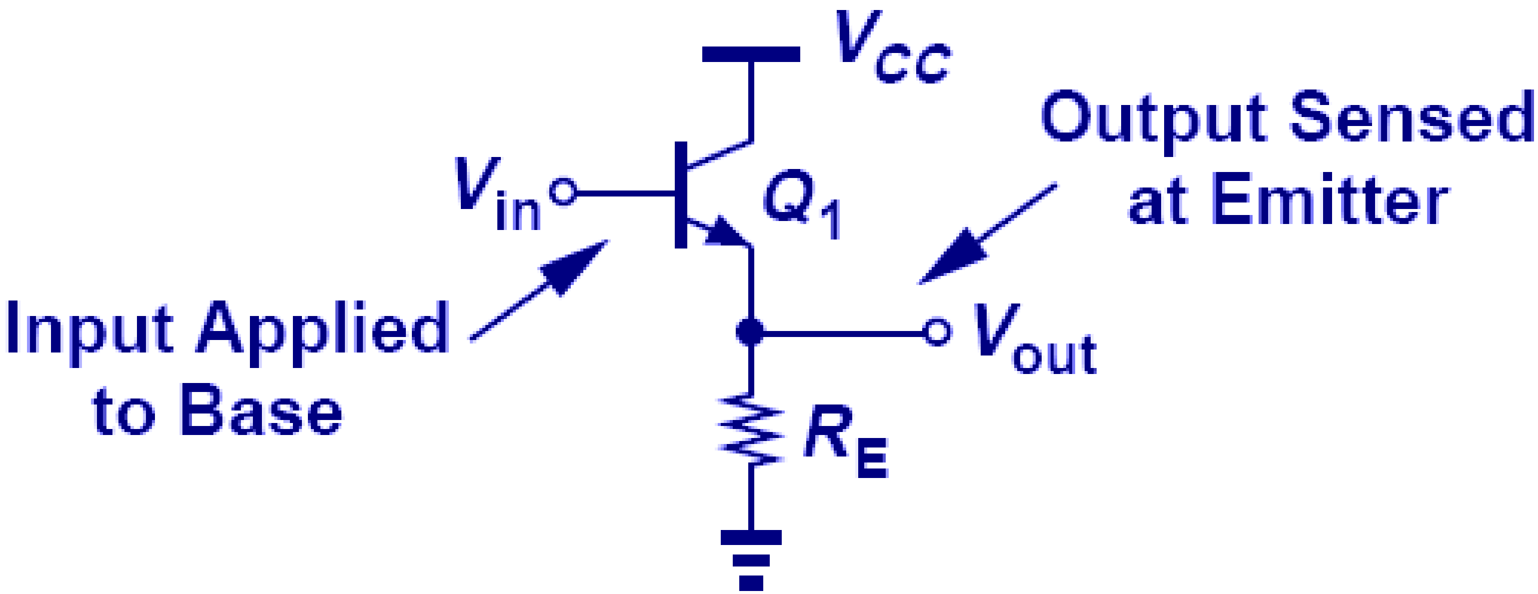
Lecture 10

OUTLINE

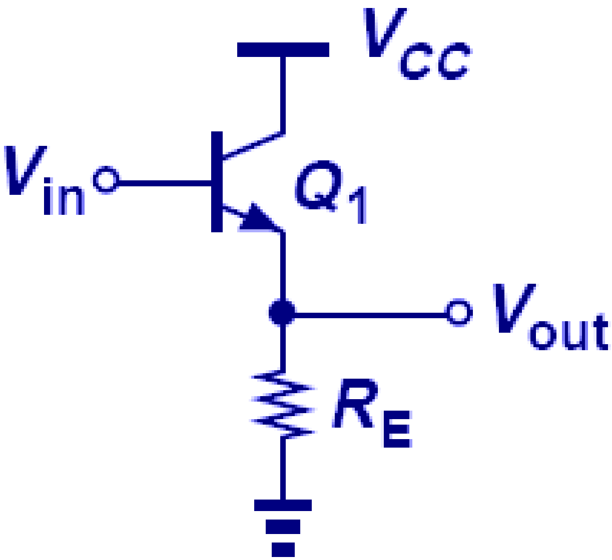
- BJT Amplifiers (3)
  - Emitter follower (Common-collector amplifier)
    - Analysis of emitter follower core
    - Impact of source resistance
    - Impact of Early effect
    - Emitter follower with biasing

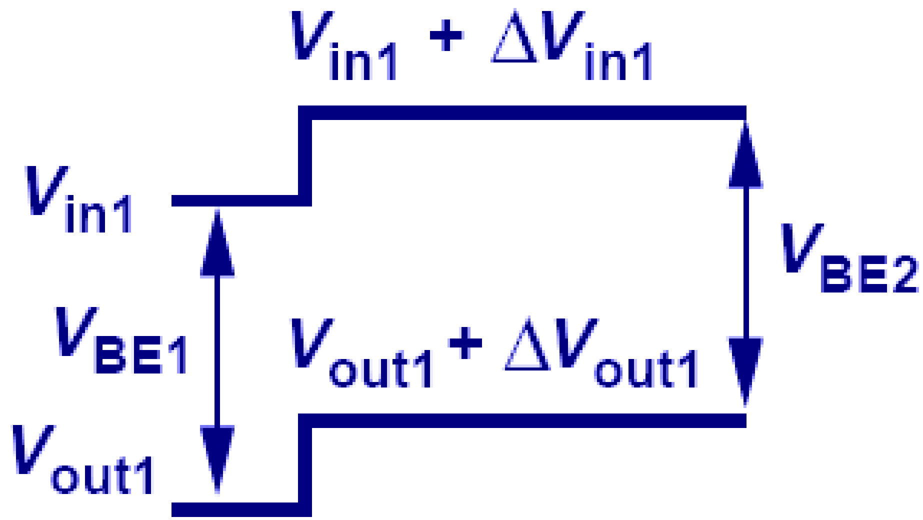
Reading: Chapter 5.3.3-5.4

Emitter Follower (Common Collector Amplifier)



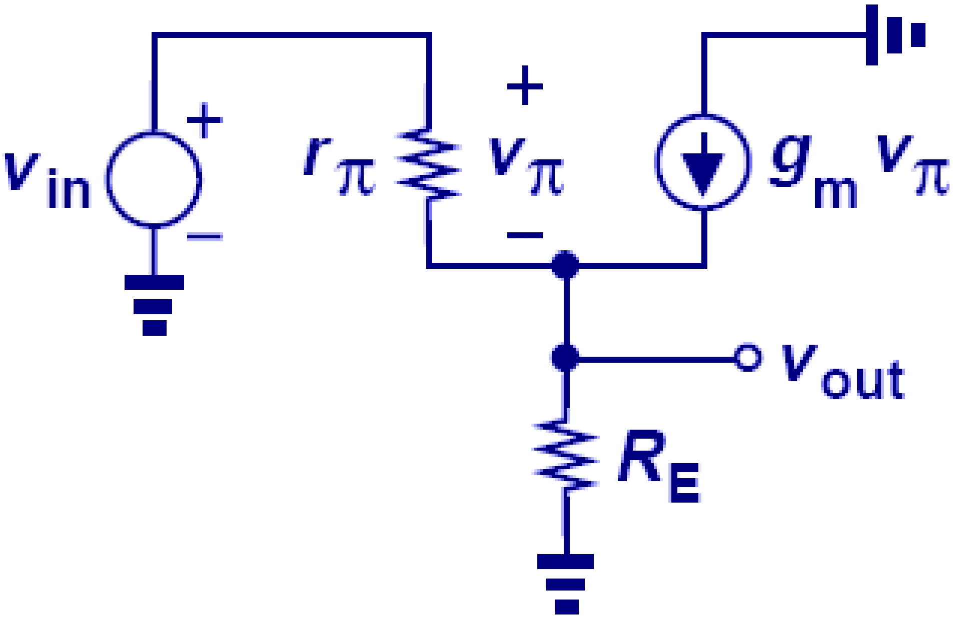
Emitter Follower Core





- When the input is increased by ΔV, output is also increased by an amount that is less than ΔV due to the increase in collector current and hence the increase in potential drop across R_E.
- However the absolute values of input and output differ by a V_{BE}.

Small-Signal Model of Emitter Follower

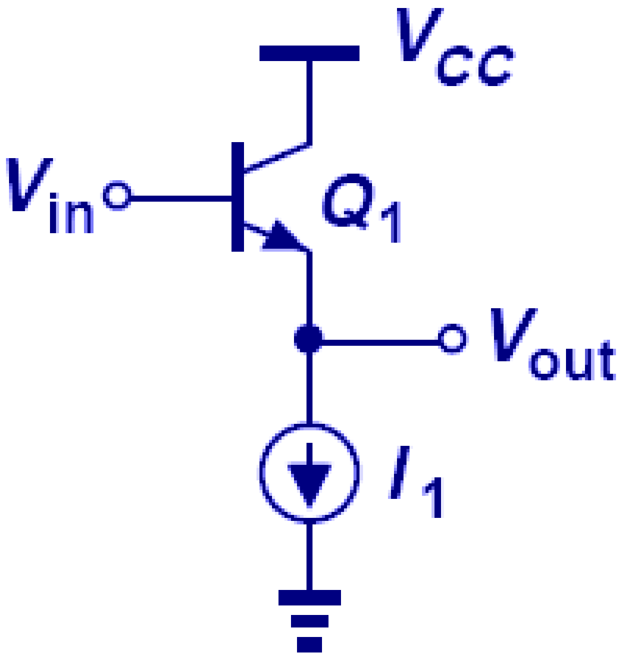


$$V_A = \infty$$

$$\frac{v_{out}}{v_{in}} = \frac{1}{1 + \frac{r_\pi}{\beta + 1} \cdot \frac{1}{R_E}} \approx \frac{R_E}{R_E + \frac{1}{g_m}}$$

- As shown above, the voltage gain is less than unity and positive.

Unity-Gain Emitter Follower

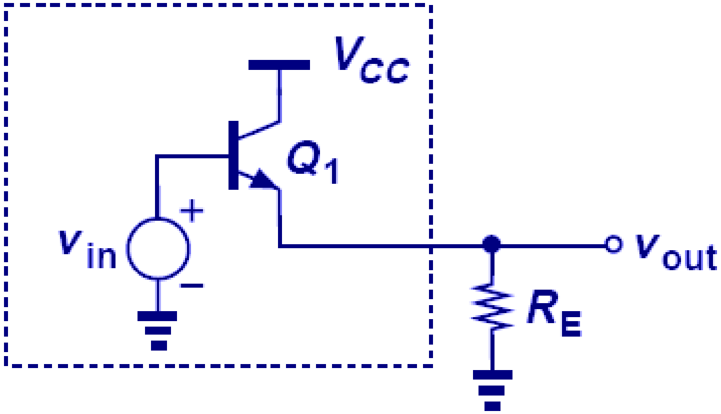


$$V_A = \infty$$

$$A_v = 1$$

- The voltage gain is unity because a constant collector current (= I_1) results in a constant V_{BE}, and hence Vout follows Vin exactly.

Analysis of Emitter Follower as a Voltage Divider



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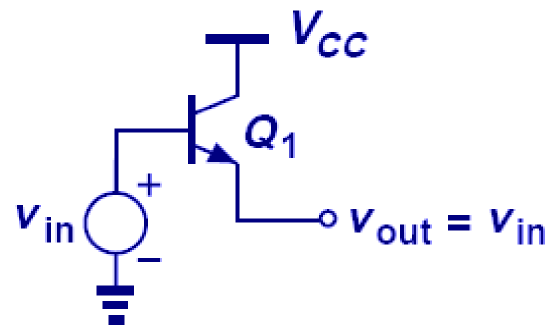

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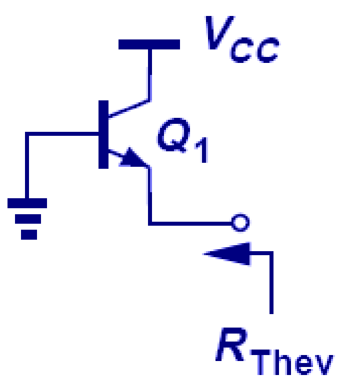

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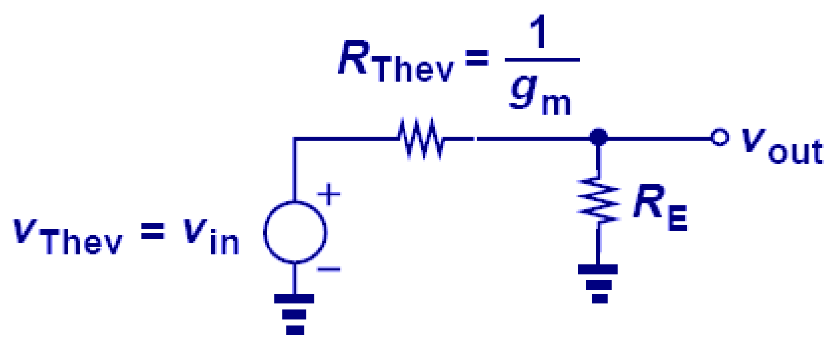
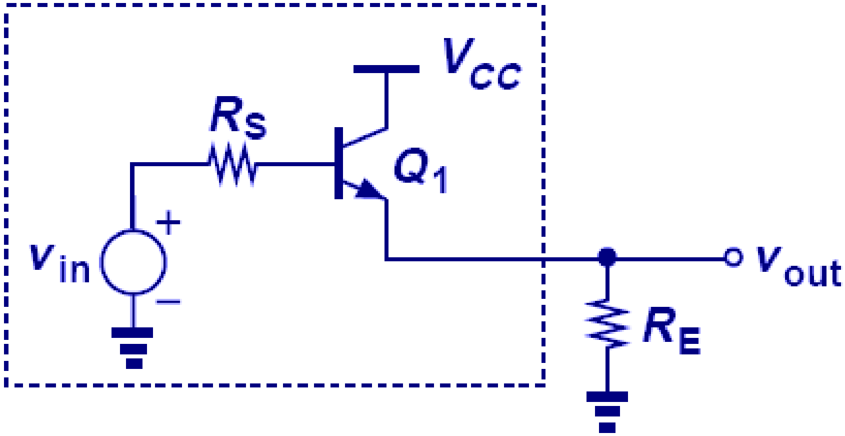


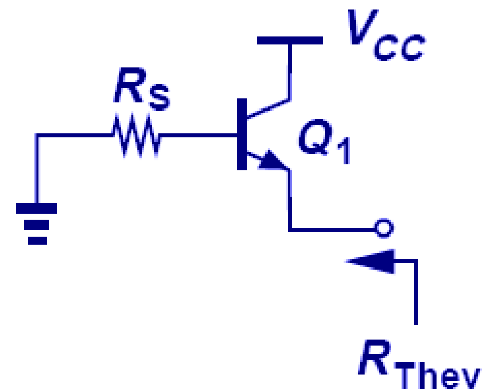
(d)

$$V_A = \infty$$

Emitter Follower with Source Resistance



(a)



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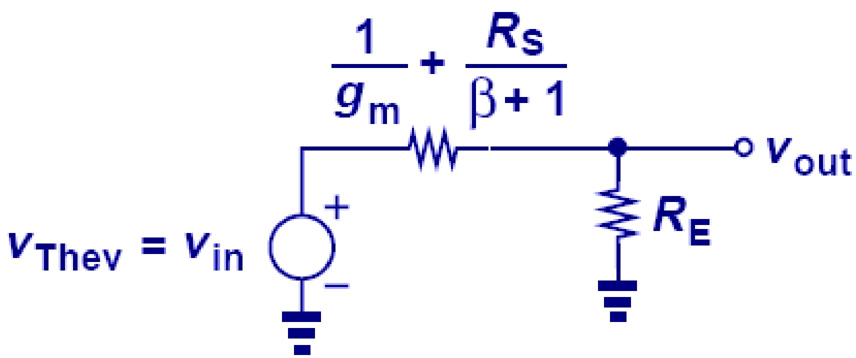
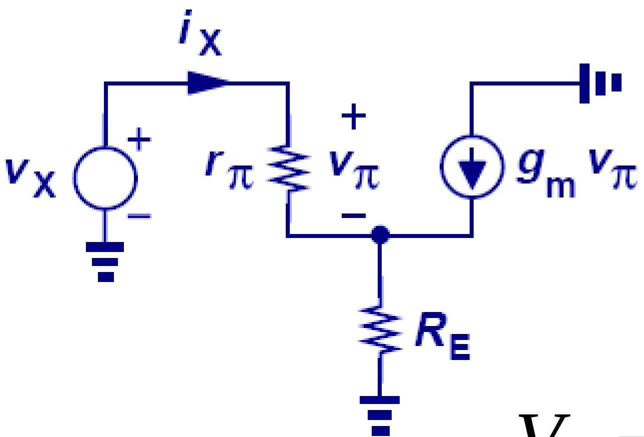


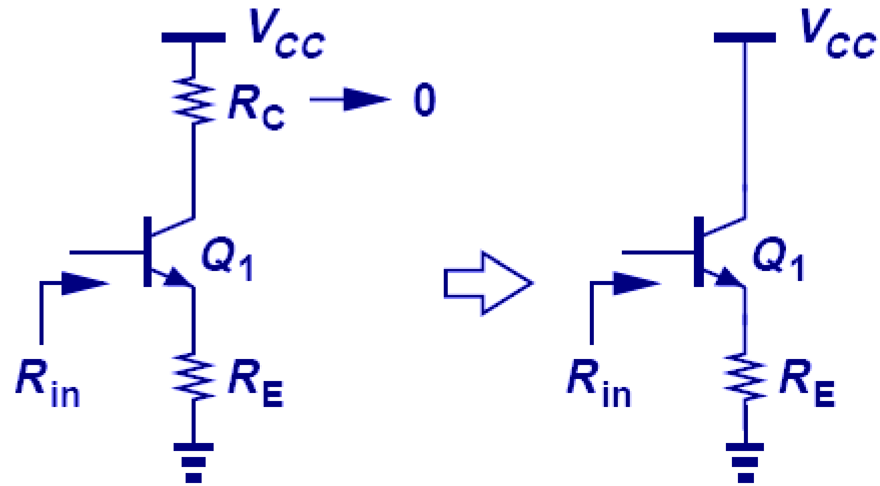
(c)

$$V_A = \infty$$

$$\frac{v_{out}}{v_{in}} = \frac{R_E}{R_E + \frac{R_S}{\beta + 1} + \frac{1}{g_m}}$$

Input Impedance of Emitter Follower



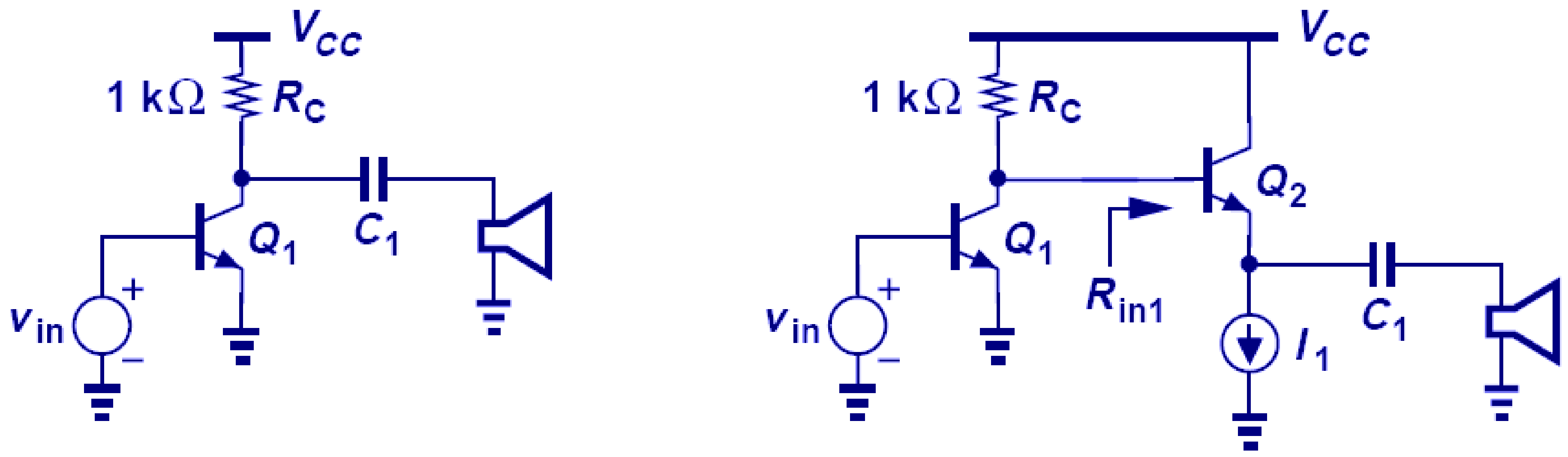


$$V_A = \infty$$

$$\frac{v_X}{i_X} = r_\pi + (1+\beta)R_E$$

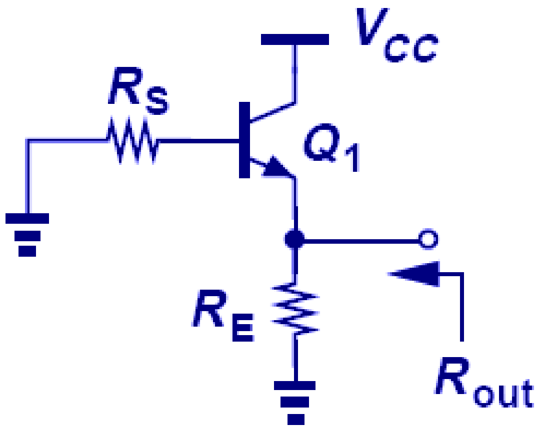
- The input impedance of emitter follower is exactly the same as that of CE stage with emitter degeneration. This is not surprising because the input impedance of CE with emitter degeneration does not depend on the collector resistance.

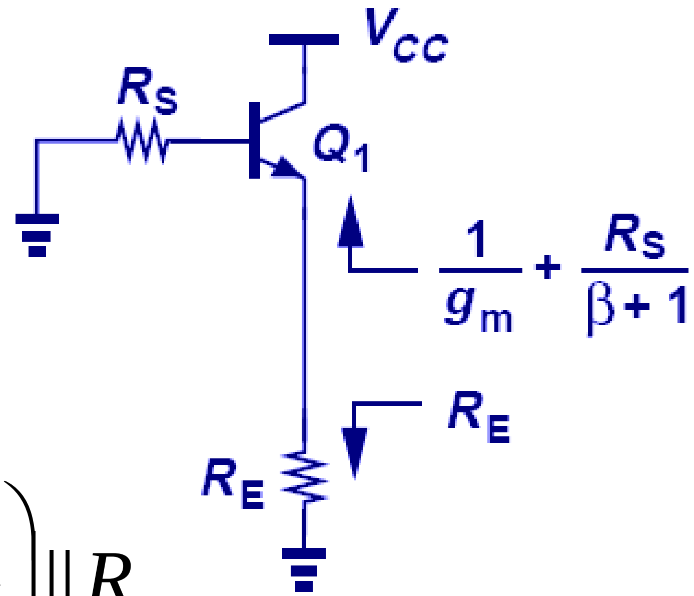
Emitter Follower as Buffer



- Since the emitter follower increases the load resistance to a much higher value, it is suited as a buffer between a CE stage and a heavy load resistance to alleviate the problem of gain degradation.

Output Impedance of Emitter Follower

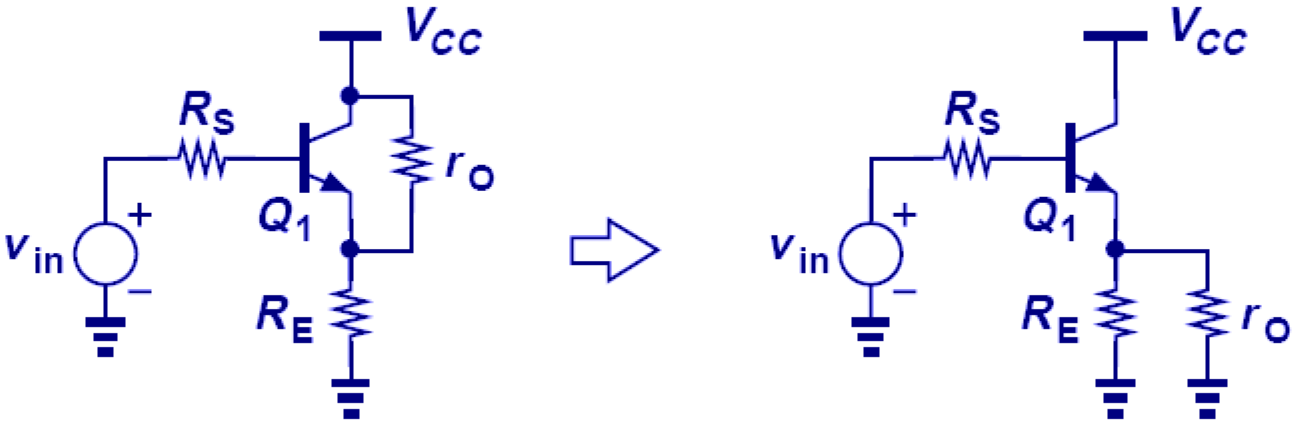




$$R_{out} = \left(\frac{R_s}{\beta+1} + \frac{1}{g_m}\right) \| R_E$$

- Emitter follower lowers the source impedance by a factor of β+1 → improved driving capability.

Emitter Follower with Early Effect



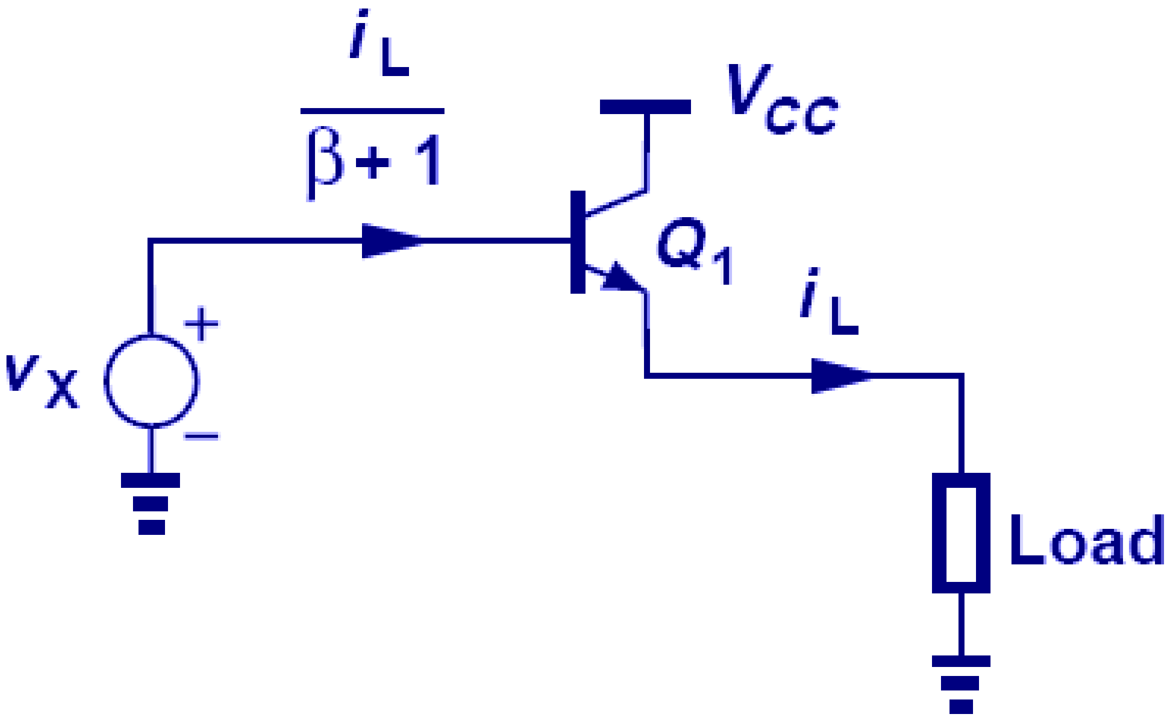
$$A_v = \frac{R_E \parallel r_O}{R_E \parallel r_O + \frac{R_S}{\beta + 1} + \frac{1}{g_m}}$$

$$R_{in} = R_S + r_\pi + (\beta + 1)(R_E \parallel r_O)$$

$$R_{out} = \left(\frac{R_s}{\beta + 1} + \frac{1}{g_m} \right) \parallel R_E \parallel r_O$$

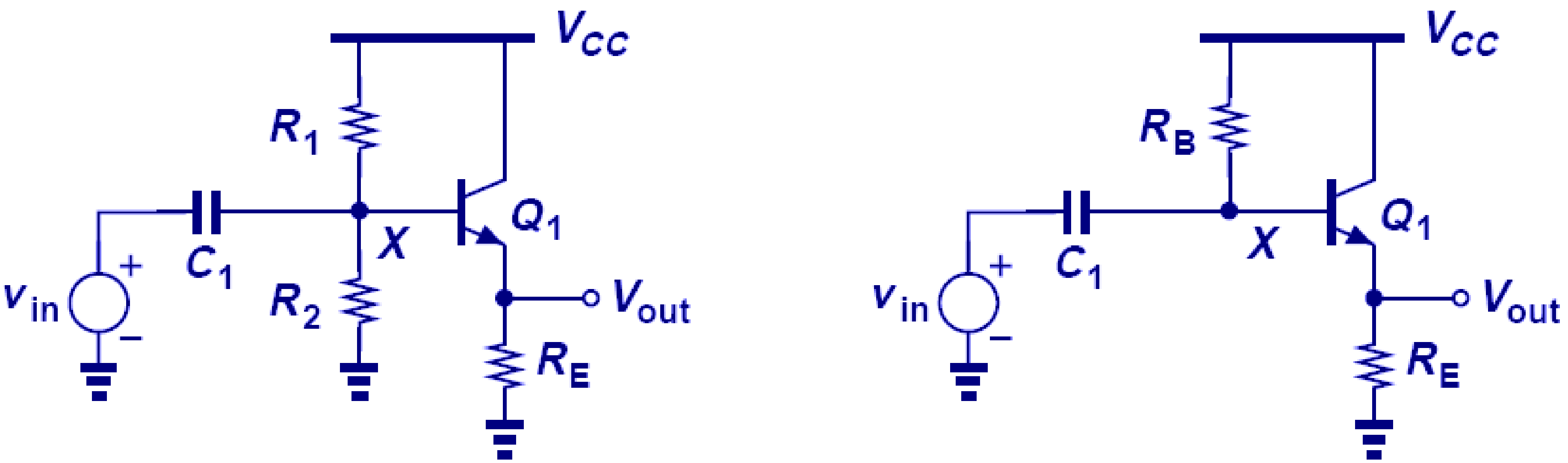
- Since r_O is in parallel with R_E, its effect can be easily incorporated into voltage gain and input and output impedance equations.

Current Gain



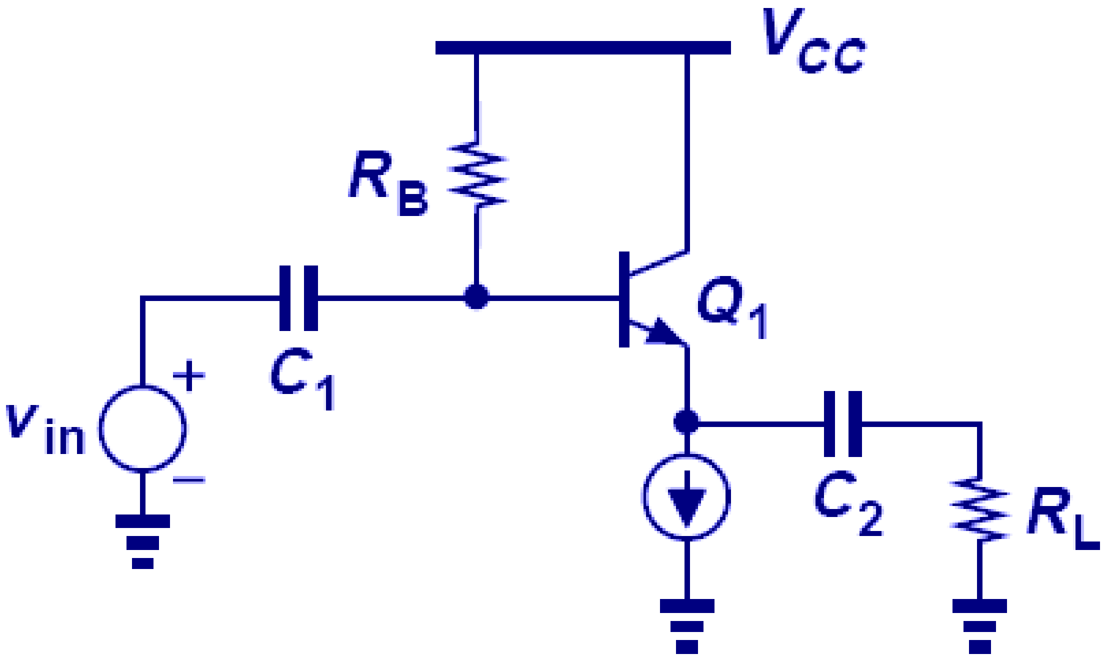
- There is a current gain of $(\beta+1)$ from base to emitter.
- Effectively speaking, the load resistance is multiplied by $(\beta+1)$ as seen from the base.

Emitter Follower with Biasing



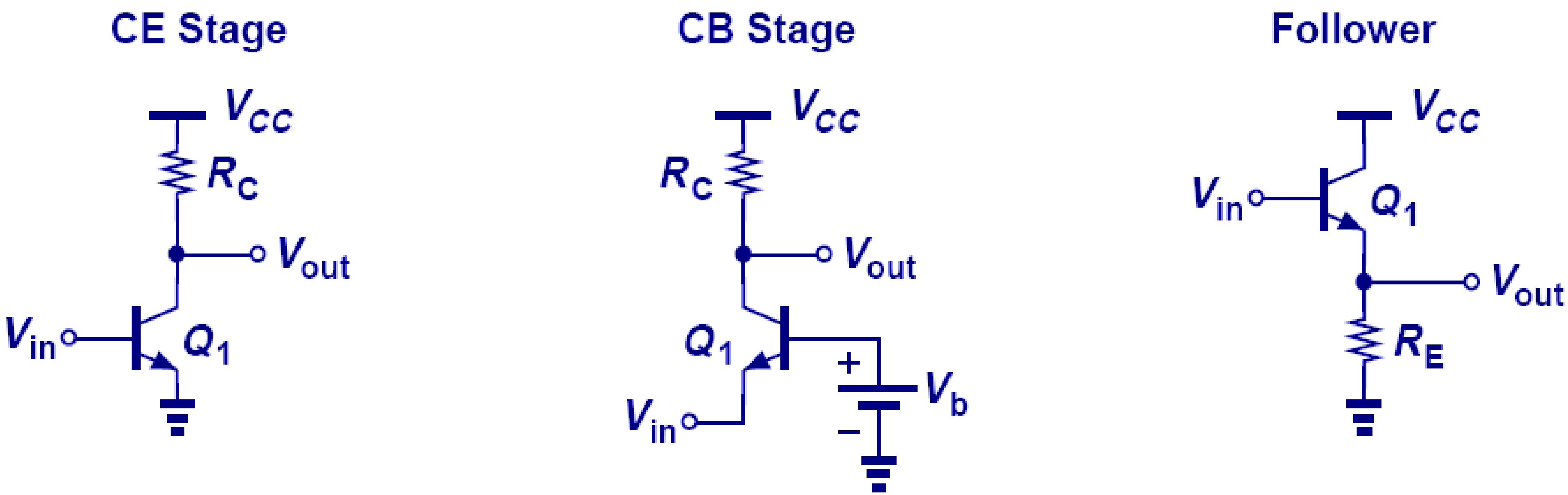
- A biasing technique similar to that of CE stage can be used for the emitter follower.
- Also, V_b can be close to V_{cc} because the collector is also at V_{cc}.

Supply-Independent Biasing



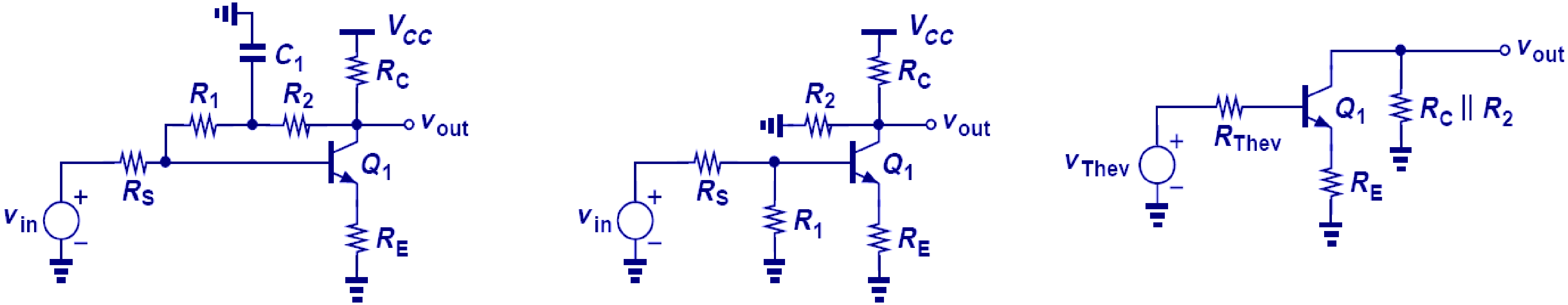
- By putting a constant current source at the emitter, the bias current, V_{BE}, and $I_B R_B$ are fixed regardless of the supply value.

Summary of Amplifier Topologies



- The three amplifier topologies studied so far have different properties and are used on different occasions.
- CE and CB have voltage gain with magnitude greater than one, while follower's voltage gain is at most one.

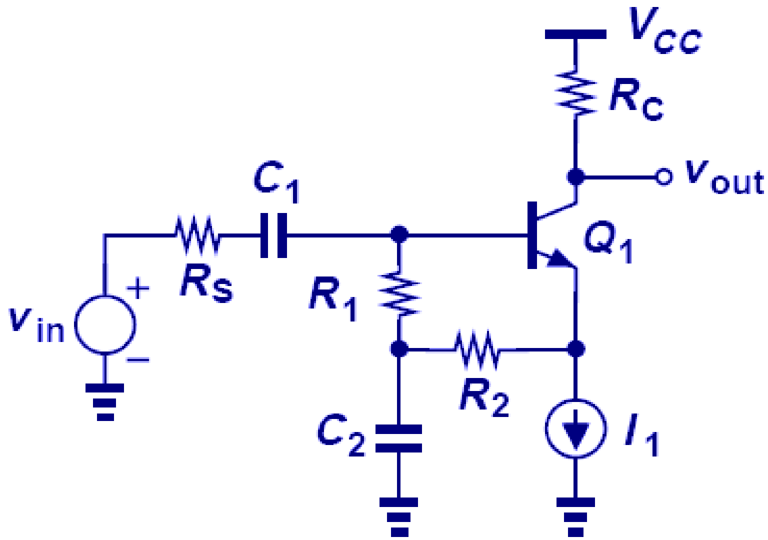
Amplifier Example I

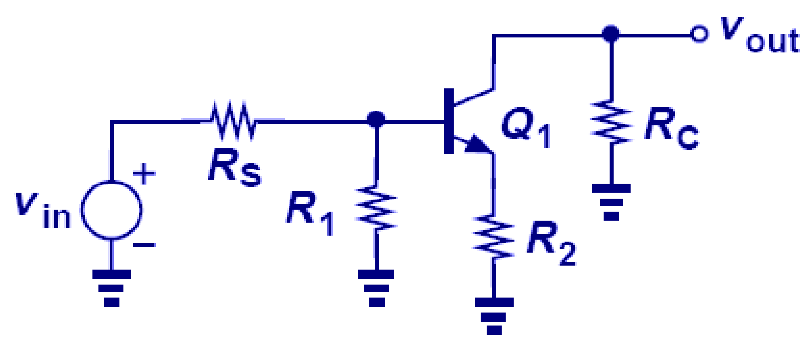


$$\frac{v_{out}}{v_{in}} = -\frac{R_2 \| R_C}{\frac{R_1 \| R_S}{\beta+1} + \frac{1}{g_m} + R_E} \cdot \frac{R_1}{R_1 + R_S}$$

- The keys in solving this problem are recognizing the AC ground between R_1 and R_2, and Thevenin transformation of the input network.

Amplifier Example II

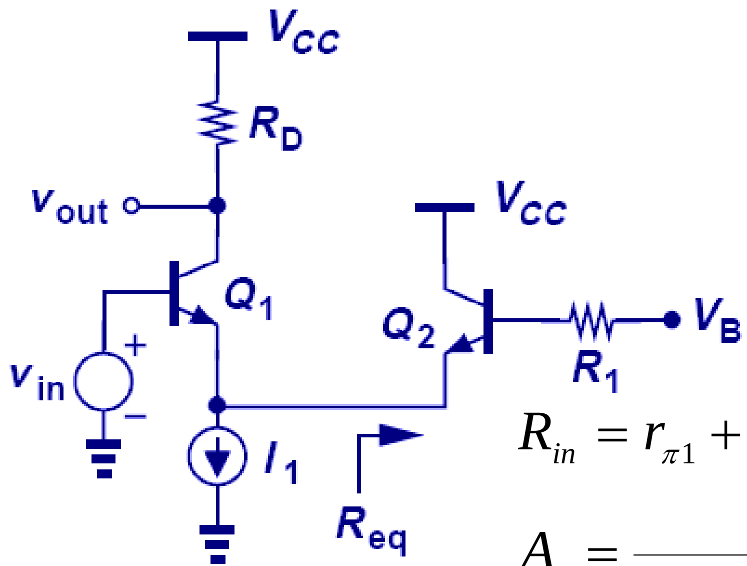


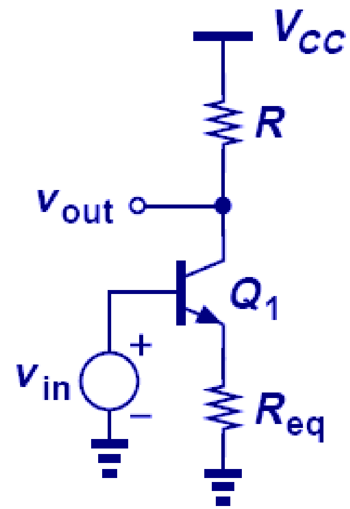


$$\frac{v_{out}}{v_{in}} = -\frac{R_C}{\frac{R_S \parallel R_1}{\beta+1} + \frac{1}{g_m} + R_2} \cdot \frac{R_1}{R_1 + R_S}$$

- Again, AC ground/short and Thevenin transformation are needed to transform the complex circuit into a simple stage with emitter degeneration.

Amplifier Example III



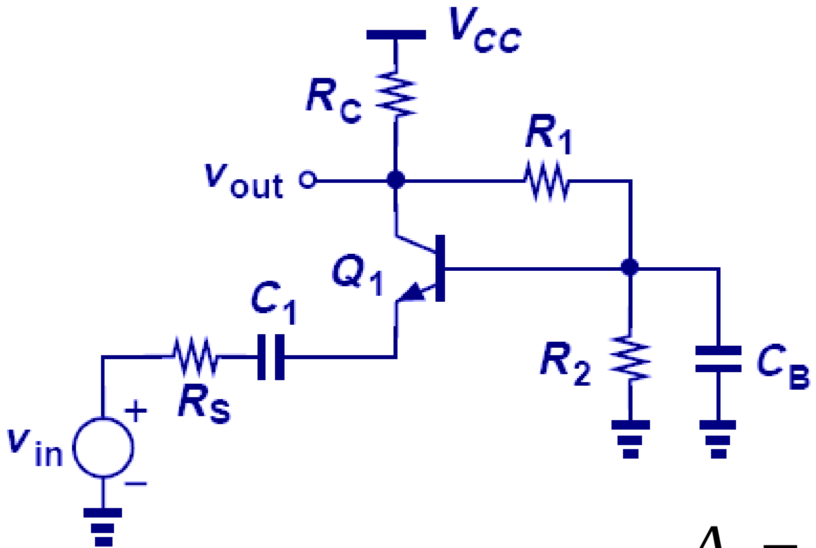


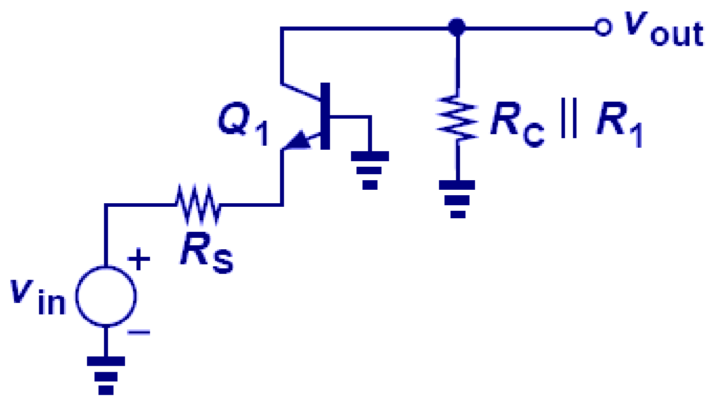
$$R_{in} = r_{\pi 1} + R_1 + r_{\pi 2}$$

$$A_v = \frac{-R_C}{\frac{1}{g_{m1}} + \frac{R_1}{\beta + 1} + \frac{1}{g_{m2}}}$$

- The key for solving this problem is first identifying R_{eq}, which is the impedance seen at the emitter of Q_2 in parallel with the infinite output impedance of an ideal current source. Second, use the equations for degenerated CE stage with RE replaced by R_{eq}.

Amplifier Example IV

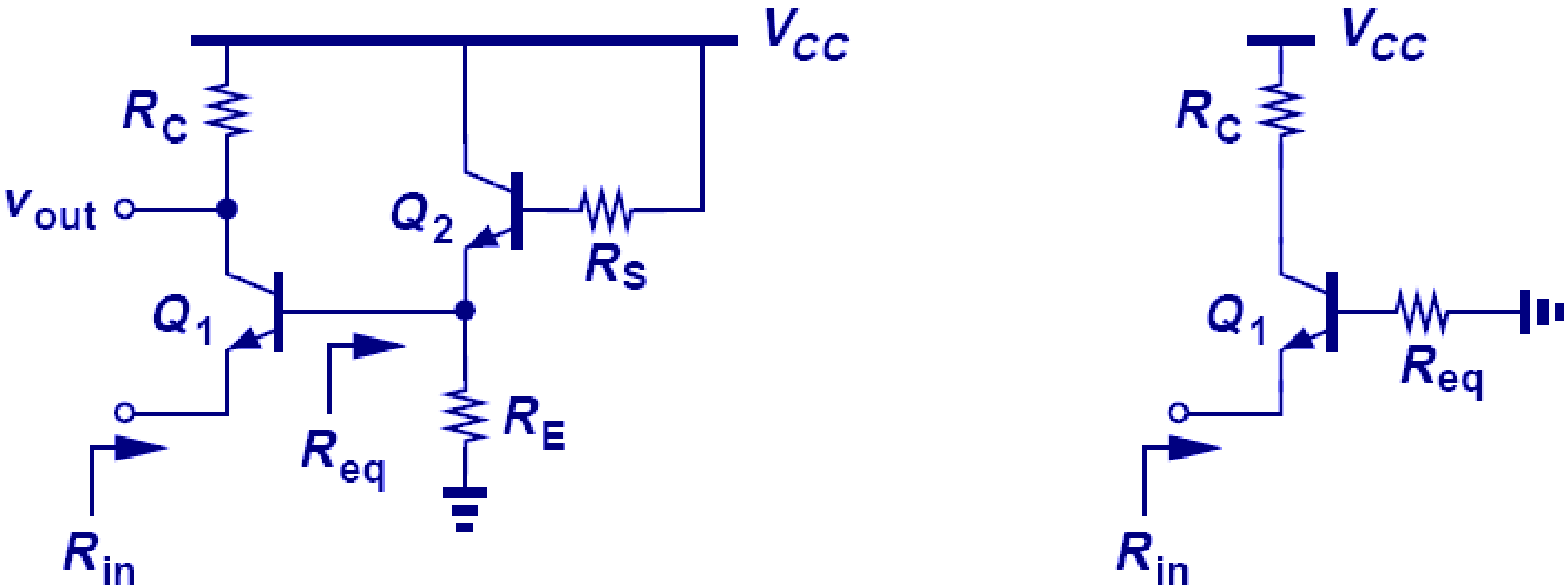




$$A_v = \frac{R_C \| R_1}{R_S + \frac{1}{g_m}}$$

- The key for solving this problem is recognizing that CB at frequency of interest shorts out R_2 and provide a ground for R_1.
- R_1 appears in parallel with RC and the circuit simplifies to a simple CB stage.

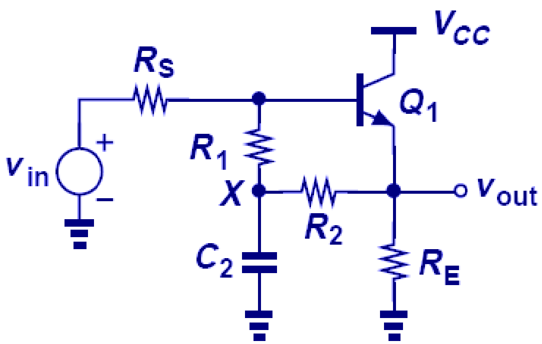
Amplifier Example V



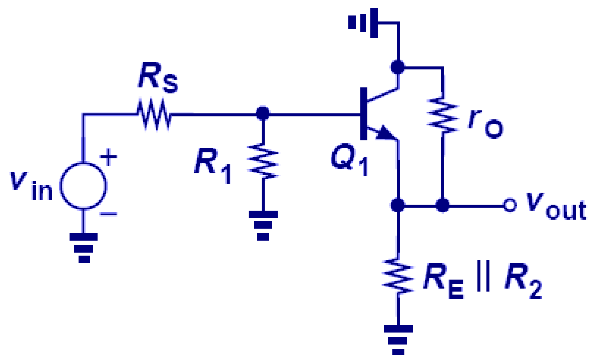
$$R_{in} = \frac{1}{\beta+1}\left\lfloor\left(\frac{R_B}{\beta+1}+\frac{1}{g_{m2}}\right) \| R_E\right\rfloor + \frac{1}{g_{m1}}$$

- The key for solving this problem is recognizing the equivalent base resistance of Q_1 is the parallel connection of RE and the impedance seen at the emitter of Q_2.

Amplifier Example VI



(a)



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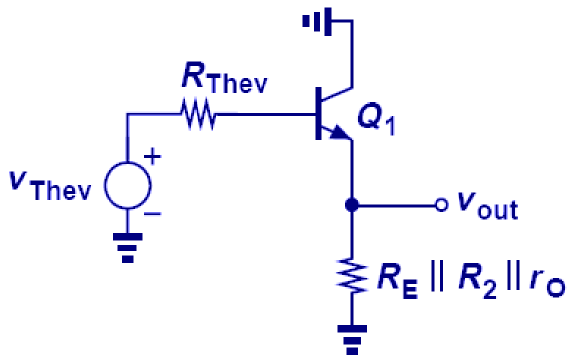


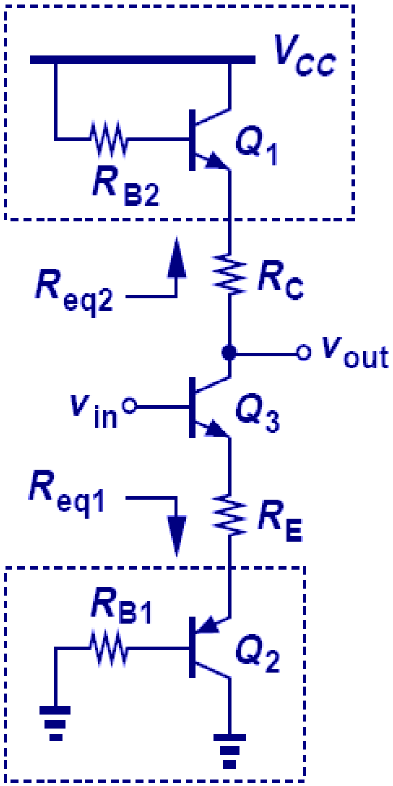
(c)

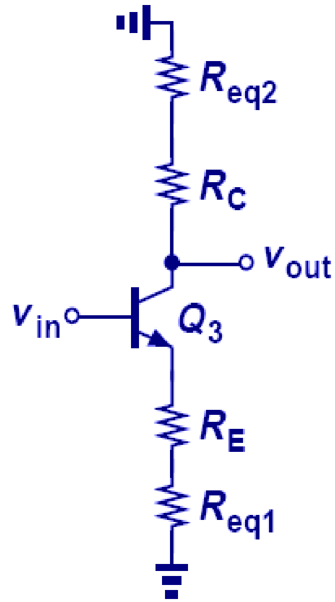
$$\frac{v_{out}}{v_{in}} = \frac{R_E \,||\, R_2 \,||\, r_O}{R_E \,||\, R_2 \,||\, r_O + \frac{1}{g_m} + \frac{R_S \,||\, R_1}{\beta + 1}} \cdot \frac{R_1}{R_1 + R_S}$$

$$R_{out} = \left(\frac{R_S \,||\, R_1}{\beta + 1} + \frac{1}{g_m} \right) \,||\, R_E \,||\, R_2 \,||\, r_O$$

- The key in solving this problem is recognizing a DC supply is actually an AC ground and using Thevenin transformation to simplify the circuit into an emitter follower.

Amplifier Example VII





$$R_{in} = r_{\pi 1} + (\beta + 1)\left(R_E + \frac{R_{B1}}{\beta + 1} + \frac{1}{g_{m2}}\right)$$

$$R_{out} = R_C + \frac{R_{B2}}{\beta + 1} + \frac{1}{g_{m3}}$$

$$A_v = -\frac{R_C + \frac{R_{B2}}{\beta + 1} + \frac{1}{g_{m3}}}{\frac{R_{B1}}{\beta + 1} + \frac{1}{g_{m2}} + \frac{1}{g_{m1}}}$$

- Impedances seen at the emitter of Q_1 and Q_2 can be lumped with R_C and R_E, respectively, to form the equivalent emitter and collector impedances.