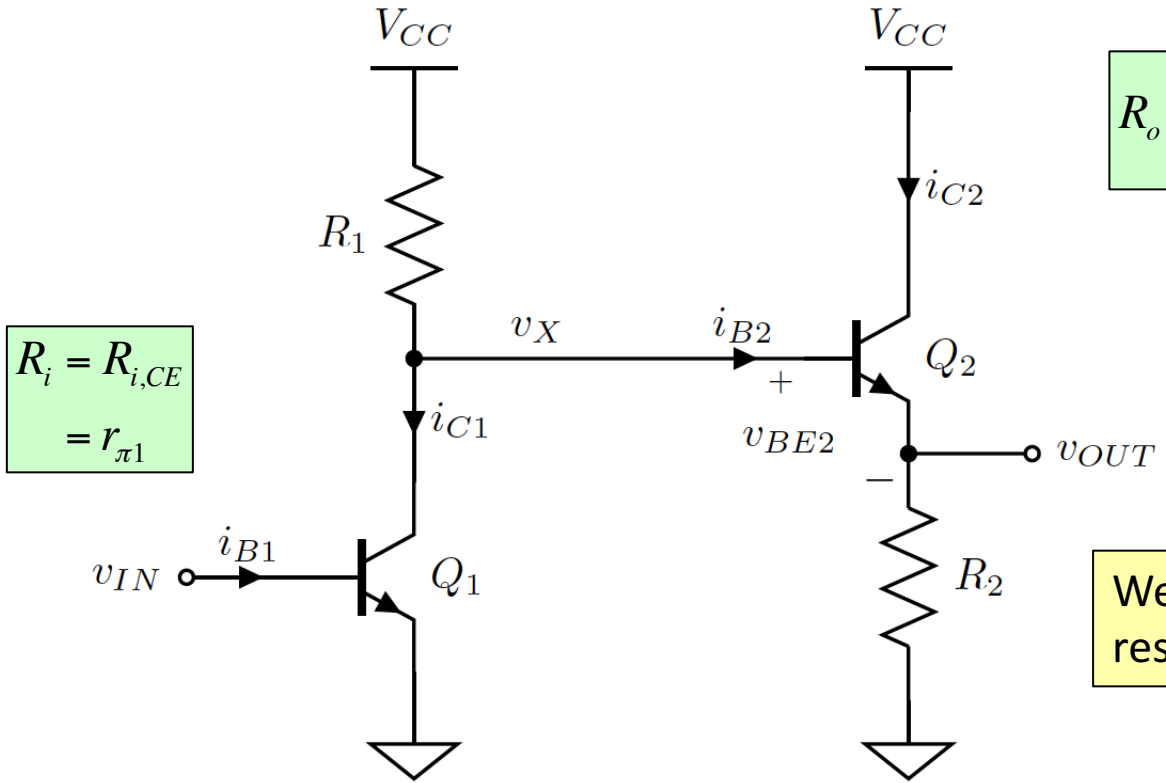
$$= -g_{m1} R_1 \cdot \frac{r_{\pi 2}\left(1 + g_{m2} R_2\right)}{r_{\pi 2}\left(1 + g_{m2} R_2\right) + R_1} \cdot \frac{g_{m2} R_2}{1 + g_{m2} R_2}$$

$$\approx -g_{m1} R_1$$

Gain is dominated by the CE amplifier (what we want)

The CE-CC Amplifier

- Small Signal Analysis:



$$R_i = R_{i,CE} = r_{\pi 1}$$

$$R_o = R_{o,CC} = \frac{R_2}{1 + g_{m2} R_2} \approx \frac{1}{g_{m2}}$$

Recall: $\frac{1}{g_{m2}} = \frac{V_T}{I_{C2}}$

We can control output resistance by the value of I_{C2}

Can we do the same for input resistance?

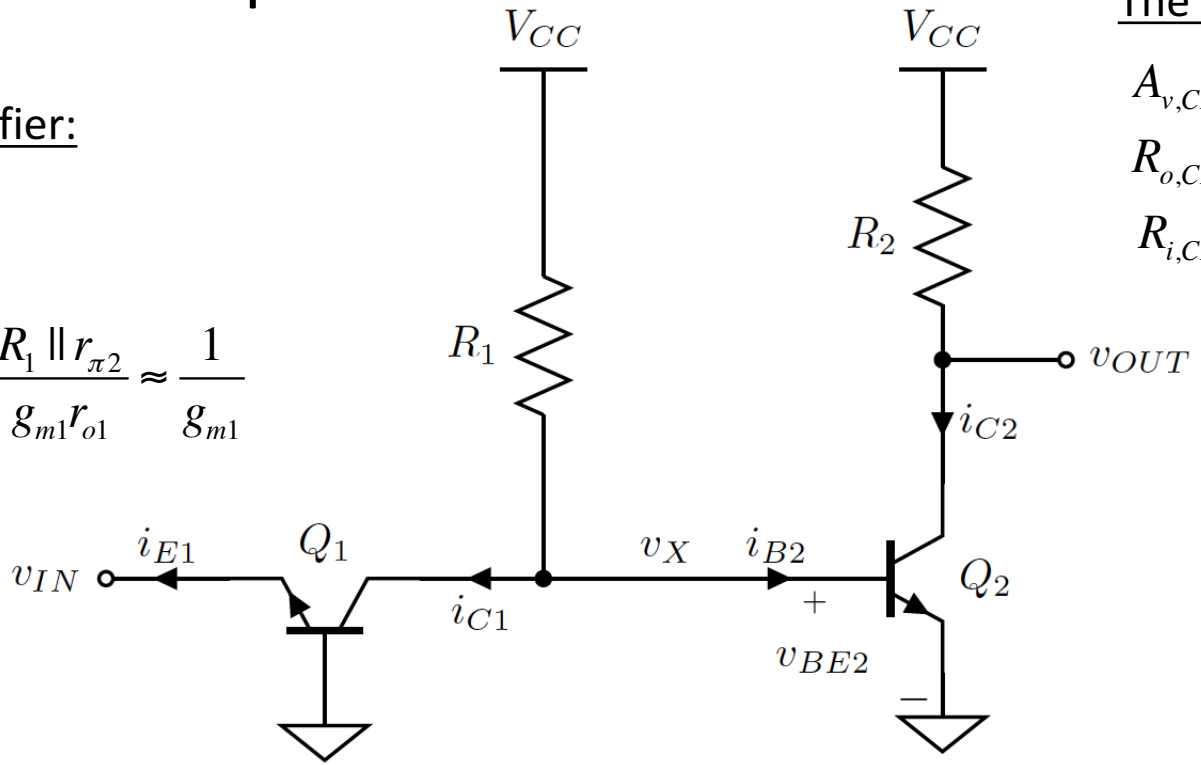
- The CB-CE Amplifier

The CB amplifier:

$$A_{v,CB} = g_{m1}R_1$$

$$R_{o,CB} = R_1$$

$$R_{i,CB} = \frac{1}{g_{m1}} + \frac{R_1 \| r_{\pi 2}}{g_{m1}r_{o1}} \approx \frac{1}{g_{m1}}$$



The CE amplifier:

$$A_{v,CE} = -g_{m2}R_2$$

$$R_{o,CE} = R_2$$

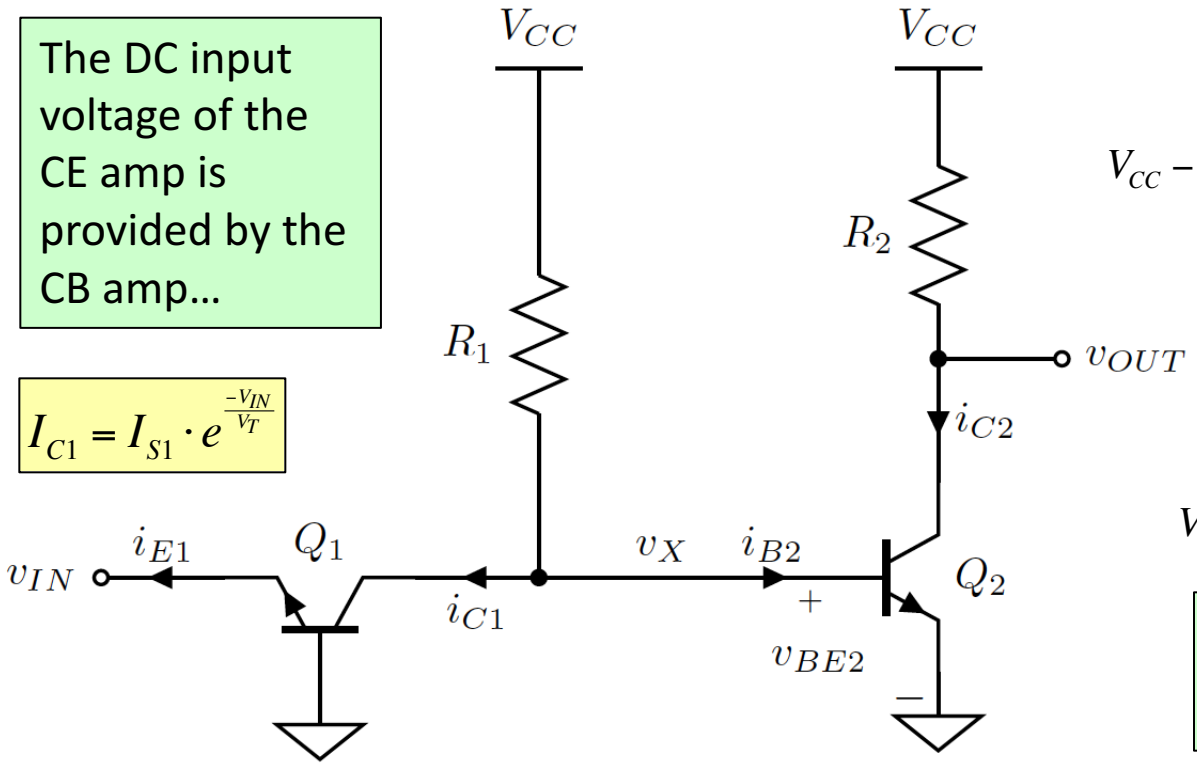
$$R_{i,CE} = r_{\pi 2}$$

The CB-CE Amplifier

- DC Analysis

The DC input voltage of the CE amp is provided by the CB amp…

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



KVL at the interface loop to get I_{C2}:

$$V_{CC} - \left(I_{C1} + I_{B2}\right) R_1 - V_{BE2} = 0$$

$$V_{CC} - I_{S1} \cdot e^{\frac{-V_{IN}}{V_T}} \cdot R_1 - \frac{I_{C2}}{\beta_2} R_1 - V_T \ln\left(\frac{I_{C2}}{I_{S2}}\right) = 0$$

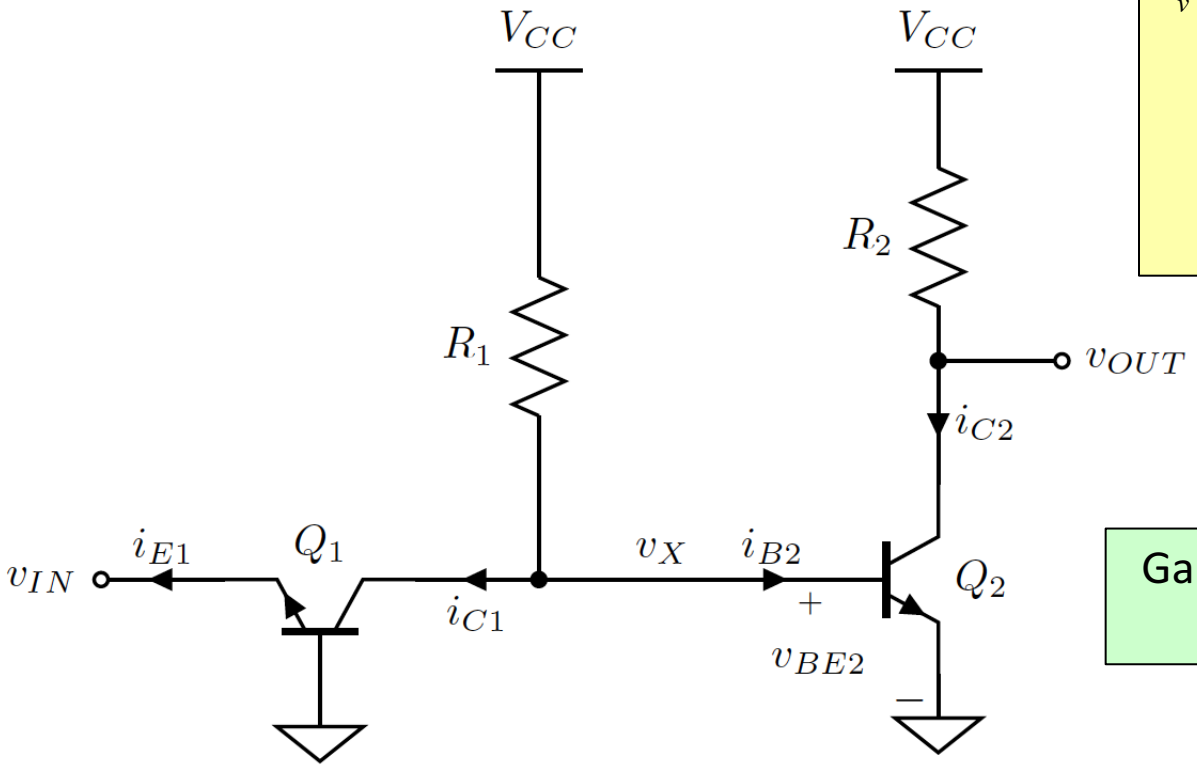
Estimate using relative values

$$V_{CC} - I_{S1} \cdot e^{\frac{-V_{IN}}{V_T}} \cdot R_1 - \frac{I_{C2}}{\beta_2} R_1 - 0.7\text{V} = 0$$

$$I_{C2} \approx \beta_2 \cdot \frac{V_{CC} - I_{S1} \cdot e^{\frac{-V_{IN}}{V_T}} \cdot R_1 - 0.7\text{V}}{R_1}$$

The CB-CE Amplifier

- Small Signal Analysis



$$A_v = A_{v,CB} \cdot \frac{R_{i,CC}}{R_{i,CC} + R_{o,CE}} \cdot A_{v,CE}$$

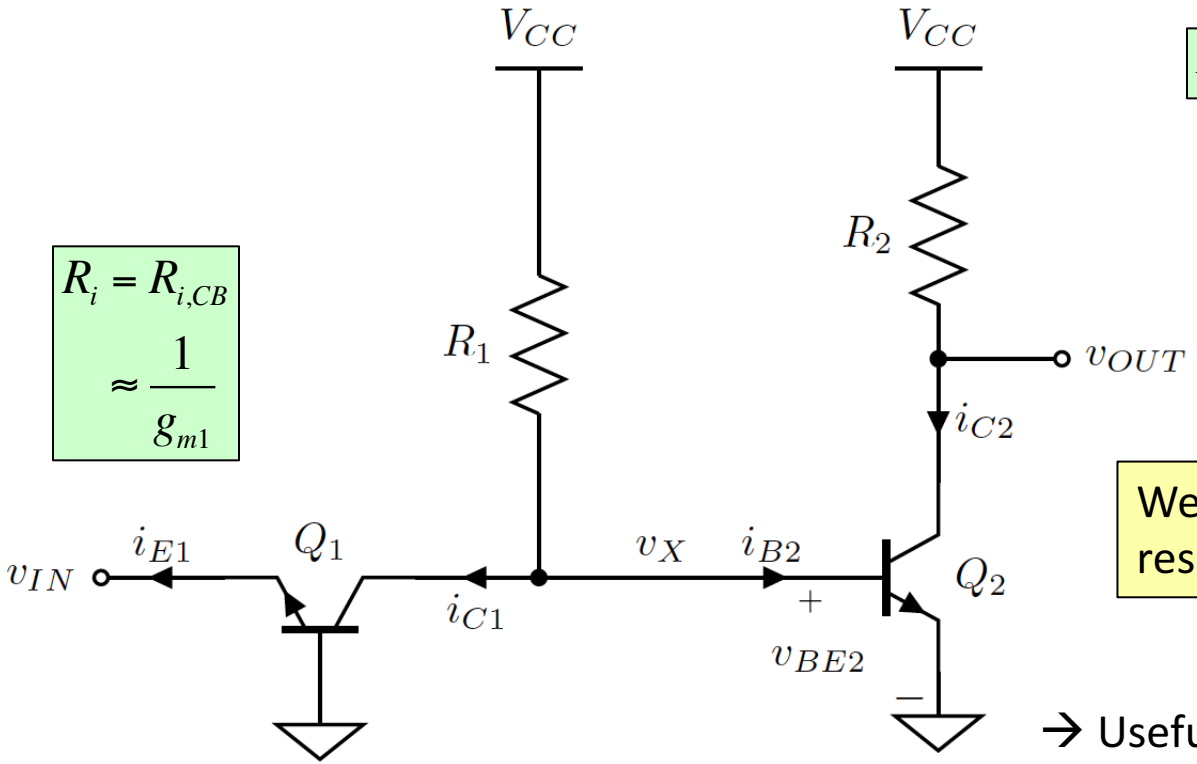
$$= g_{m1} R_1 \cdot \frac{r_{\pi 2}}{r_{\pi 2} + R_1} \cdot \left(-g_{m2} R_2\right)$$

$$\approx -g_{m1} R_1 \cdot g_{m2} R_2$$

Gain is provided by both the CB and CE stages

The CB-CE Amplifier

- Small Signal Analysis



$$R_o = R_{o,CC} = R_2$$

$$R_i = R_{i,CB} \approx \frac{1}{g_{m1}}$$

Recall: $\frac{1}{g_{m1}} = \frac{V_T}{I_{C1}}$

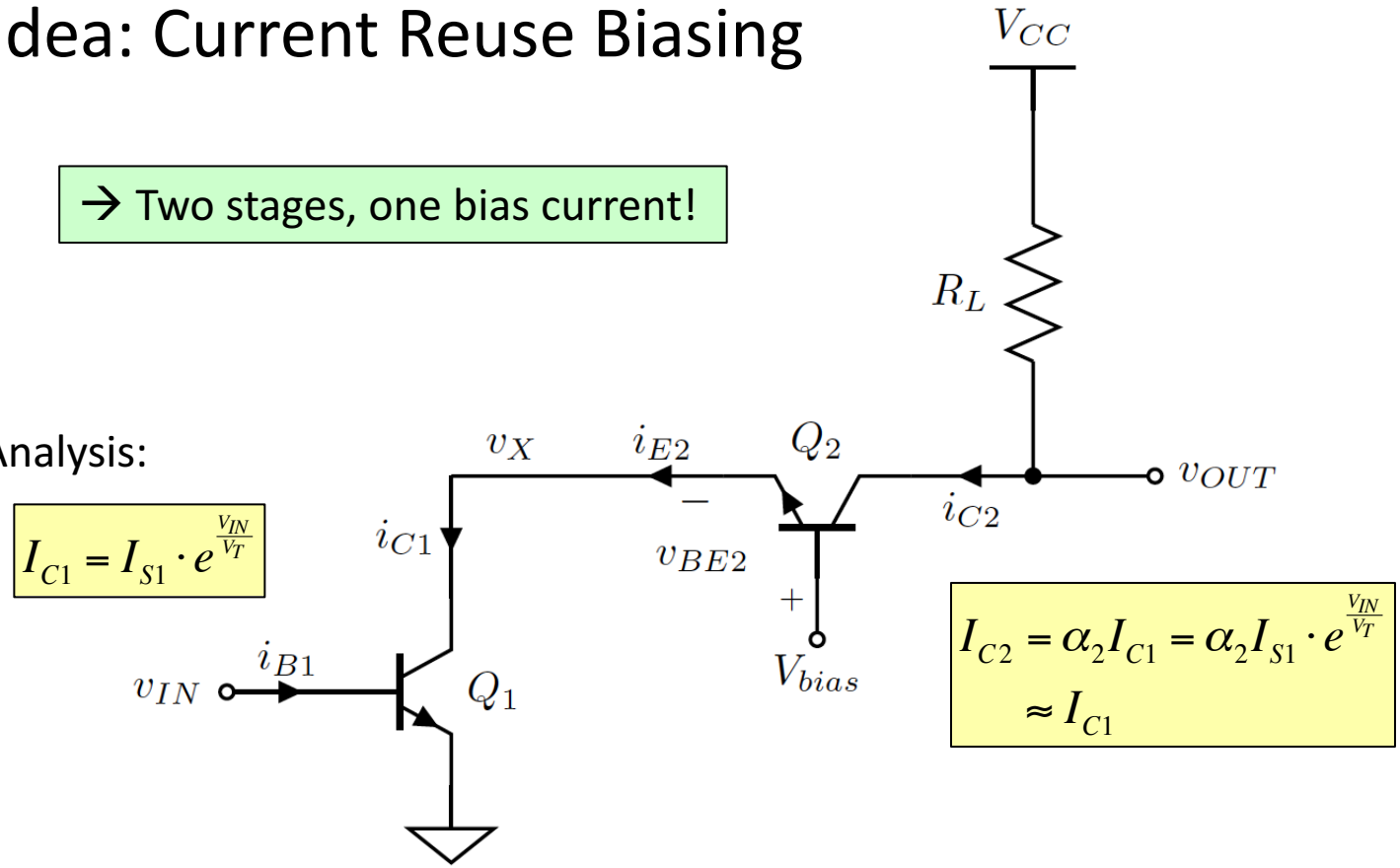
We can control input resistance by the value of I_{C1}

→ Useful for antenna/sensor interfaces

The CE-CB Amplifier (Cascode Amplifier)

- Idea: Current Reuse Biasing

→ Two stages, one bias current!



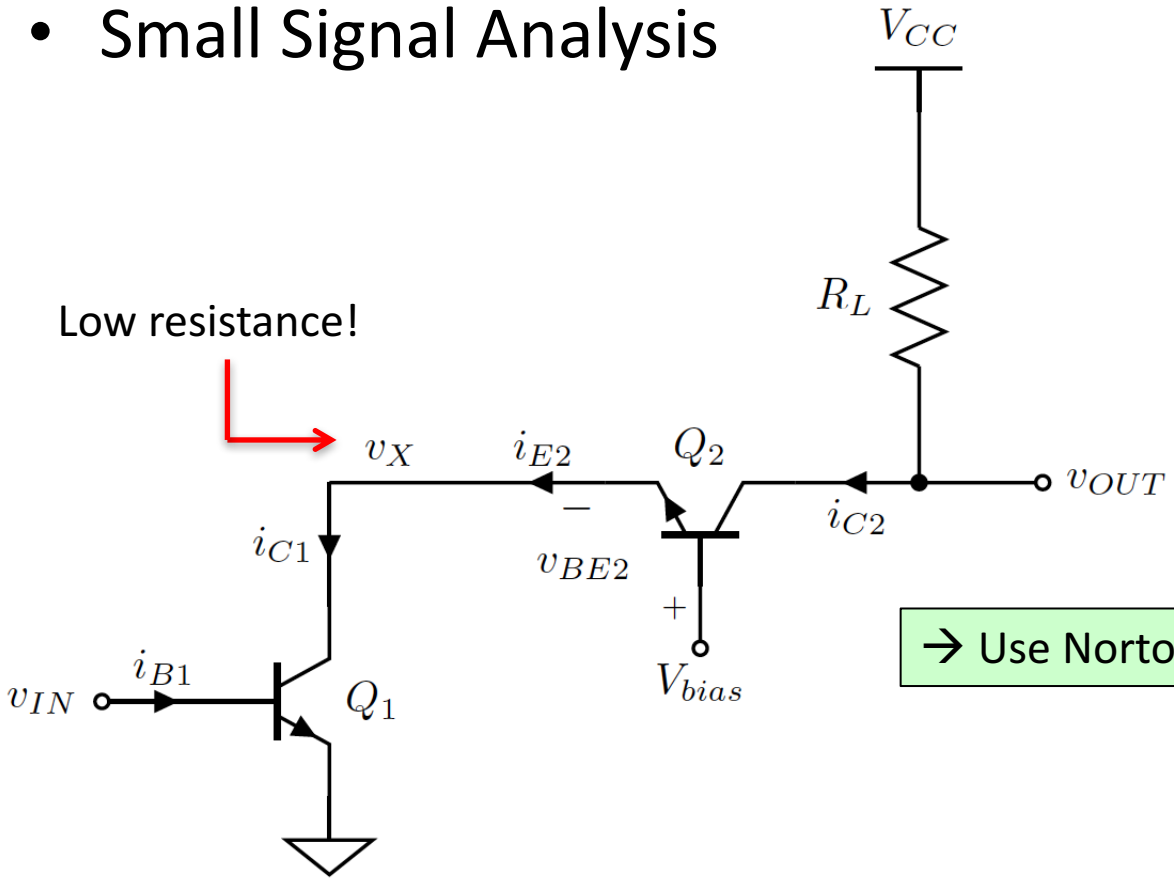
DC Analysis:

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

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

The CE-CB Amplifier (Cascode Amplifier)

- Small Signal Analysis



Expect:

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

→ Use Norton model for the CE stage

Next Meeting

- Cascode Amplifiers
- Operational Amplifiers