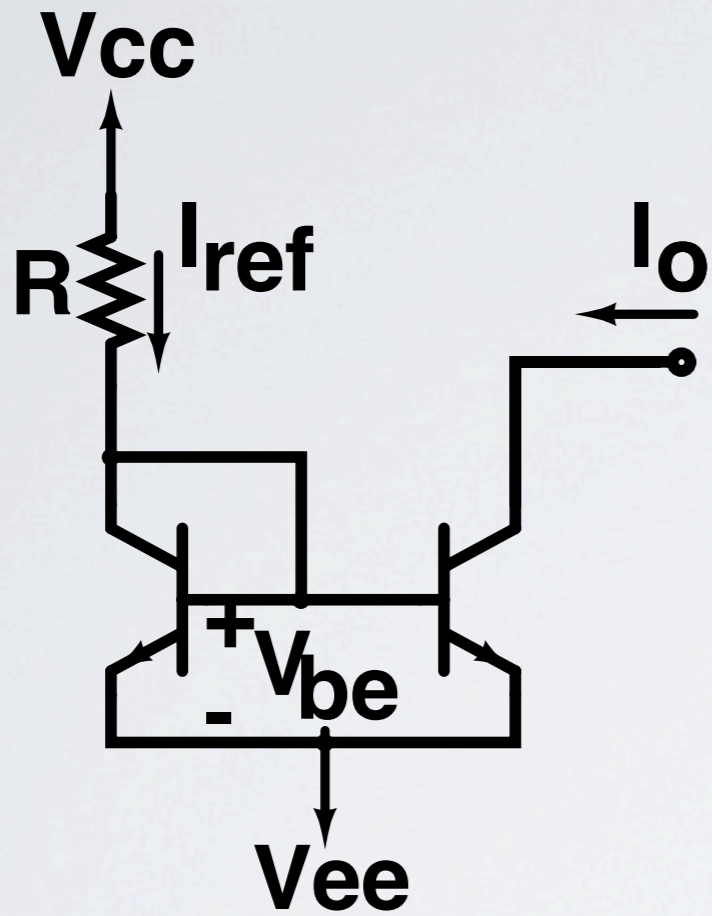
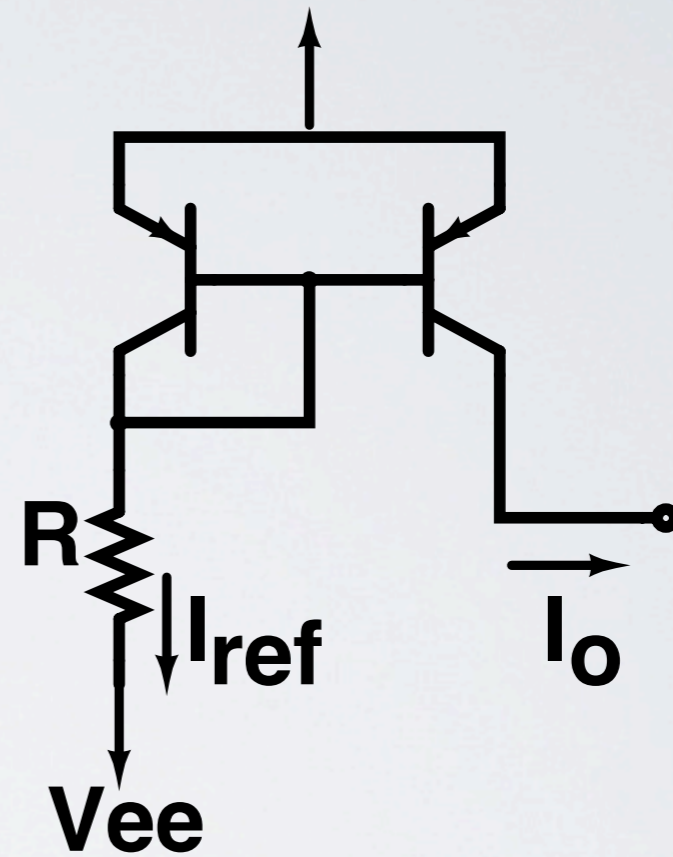


CURRENT SOURCES & ACTIVE LOADS

INEL 4202 - Electronics II - Spring 2013

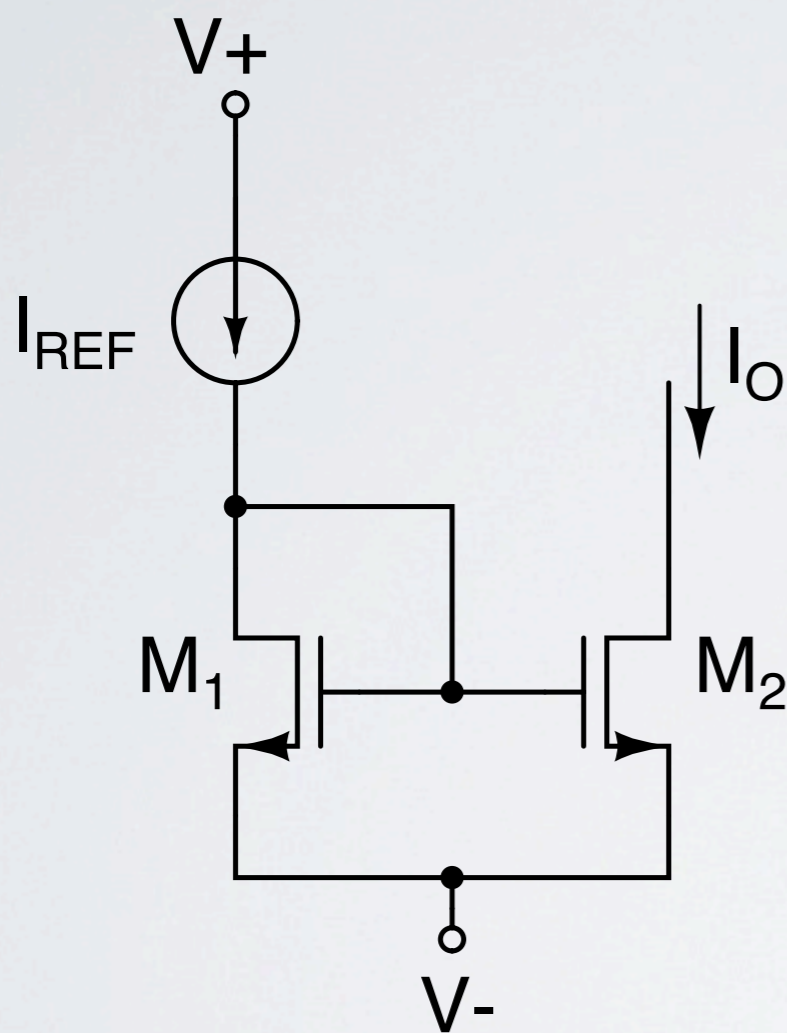


Basic C.S.



Basic C.S. with PNP BJTs

MOSFET CSs

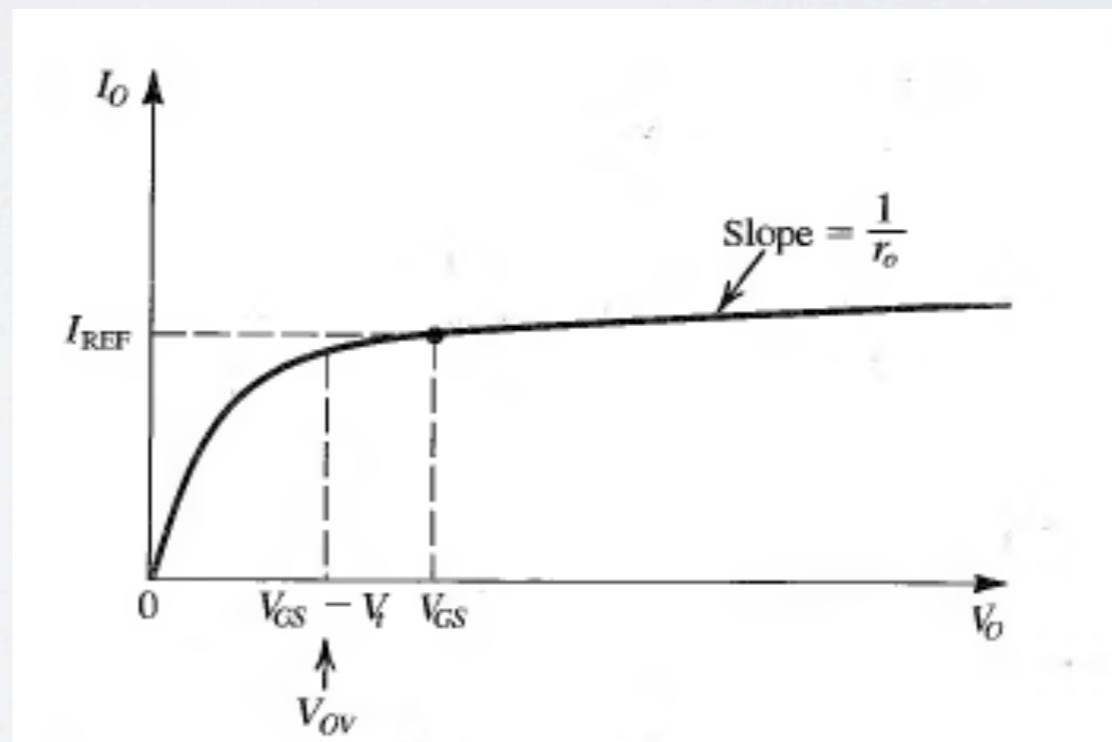


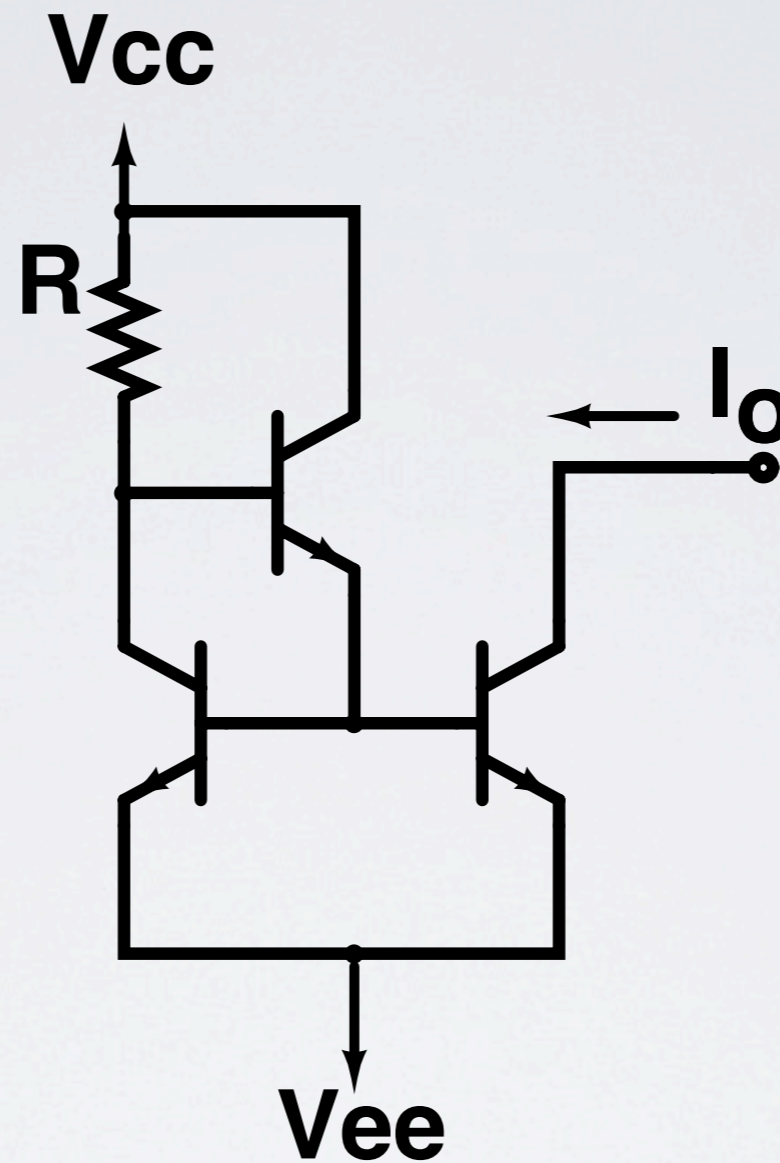
$$v_{GS,1} = v_{GS,2} = v_{DS,1}$$

$$i_{D,1} = \frac{\mu_n C_{ox}}{2} \left(\frac{W}{L}\right)_1 (v_{GS,1} - V_t)^2$$

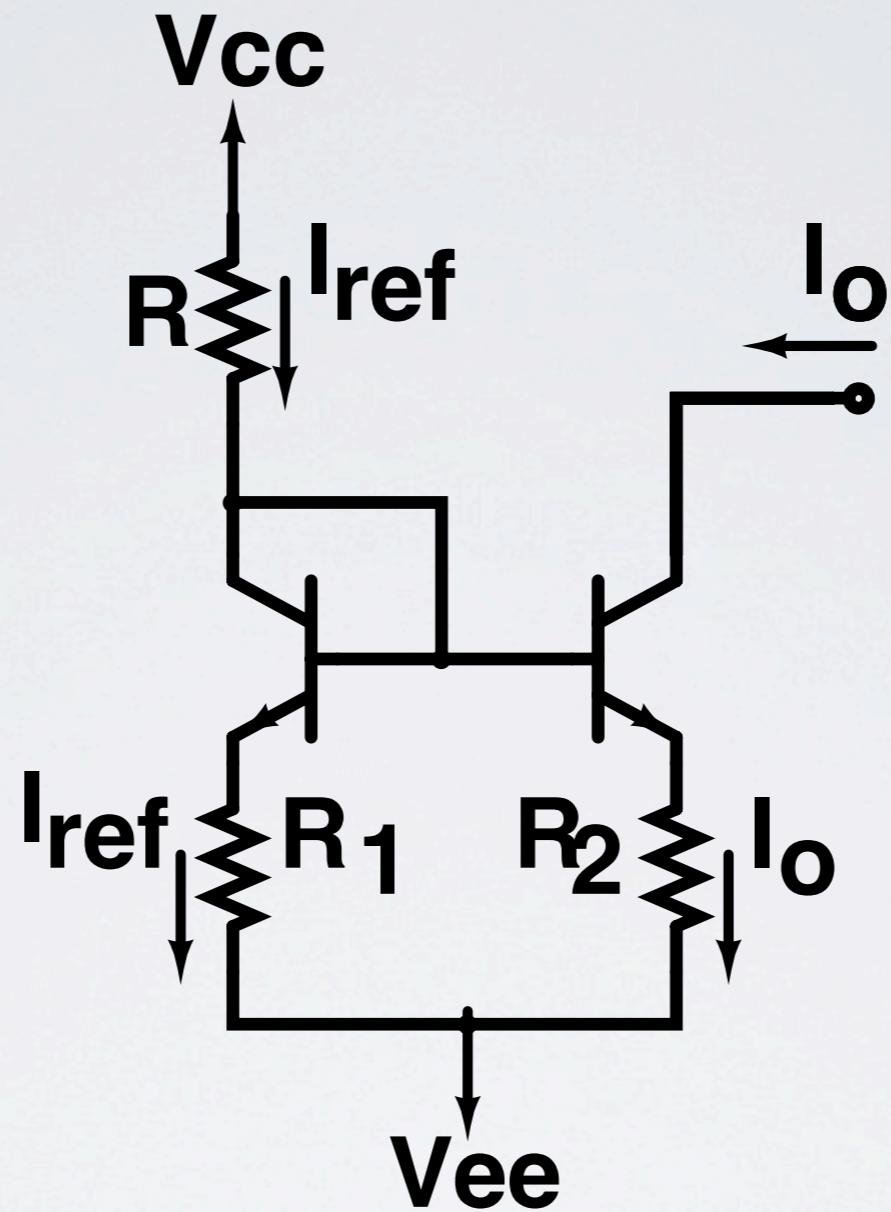
$$i_{D,2} = \frac{\mu_n C_{ox}}{2} \left(\frac{W}{L}\right)_2 (v_{GS,1} - V_t)^2$$

$$\frac{i_{D,2}}{i_{D,1}} = \frac{I_O}{I_{REF}} = \frac{(W/L)_1}{(W/L)_2}$$



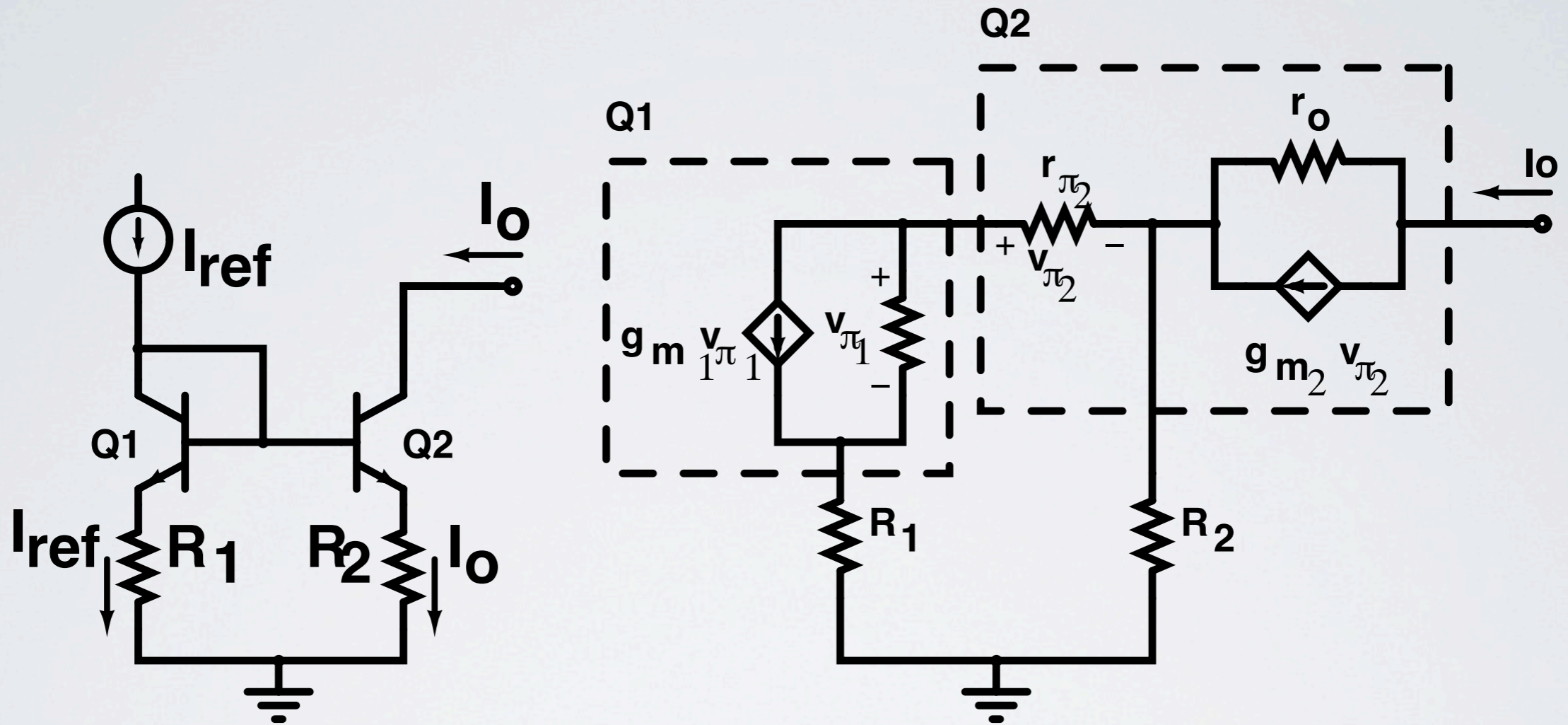


Mirror with base-current compensation



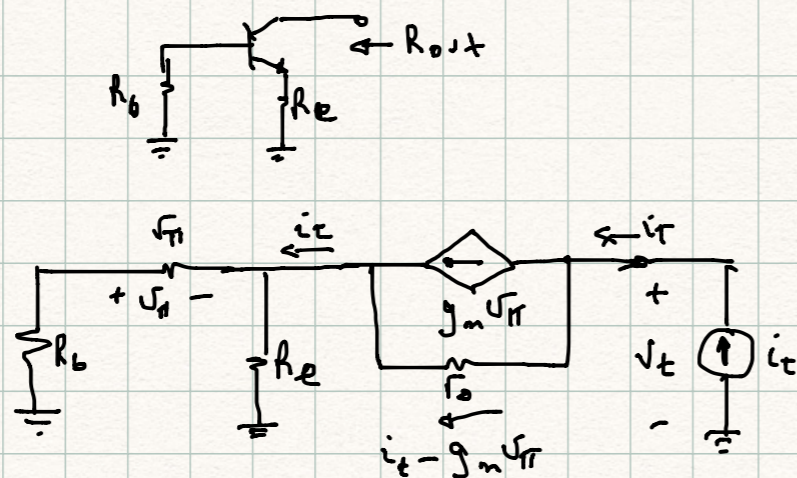
**Basic Source with
Emitter Resistors**

Output Resistance



Mirror with emitter resistors

small-signal equivalent circuit



$$v_t = i_t (R_e \parallel (r_\pi + R_b)) + r_o (i_c - g_m v_\pi)$$

$$v_\pi = - \frac{r_\pi}{r_\pi + R_b} i_c (R_e \parallel (r_\pi + R_b))$$

Let $R_A = R_e \parallel (r_\pi + R_b)$

$$v_t = i_t R_A + i_c r_o + i_t r_o \frac{\beta R_A}{r_\pi + R_b}$$

$$R_{eq} = \frac{v_t}{i_t} = R_A + r_o \left(1 + \frac{\beta R_A}{r_\pi + R_b} \right)$$

$$\frac{\beta R_A}{r_\pi + R_b} = \frac{R_e (\cancel{r_\pi + R_b})}{R_e + r_\pi + R_b} \frac{1}{\cancel{r_\pi + R_b}}$$

$$\therefore R_{out} = R_A + r_o \left(1 + \frac{\beta R_e}{R_e + r_\pi + R_b} \right)$$

$$R_{OUT} = R_A + r_o \left(1 + \frac{\beta R_e}{R_e + r_\pi + R_b} \right)$$

$$R_e = R_2 \quad R_b = R_1 + 1/g_{m1}$$

$$R_A = R_2 \parallel (r_{\pi 2} + R_1) \ll r_o$$

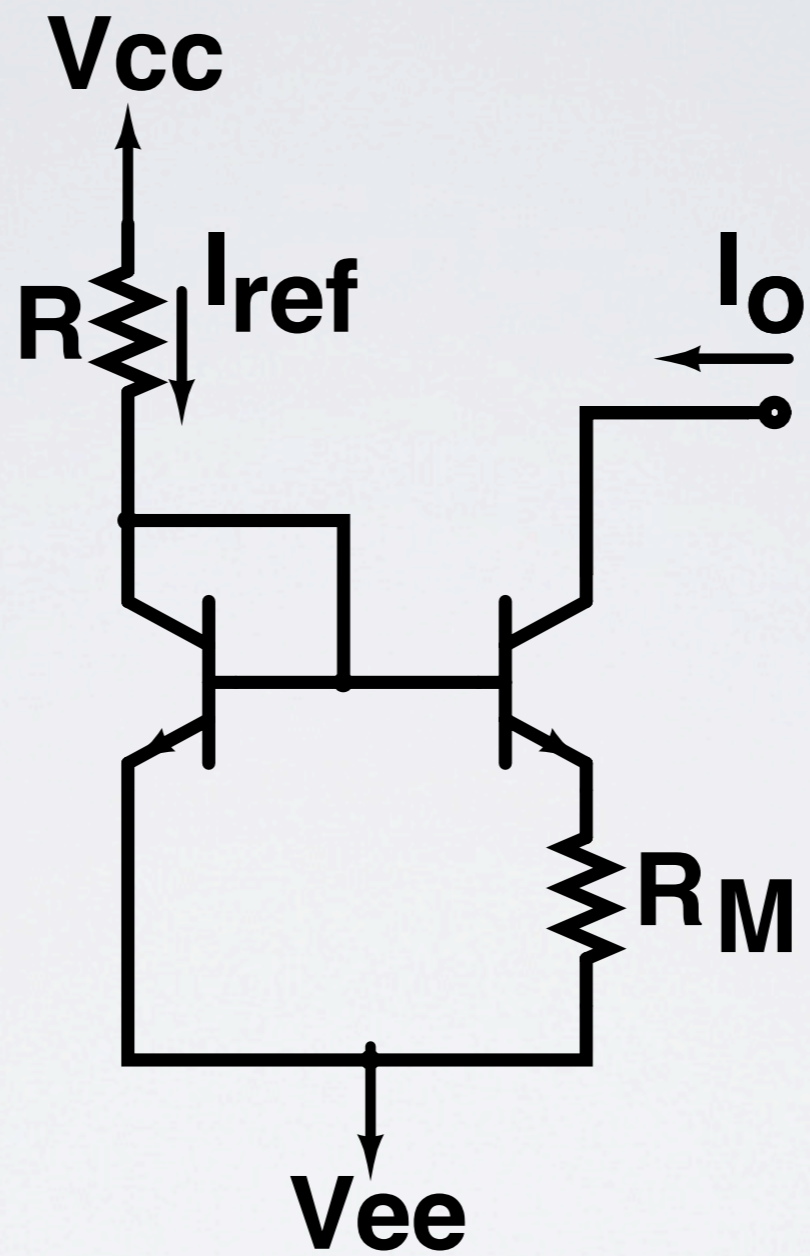
$$R_{OUT} \simeq r_o \left(1 + \frac{\beta R_2}{R_2 + r_\pi + R_1 + 1/g_{m1}} \right)$$

$$R_{OUT} \simeq \boxed{r_o \left(1 + \frac{\beta R_2}{R_2 + r_\pi + R_1} \right)}$$

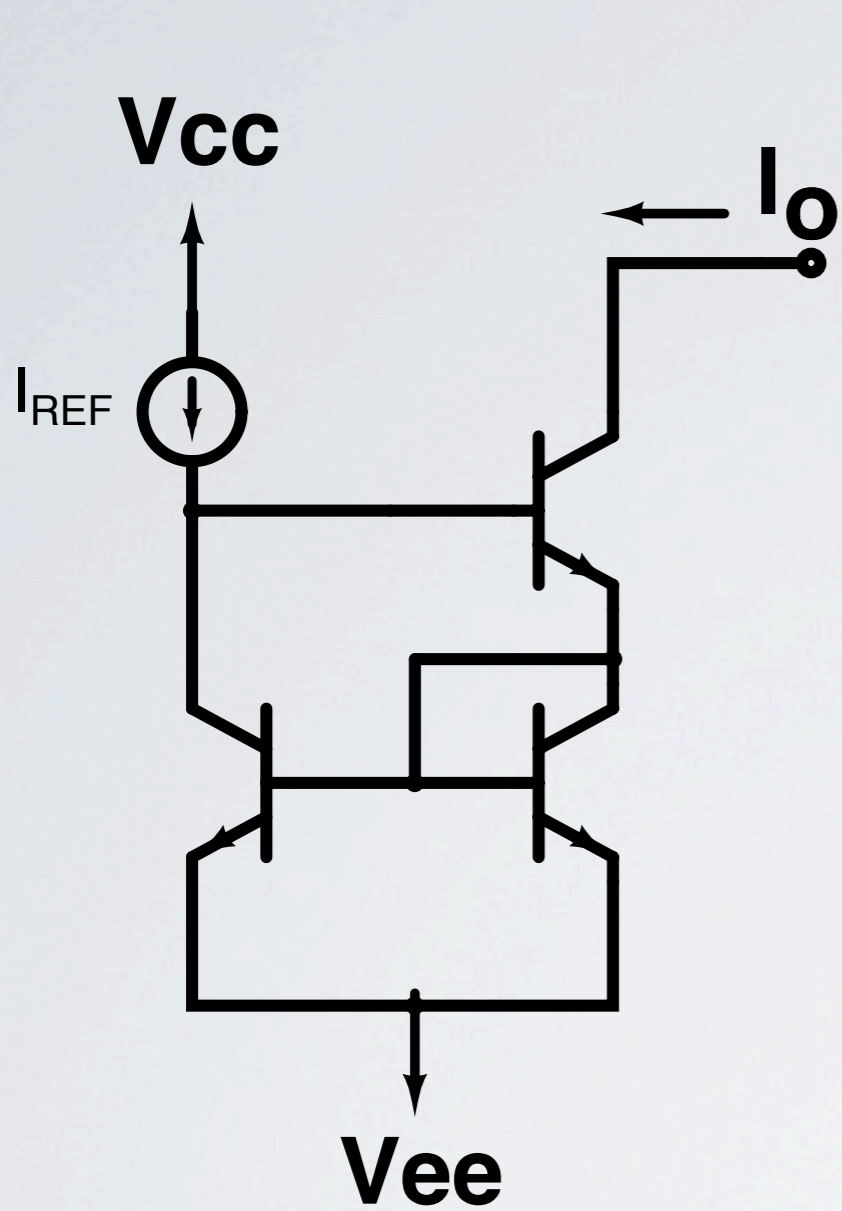
Let this be equation (1)

If $R_1 = 0$

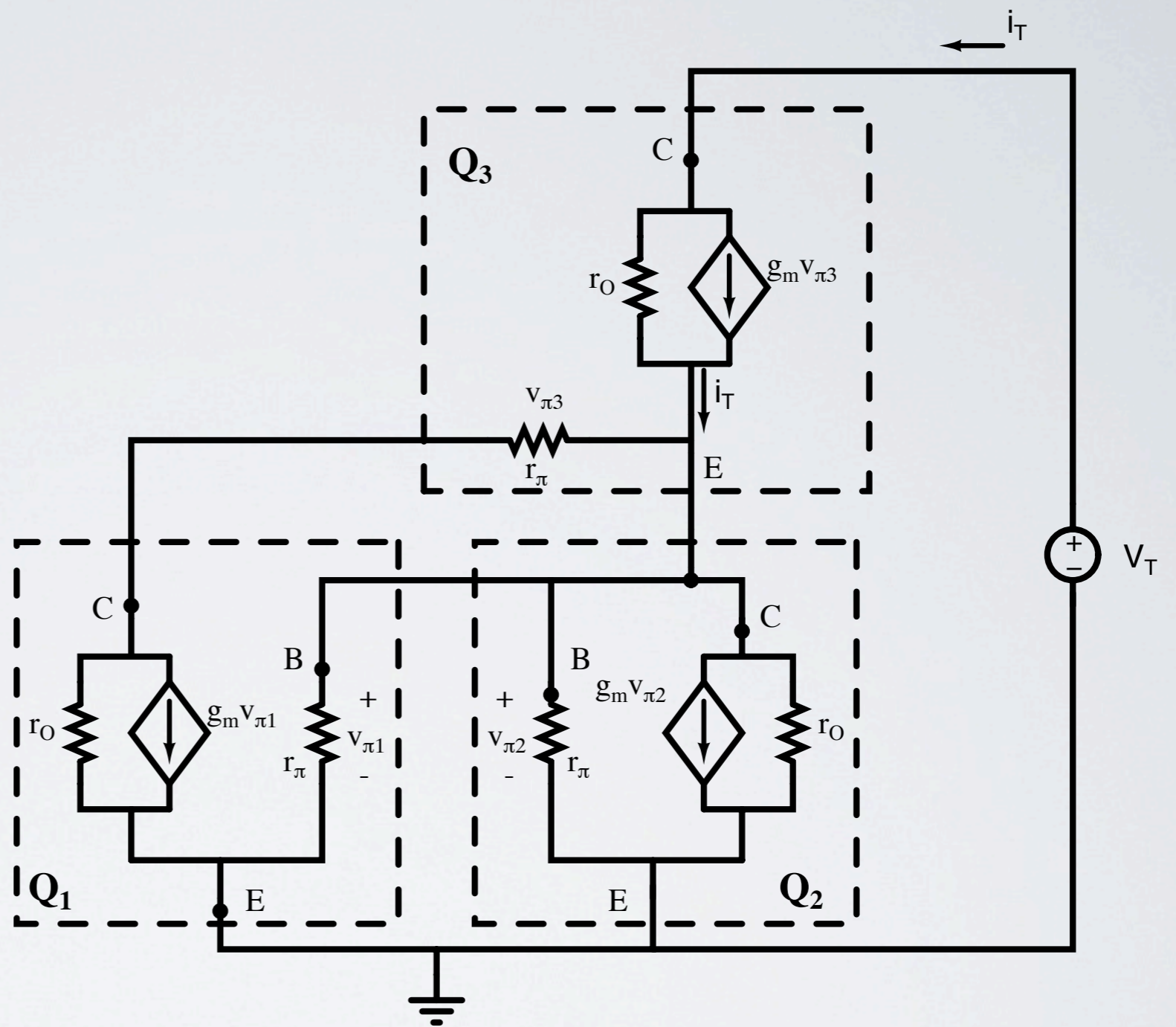
$$R_{OUT} \simeq r_o \left(1 + \frac{\beta R_2}{R_2 + r_\pi} \right) = r_o \left(1 + \frac{g_m r_\pi R_2}{R_2 + r_\pi} \right) = r_o (1 + g_m (R_2 \parallel r_\pi))$$

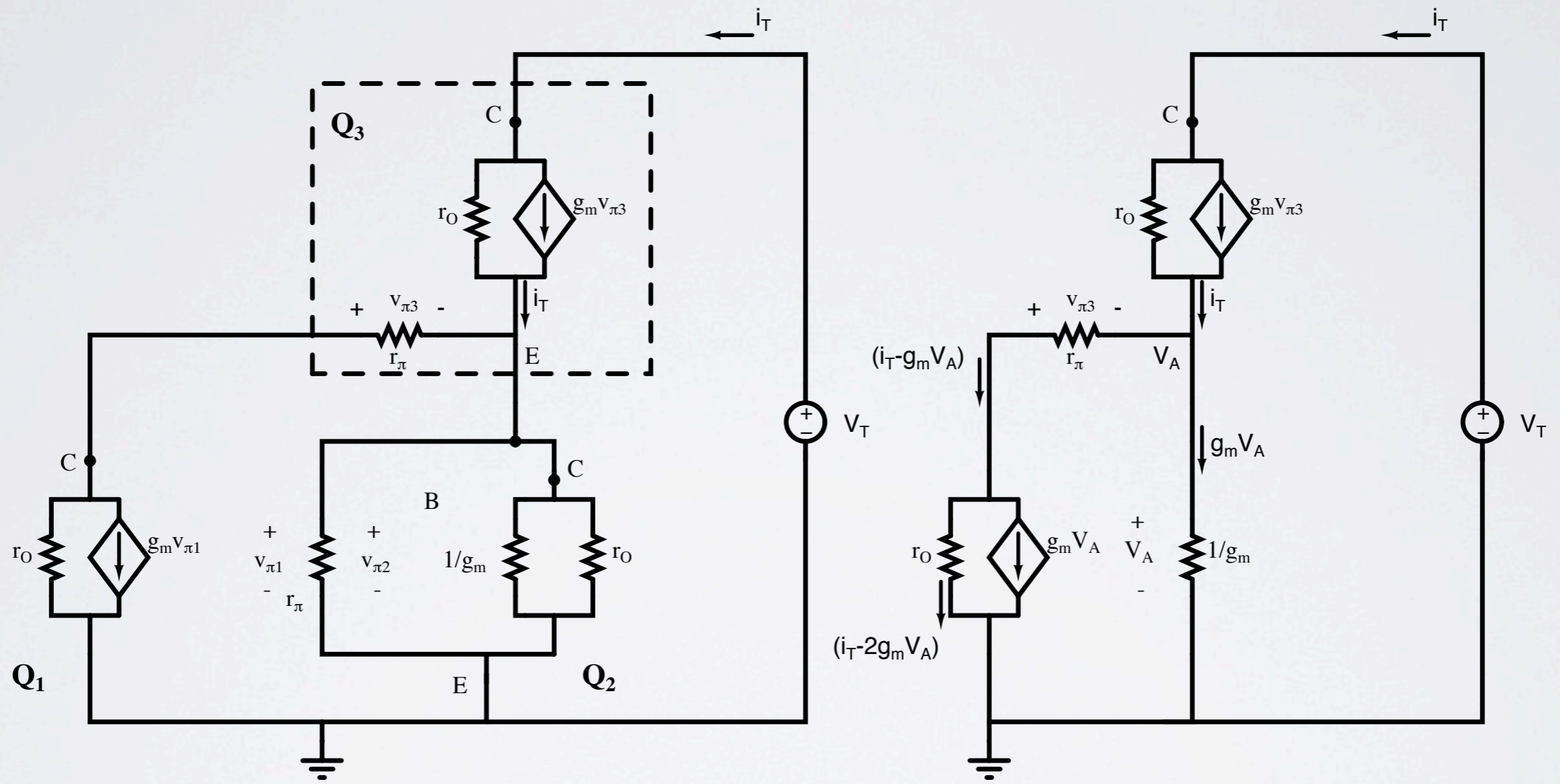


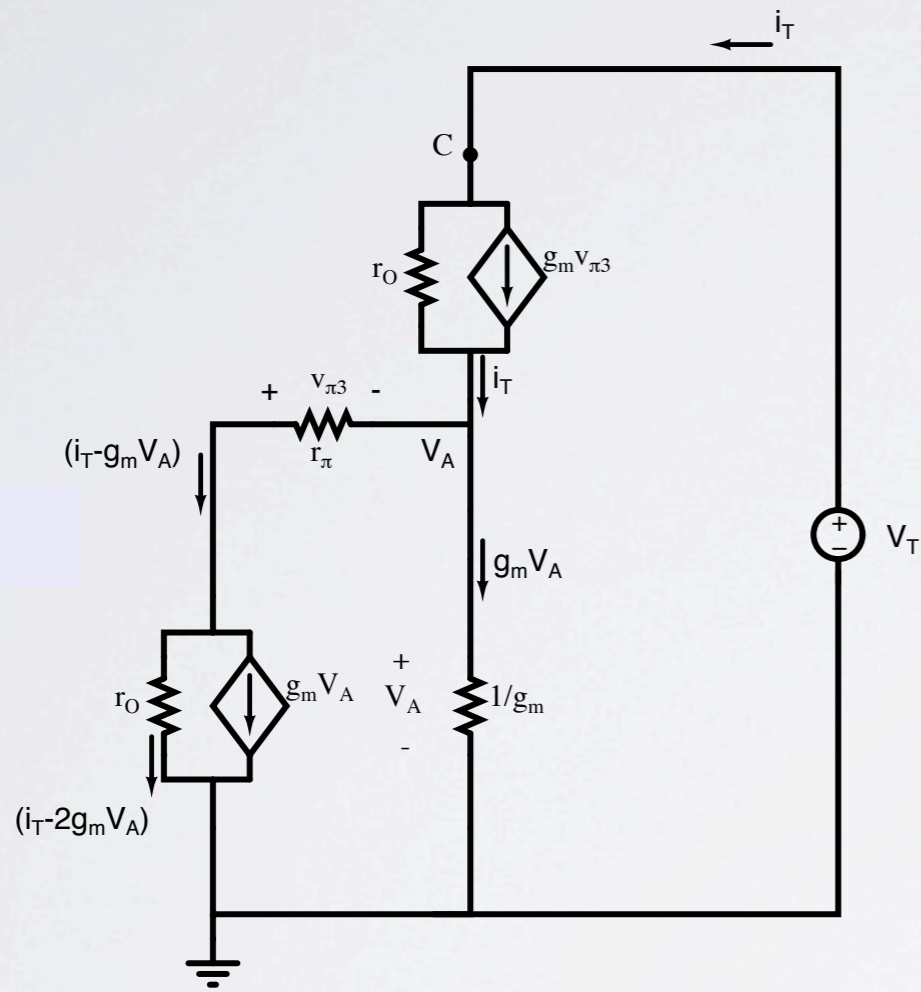
Widlar C.S.



Wilson C.S.







$$V_T = (i_T - g_m v_{\pi 3}) r_O + v_A$$

$$V_A = (i_T - g_m v_A) r_{\pi} + (i_T - 2g_m v_A) r_O$$

$$= \frac{r_{\pi} + r_O}{1 + \beta + 2g_m r_O} i_T \simeq \frac{1}{2g_m} i_T$$

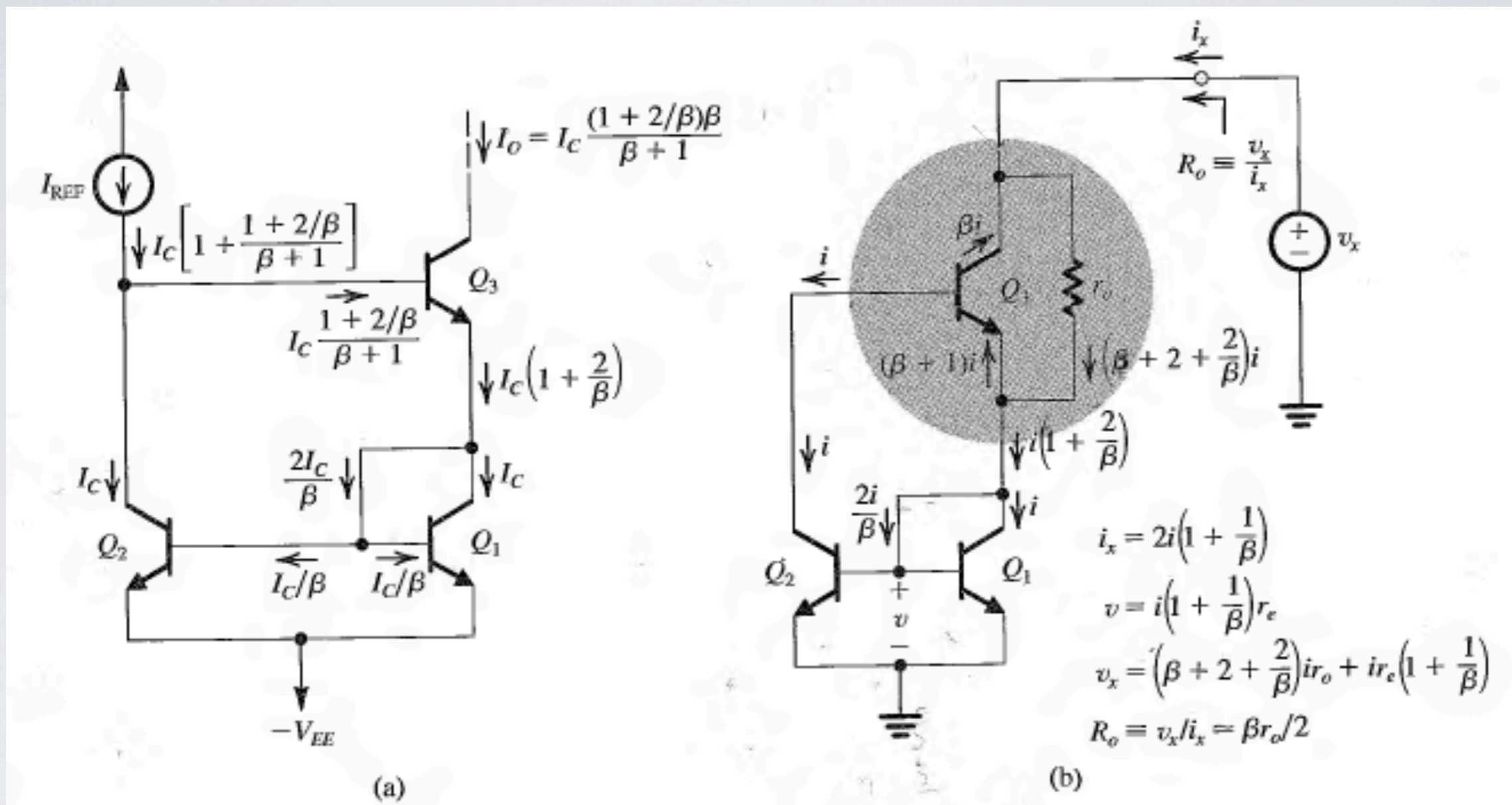
$$v_{\pi,3} = -(i_T - g_m v_A) r_{\pi} = -i_T r_{\pi} + \beta v_A$$

$$= -i_T r_{\pi} + \beta \frac{1}{2g_m} i_T = i_T \frac{\beta - 2\beta}{2g_m} = -i_T \frac{\beta}{2g_m}$$

$$V_T = i_T r_O + i_T \frac{\beta g_m}{2g_m} r_O + \frac{1}{2g_m} i_T$$

$$R_{OUT} = \frac{V_T}{i_T} = r_O + \frac{\beta r_O}{2} + \frac{1}{2g_m} \simeq \boxed{\frac{\beta r_O}{2}}$$

Textbook approach



$$I_o = I_c \frac{(1 + 2/\beta)\beta}{\beta + 1}$$

$$I_{REF} \downarrow I_c \left[1 + \frac{1 + 2/\beta}{\beta + 1} \right]$$

$$I_c \frac{1 + 2/\beta}{\beta + 1}$$

$$\downarrow I_c \left(1 + \frac{2}{\beta} \right)$$

$$I_c \downarrow$$

$$\frac{2I_c}{\beta} \downarrow$$

$$\downarrow I_c$$

$$-V_{EE}$$

$$i_x$$

$$R_o \equiv \frac{v_x}{i_x}$$

$$v_x$$

$$i$$

$$\beta i$$

$$(\beta + 1)i \uparrow$$

$$\downarrow (\beta + 2 + \frac{2}{\beta})i$$

$$\downarrow i \left(1 + \frac{2}{\beta} \right)$$

$$\downarrow i$$

$$\frac{2i}{\beta} \downarrow$$

$$\downarrow i$$

$$i_x = 2i \left(1 + \frac{1}{\beta} \right)$$

$$v = i \left(1 + \frac{1}{\beta} \right) r_e$$

$$v_x = \left(\beta + 2 + \frac{2}{\beta} \right) i r_o + i r_e \left(1 + \frac{1}{\beta} \right)$$

$$R_o \equiv v_x / i_x = \beta r_o / 2$$

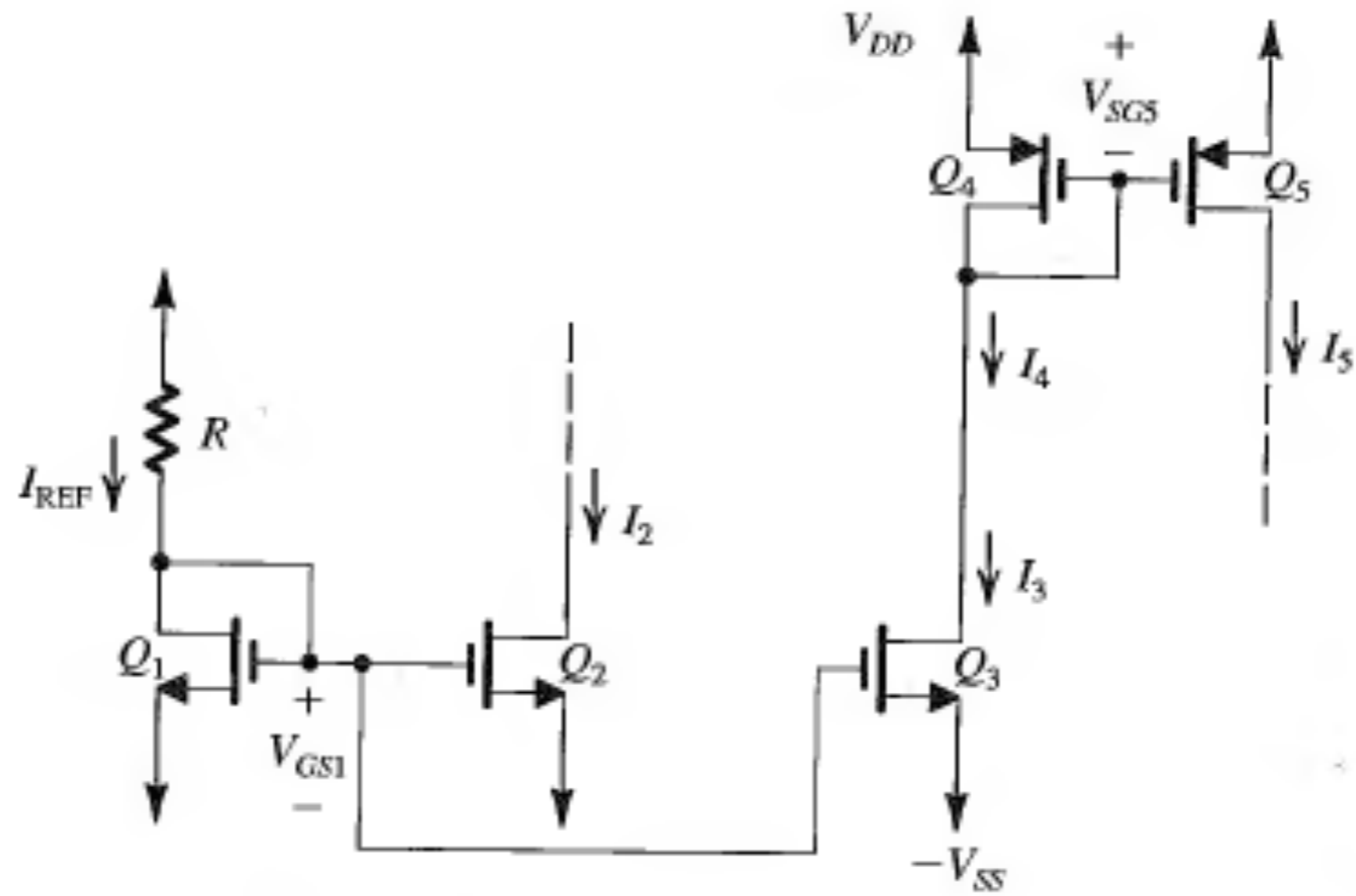
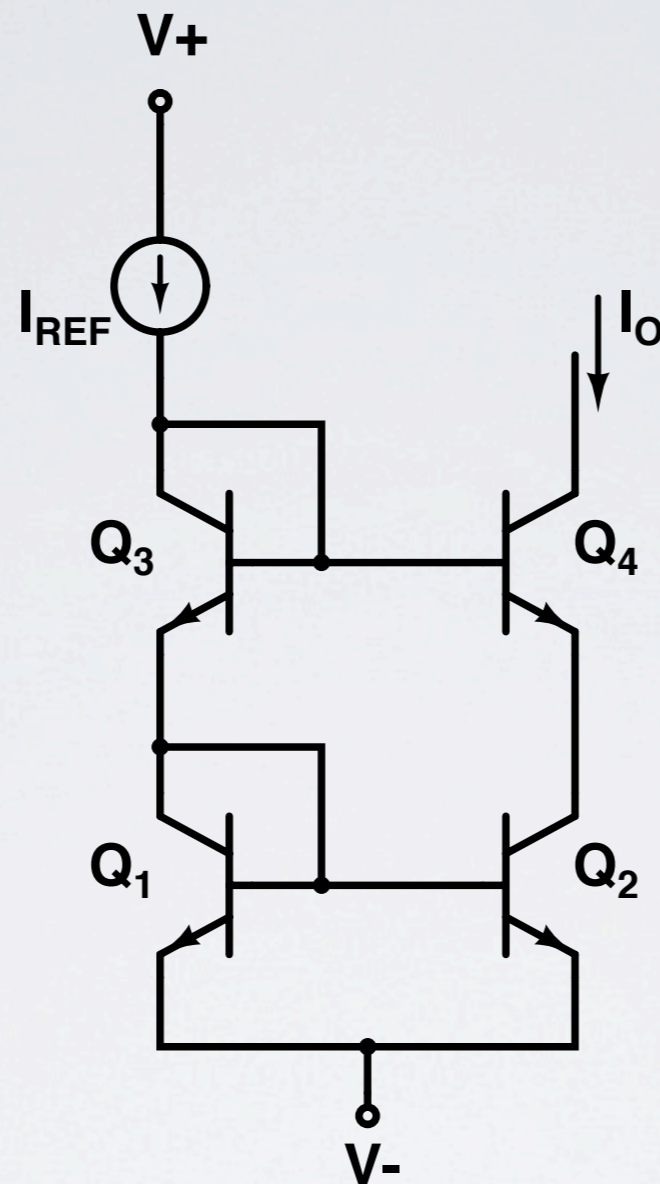


FIGURE 6.7 A current-steering circuit.

Cascode C.S.

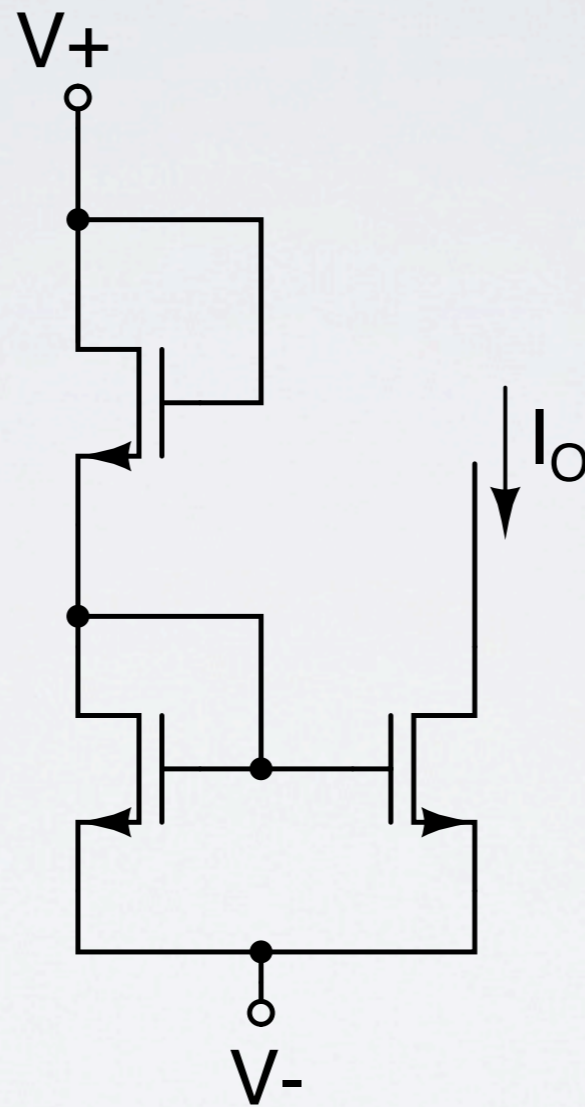


Equation 1: $R_{OUT} \simeq \beta r_o$

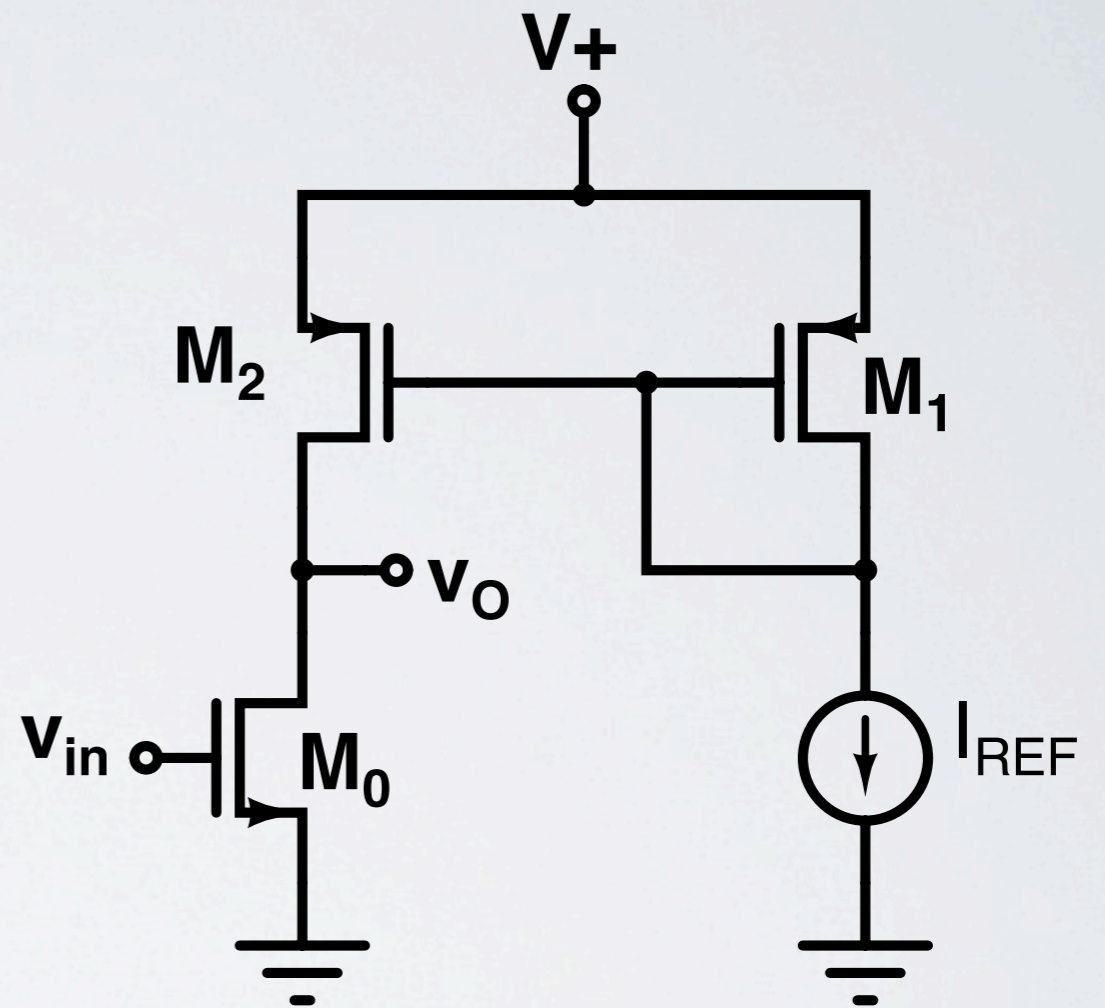
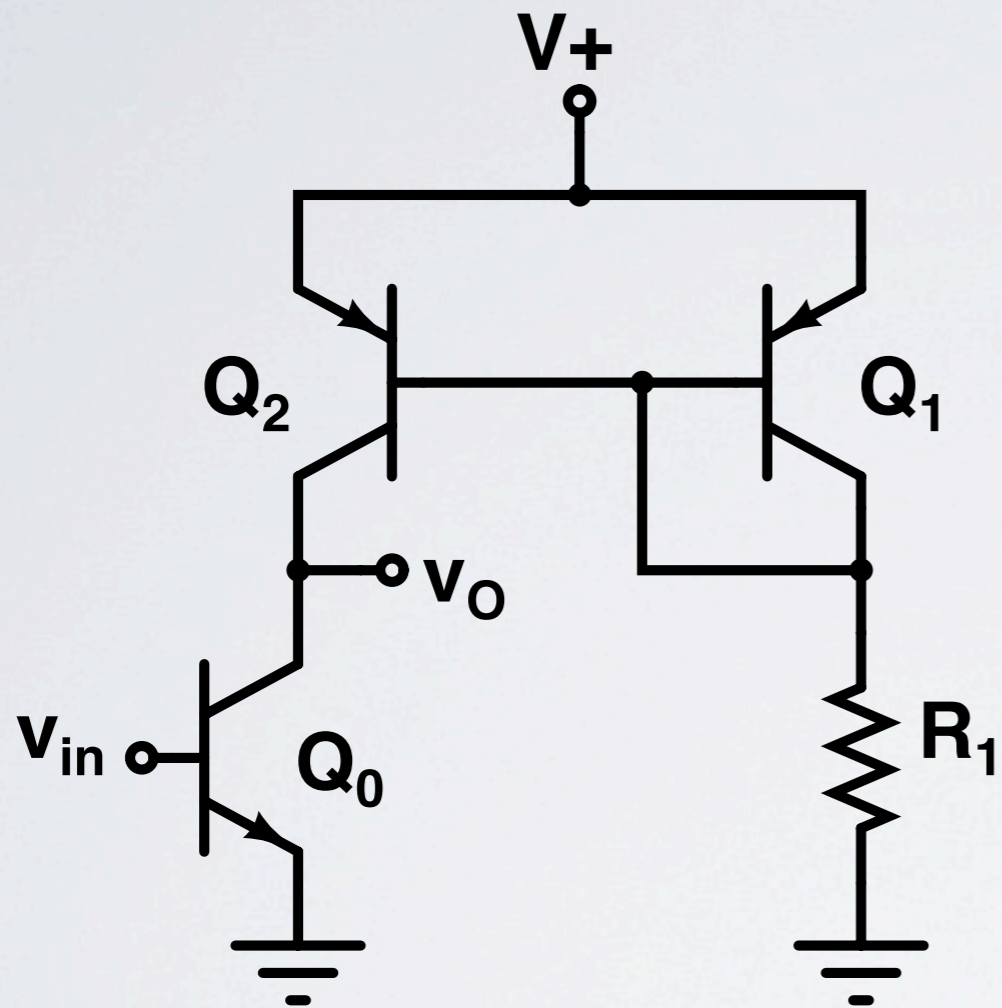
but: $R_{OUT} \simeq \beta r_o / 2$

For MOSFET Cascode: $R_{OUT} \simeq g_{m3} r_{o2} r_{o4}$

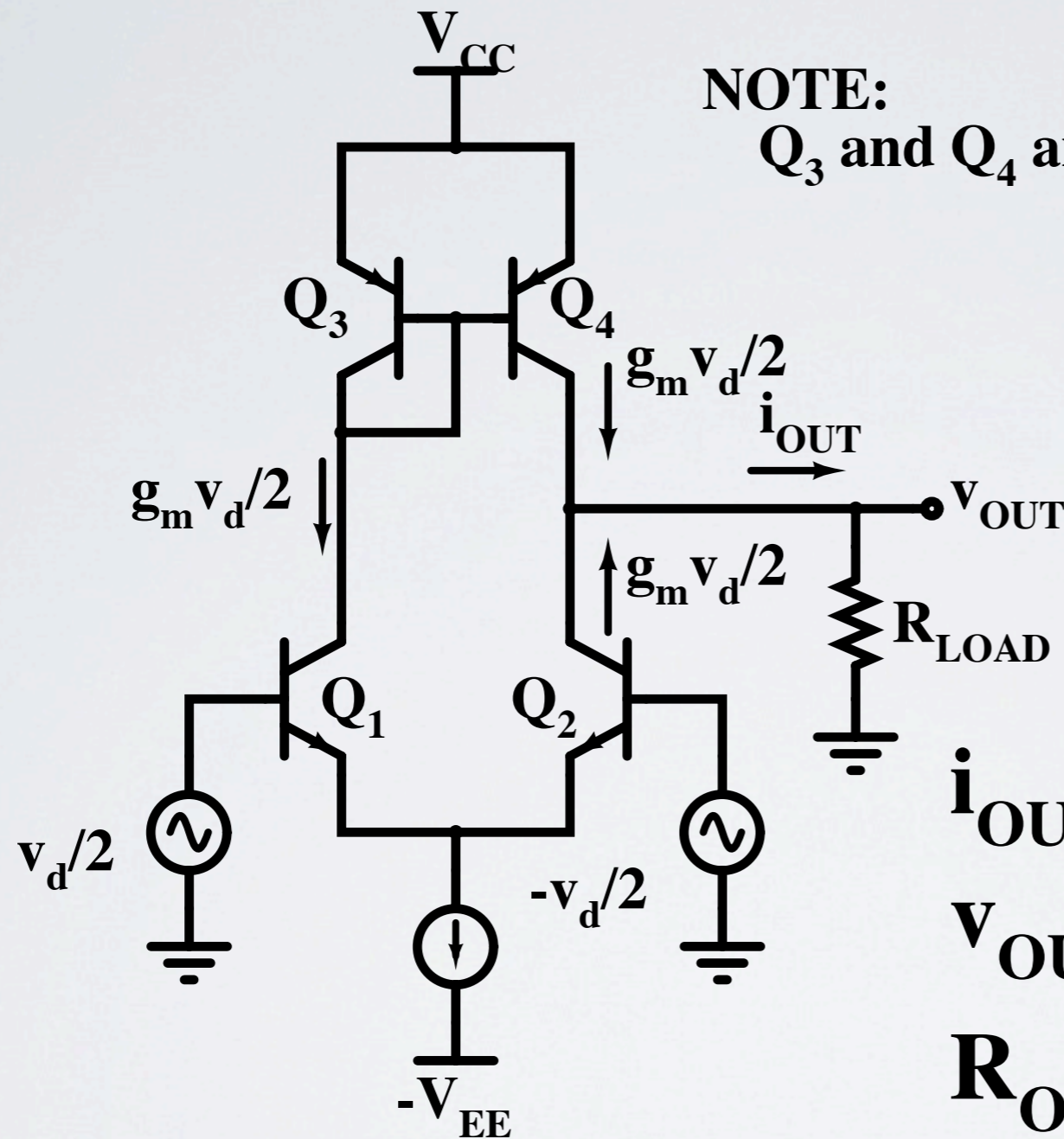
MOSFET CSs



Active Loads



Active Loads

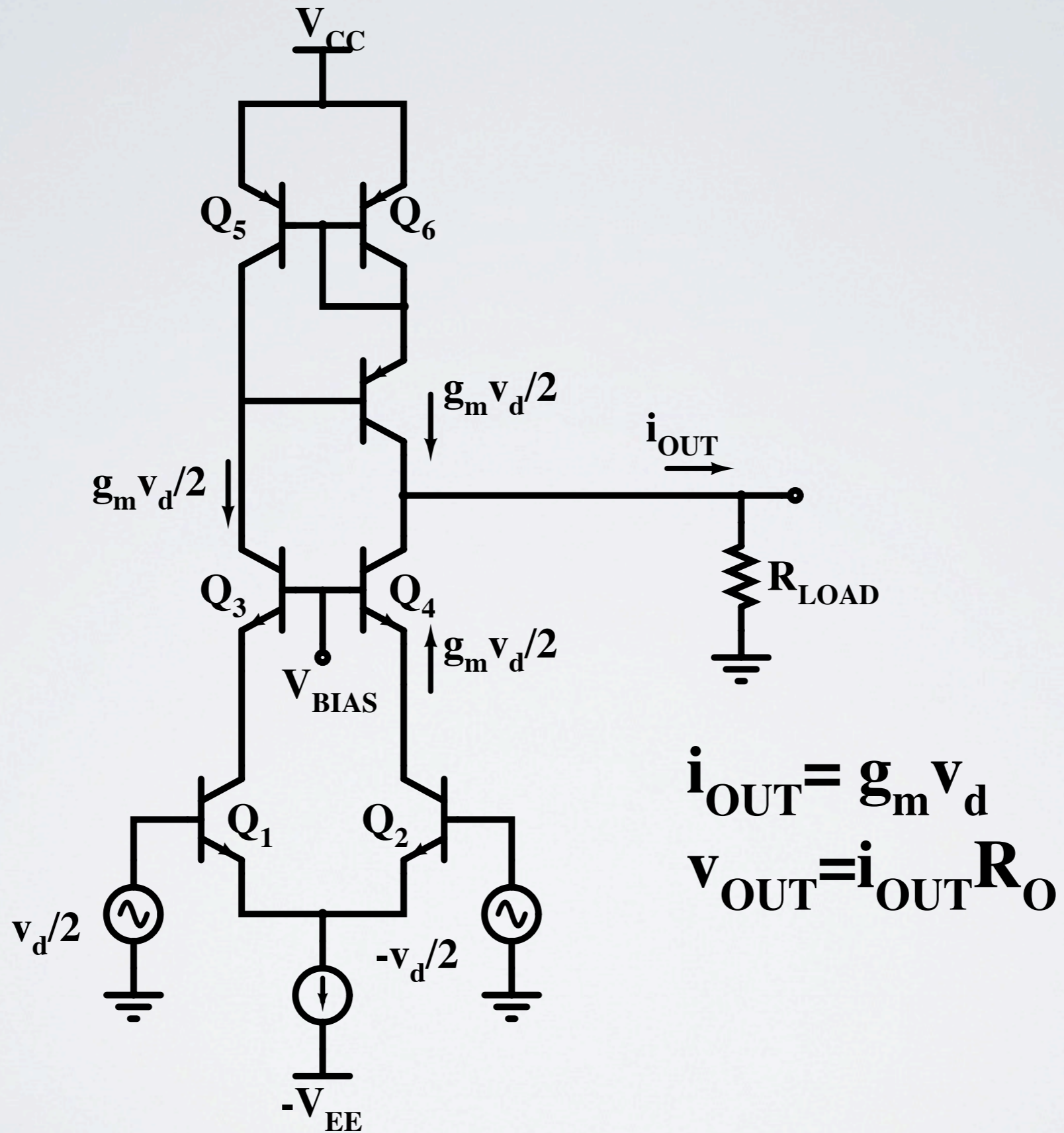


NOTE:
 Q_3 and Q_4 are PNP BJTs

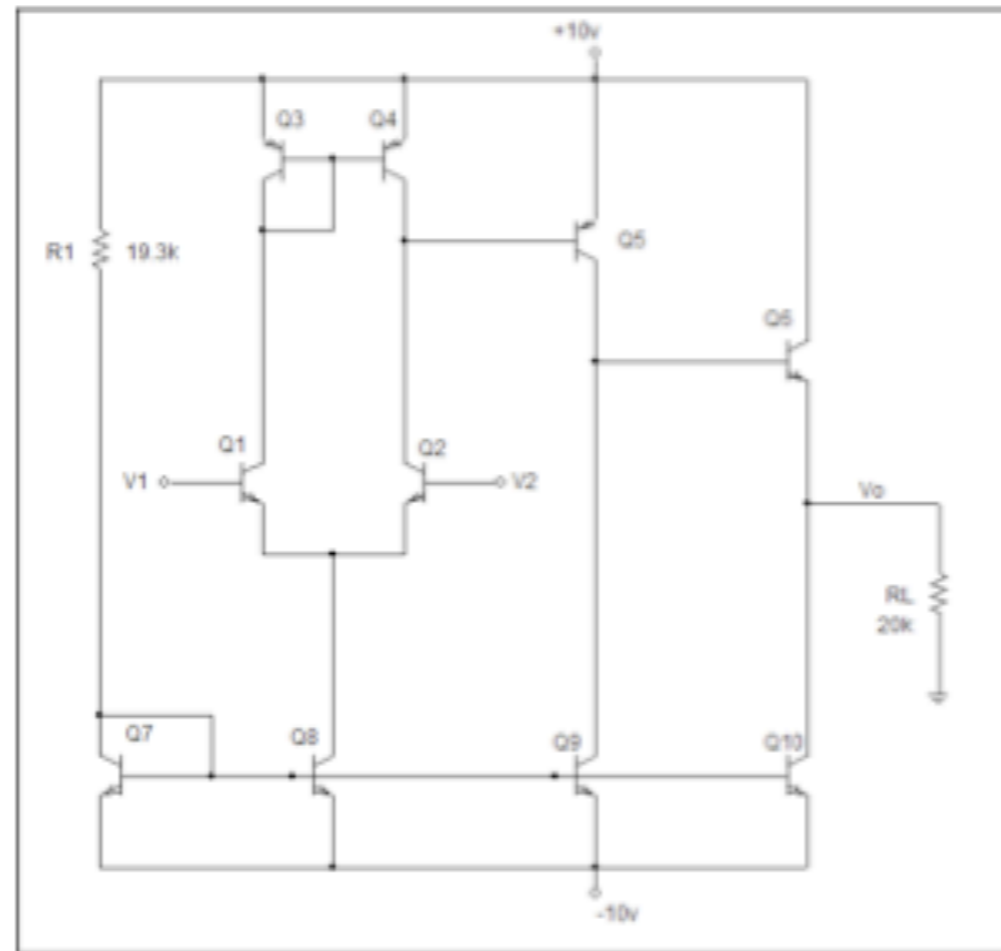
$$i_{OUT} = g_m v_d$$

$$v_{OUT} = i_{OUT} R_O$$

$$R_O = R_{LOAD} \parallel r_{O2} \parallel r_{O4}$$



3. (33 pts.) The transistor parameters of the op-amp shown below are: $\beta = 200$, $r_o = 100k\Omega$ (NPN and PNP).



Determine

- the differential voltage gain A_d ,
- the common mode voltage gain A_c ,
- the CMRR, and
- the differential input resistance of this amplifier.
- R_{in} for CM
- Bias current
- f_t and SR if $C=1.6nF$ (between Q5's base and collector)