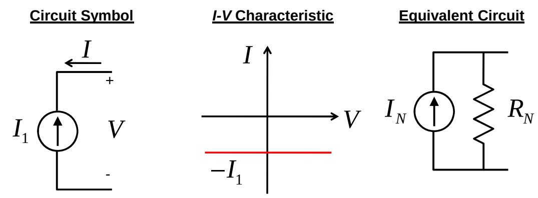
Lecture 11

OUTLINE

- Cascode Stage

Reading: Chapter 9.1

Ideal Current Source

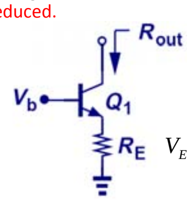


- An ideal current source has infinite output impedance.

How can we increase the output impedance of a BJT that is used as a current source?

Boosting the Output Impedance

- Recall that emitter degeneration boosts the impedance seen looking into the collector.
  - This improves the gain of the CE or CB amplifier. However, headroom is reduced.

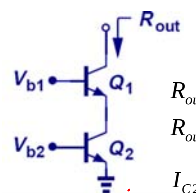


$V_E = I_E R_E$

$$R_{out} = [1 + g_m(R_E \| r_\pi)]r_O + R_E \| r_\pi$$

Cascode Stage

- In order to relax the trade-off between output impedance and voltage headroom, we can use a transistor instead of a degeneration resistor:



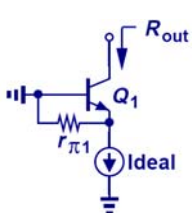
$$R_{out} = [1 + g_m(r_{O2} \| r_{\pi 1})]r_{O1} + r_{O2} \| r_{\pi 1}$$

$$R_{out} \approx g_{m1} r_{O1}(r_{O2} \| r_{\pi 1})$$

$$I_{C2} = I_{E1} \cong I_{C2} \text{ if } \beta_1 >> 1$$

- V_{CE} for Q_2 can be as low as ~ 0.4V ("soft saturation")

Maximum Bipolar Cascode Output Impedance

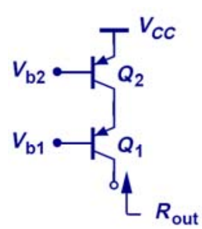


$$R_{out,\max} \approx g_{m1} r_{01} r_{\pi 1}$$

$$R_{out,\max} \approx \beta_1 r_{01}$$

- The maximum output impedance of a bipolar cascode is bounded by the ever-present r_π between emitter and ground of Q_1.

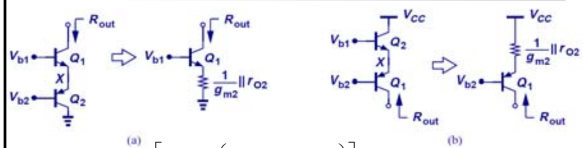
PNP Cascode Stage



$$R_{out} = [1 + g_m(r_{02} \| r_{\pi 1})]r_{01} + r_{02} \| r_{\pi 1}$$

$$R_{out} \approx g_{m1} r_{01}(r_{02} \| r_{\pi 1})$$

False Cascodes



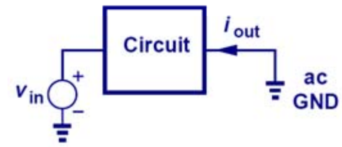
$$R_{out} = \left[1 + g_{m1}\left(\frac{1}{g_{m2}} \| r_{O2} \| r_{\pi 1}\right)\right] r_{O1} + \frac{1}{g_{m2}} \| r_{O2} \| r_{\pi 1}$$

$$R_{out} \approx \left(1 + \frac{g_{m1}}{g_{m2}}\right) r_{O1} + \frac{1}{g_{m2}} \approx 2 r_{O1}$$

- When the emitter of Q_1 is connected to the emitter of Q_2, it's no longer a cascode since Q_2 becomes a diode-connected device instead of a current source.

Short-Circuit Transconductance

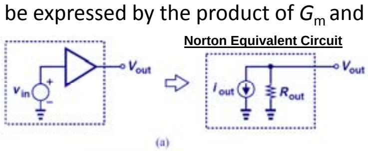
- The ***short-circuit transconductance*** of a circuit is a measure of its strength in converting an input voltage signal into an output current signal.



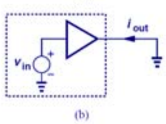
$$G_m \equiv \left.\frac{i_{out}}{v_{in}}\right|_{v_{out}=0}$$

Voltage Gain of a Linear Circuit

- By representing a linear circuit with its Norton equivalent, the relationship between V_{out} and V_{in} can be expressed by the product of G_m and R_{out}.

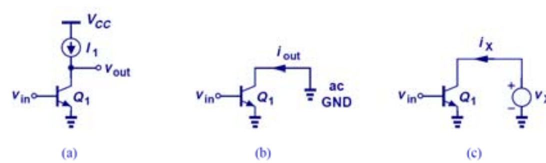


Computation of short-circuit output current:



$$v_{out} = -i_{out} R_{out} = -G_m v_{in} R_{out}$$
$$v_{out}/v_{in} = -G_m R_{out}$$

Example: Voltage Gain

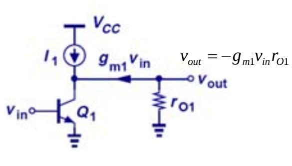


$$G_m \equiv \left.\frac{i_{out}}{v_{in}}\right|_{v_{out}=0} = g_{m1} \qquad R_{out} \equiv \frac{v_x}{i_x} = r_{o1}$$

$$A_v = -g_{m1} r_{01}$$

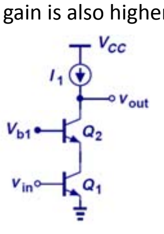
Comparison of CE and Cascode Stages

- Since the output impedance of the cascode is higher than that of a CE stage, its voltage gain is also higher.



$$v_{out} = -g_{m1} v_{in} r_{O1}$$

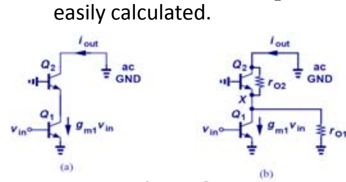
$$A_v = -g_{m1} r_{O1} = -\frac{V_A}{V_T}$$



$$A_v \approx -g_{m1} r_{O2} g_{m2} \left(r_{O1} \| r_{\pi 2}\right)$$

Voltage Gain of Cascode Amplifier

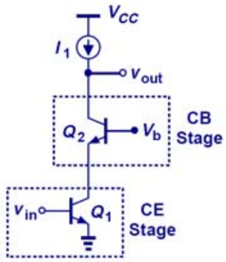
- Since r_O is much larger than $1/g_m$, most of $I_{C,Q1}$ flows into diode-connected Q_2. Using R_{out} as before, A_V is easily calculated.



$$i_{out} = g_{m1} v_{in}$$
$$\Rightarrow G_m = g_{m1}$$

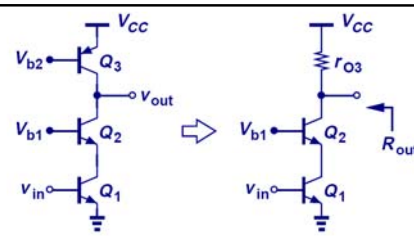
$$A_v = -G_m R_{out}$$
$$= -g_{m1}\left[\left(1 + g_{m2}\left(r_{O1} \| r_{\pi 2}\right)\right) r_{O2} + r_{O1} \| r_{\pi 2}\right]$$
$$\approx -g_{m1}\left[g_{m2}\left(r_{O1} \| r_{\pi 2}\right) r_{O2}\right]$$

Alternate View of Cascode Amplifier



- A bipolar cascode amplifier is also a CE stage in series with a CB stage.

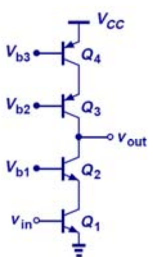
Practical Cascode Stage



$$R_{out} \approx r_{O3} \parallel g_{m2} r_{O2} (r_{O1} \parallel r_{\pi 2})$$

- Since no current source can be ideal, the output impedance drops.

Improved Cascode Stage



$$R_{out} \approx [g_{m3} r_{O3} (r_{O4} \parallel r_{\pi 3})] \parallel [g_{m2} r_{O2} (r_{O1} \parallel r_{\pi 2})]$$
$$A_v = -g_{m1} R_{out}$$

- In order to preserve the high output impedance, a cascode PNP current source is used.