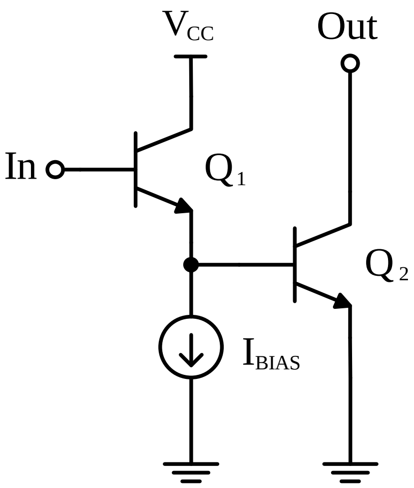
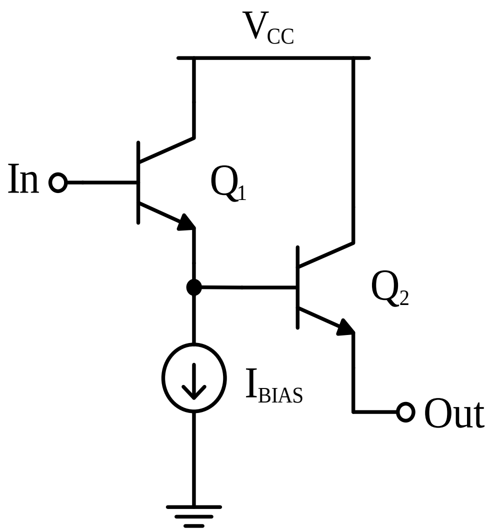
EEE 241
ANALOG ELECTRONICS
CLASS 13&14

DR NORLAILI MOHD NOH



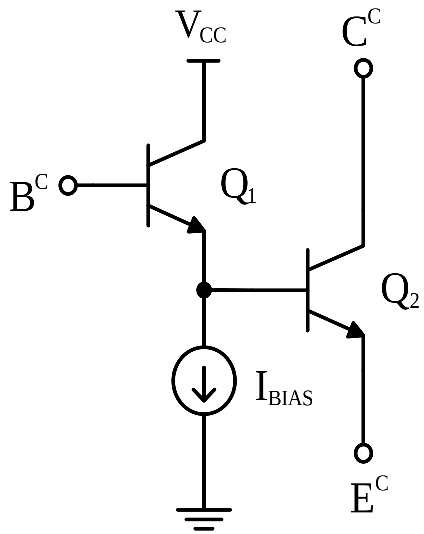
CC-CE cascade

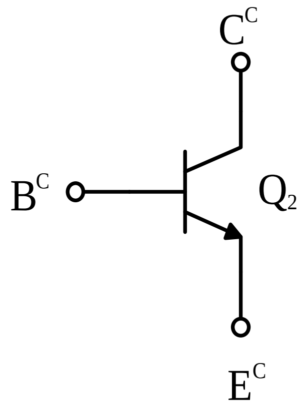


CC-CC cascade

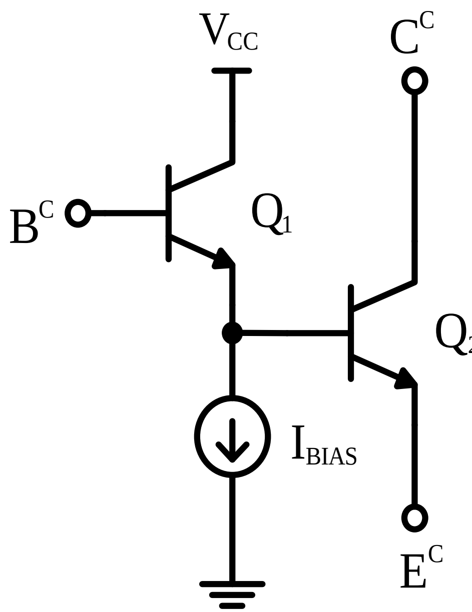
In both CC-CE and CC-CC cascades, Q1 is to increase current gain through the stage and to increase the input resistance

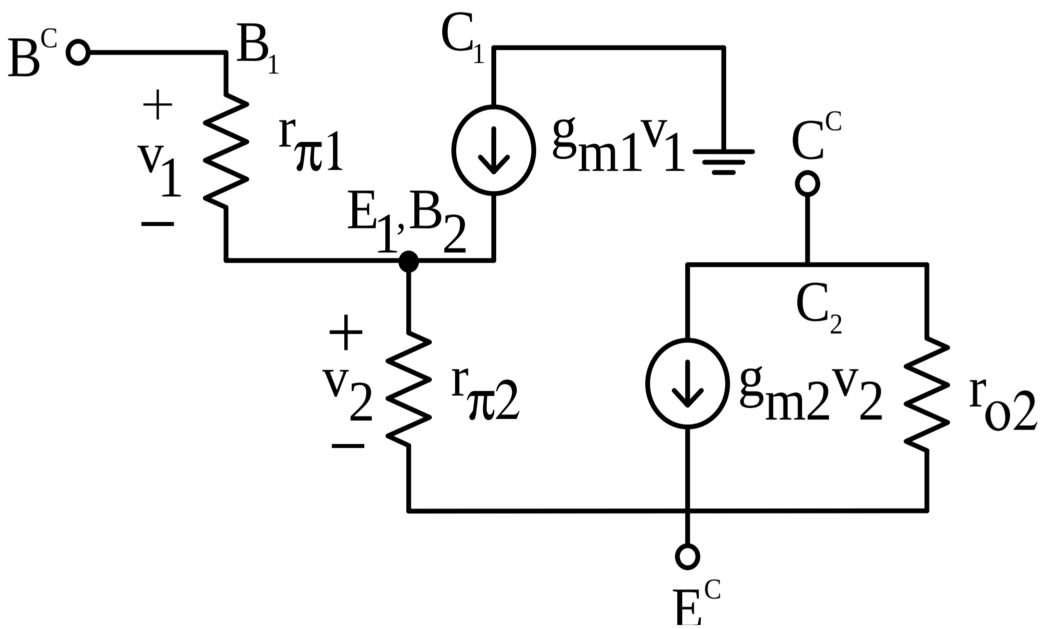
The two transistors, Q1 and Q2, can be thought of as a single composite transistor shown below



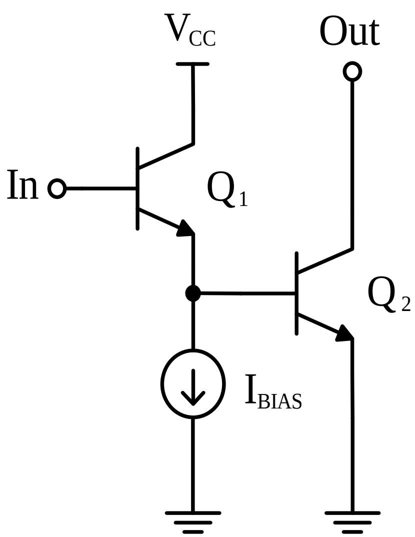


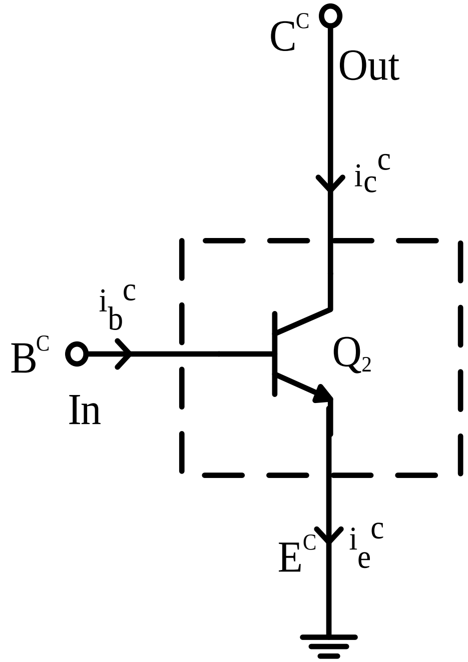
The small signal equivalent circuit for the composite device (assuming effects of r_o of Q_1 are negligible)





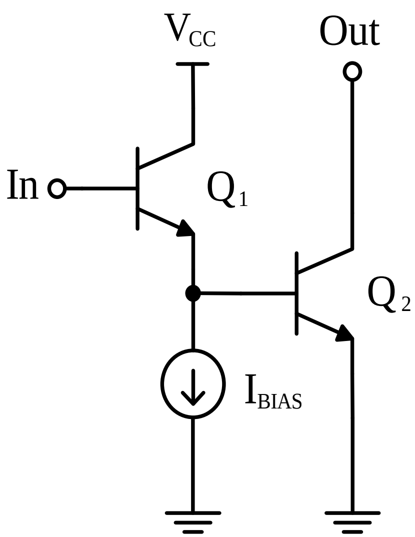
For CC-CE cascade :

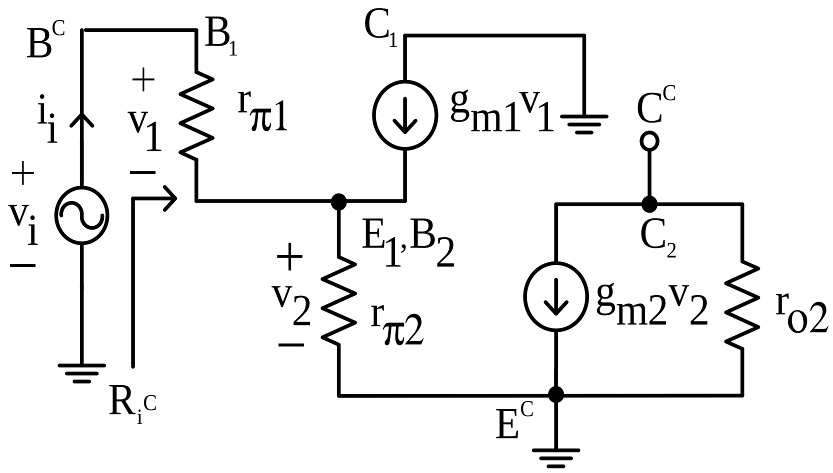




For CC-CE cascade :

The effective value of r_π, r_π^c, is the resistance seen looking into the composite B, B^C, with the composite E, E^C, grounded.



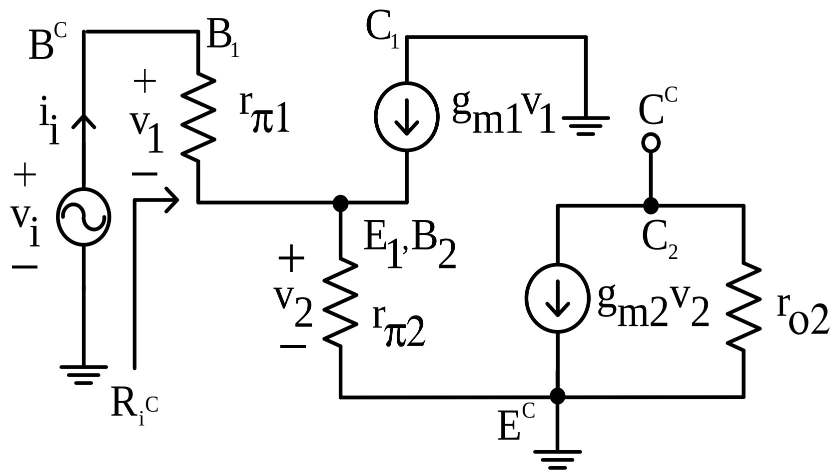


KCL at node E1,

$$i_i + g_{m1}v_1 = \frac{v_2}{r_{\pi 2}}$$

$$R_i^C = \frac{v_i}{i_i}$$

$$g_{m1}v_1 = g_{m1}i_i r_{\pi 1} = \beta_o i_i$$



$$g_{m1}v_1 = g_{m1}i_i r_{\pi 1} = \beta_o i_i$$

$$i_i + g_{m1}v_1 = \frac{v_2}{r_{\pi 2}}$$

$$i_i + \beta_o i_i = \left(v_i - i_i r_{\pi 1}\right)\frac{1}{r_{\pi 2}}$$

$$i_i\left(1+\beta_o+\frac{r_{\pi 1}}{r_{\pi 2}}\right)r_{\pi 2} = v_i$$

$$R_i^C = \frac{v_i}{i_i}$$

$$R_i^C = \left(1+\beta_o+\frac{r_{\pi 1}}{r_{\pi 2}}\right)r_{\pi 2} = r_{\pi 1} + \left(1+\beta_o\right)r_{\pi 2}$$

r_π^C which is between B^c and E^c is R_i^C

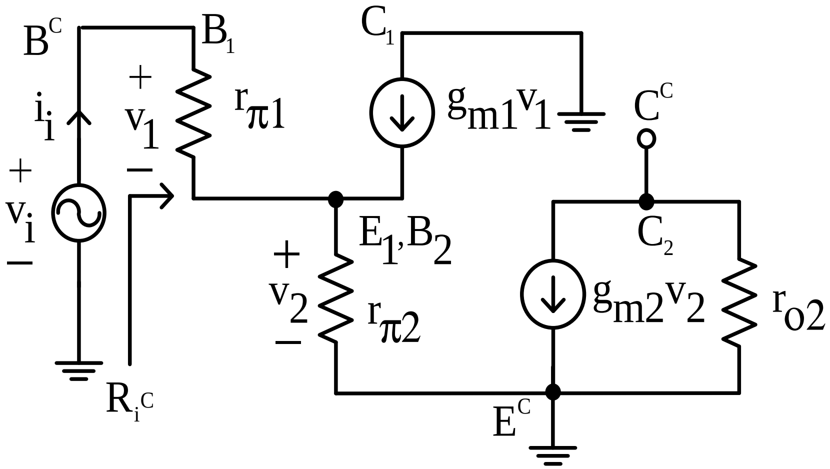
$$\therefore r_\pi^C = r_{\pi 1} + \left(1+\beta_o\right)r_{\pi 2}$$

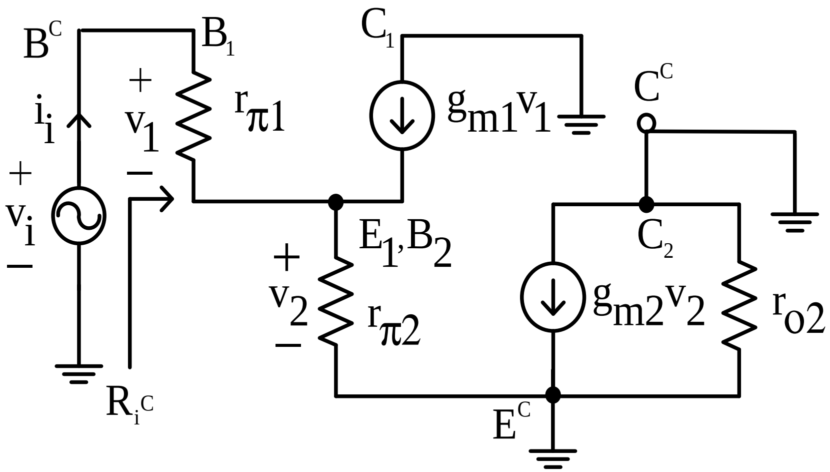
To determine the effective transconductance, g_m^C

g_m^c is the change in collector current of Q_2, i_c^c for a unit change in v_{be}^c with C^C and E^C grounded

$$G_m = \left.\frac{i_o}{v_i}\right|_{v_o=0}$$

$$g_m^c = \frac{i_c^c}{v_{be}^c}$$





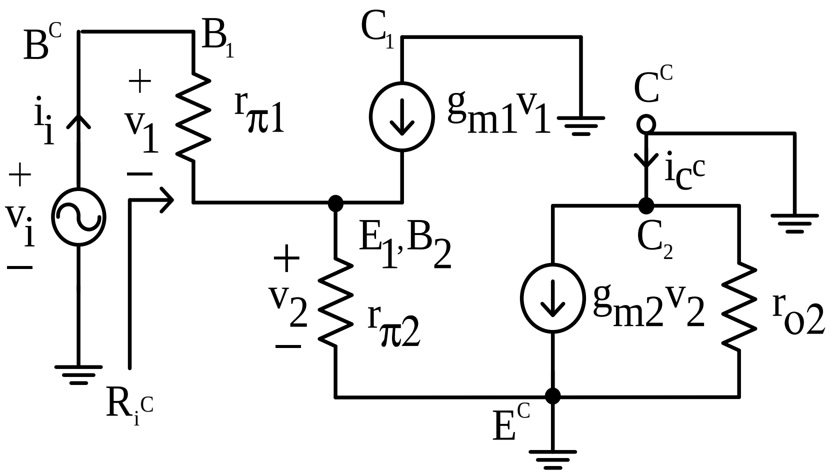
At node E1,

$$\frac{v_1}{r_{\pi 1}} + g_{m1} v_1 = \frac{v_2}{r_{\pi 2}}$$

$$v_i = v_{be}^c$$

$$\left(v_{be}^c - v_2\right)\left[\frac{1}{r_{\pi 1}} + g_{m1}\right] = \frac{v_2}{r_{\pi 2}}$$

$$v_2 = \frac{v_{be}^c\left[\frac{1}{r_{\pi 1}} + g_{m1}\right]}{\frac{1}{r_{\pi 1}} + g_{m1} + \frac{1}{r_{\pi 2}}}$$



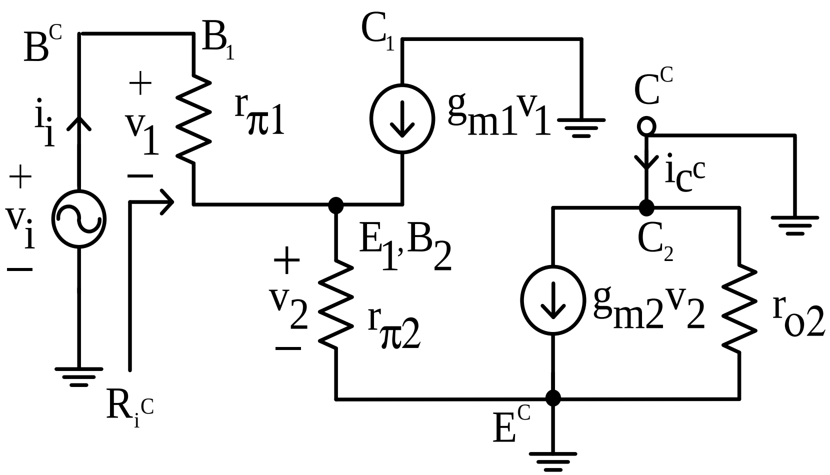
$$v_2=\frac{v_{be}^{c}\left[\frac{1}{r_{\pi1}}+g_{m1}\right]}{\frac{1}{r_{\pi1}}+g_{m1}+\frac{1}{r_{\pi2}}}$$

$$v_2=\frac{1}{\frac{1}{\frac{1}{r_{\pi1}}+g_{m1}}\left[\left(\frac{1}{r_{\pi1}}+g_{m1}\right)+\frac{1}{r_{\pi2}}\right]}v_{be}^{c}$$

$$v_2=\frac{1}{1+\frac{1}{\left(\frac{1}{r_{\pi1}}+g_{m1}\right)r_{\pi2}}}v_{be}^{c}$$

$$v_2=\frac{1}{1+\frac{r_{\pi1}}{\left(1+g_{m1}r_{\pi1}\right)r_{\pi2}}}v_{be}^{c}$$

Since the voltage across r_{o2} is 0, $i_{ro2}=0$ and $i_c^c=g_{m2}v_2$



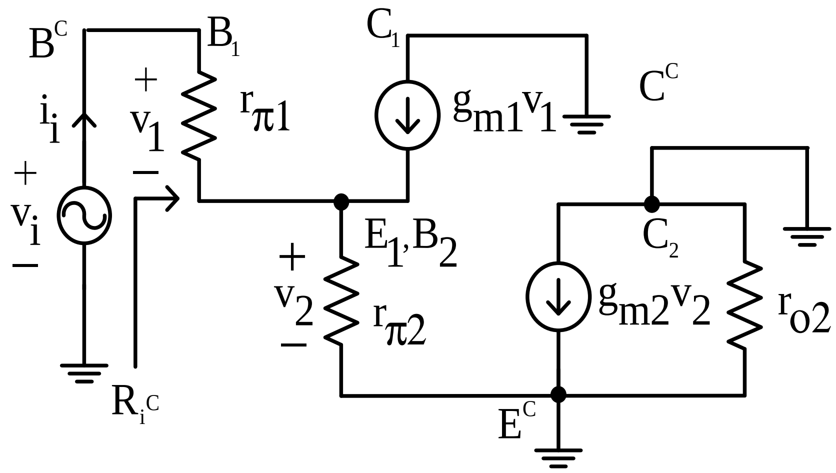
$$v_2=\frac{1}{1+\frac{r_{\pi 1}}{(1+g_{m1}r_{\pi 1})r_{\pi 2}}}v_{be}^{\ c}$$

$$\left(1+\frac{r_{\pi 1}}{(1+g_{m1}r_{\pi 1})r_{\pi 2}}\right)v_2=v_{be}^{\ c}$$

$$g_m^{\ c}=\frac{i_c^{\ c}}{v_{be}^{\ c}}=\frac{g_{m2}v_2}{\left(1+\frac{r_{\pi 1}}{(1+g_{m1}r_{\pi 1})r_{\pi 2}}\right)v_2}$$

$$g_m^{\ c}=\frac{g_{m2}}{1+\frac{r_{\pi 1}}{(1+\beta_o)r_{\pi 2}}}$$

Effective current gain, $\beta^C = \frac{i_c{}^c}{i_b{}^c}$



$i_i = i_b{}^c$

$g_{m1} v_1 = g_{m1} i_b{}^c r_{\pi 1} = \beta_o i_b{}^c$

$i_{e1} = i_b{}^c + \beta_o i_b{}^c = (1+\beta_o) i_b{}^c$

$i_{e1} = i_{b2}$

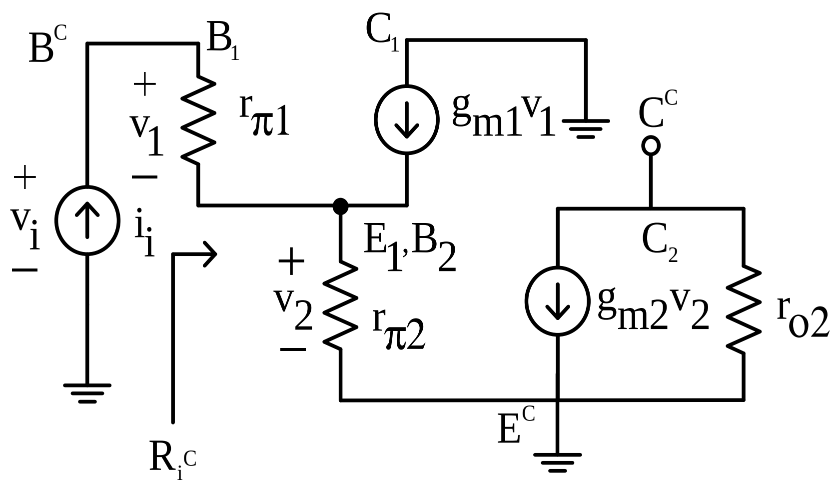
$g_{m2} v_2 = g_{m2} i_{e1} r_{\pi 2} = \beta_o i_{e1}$

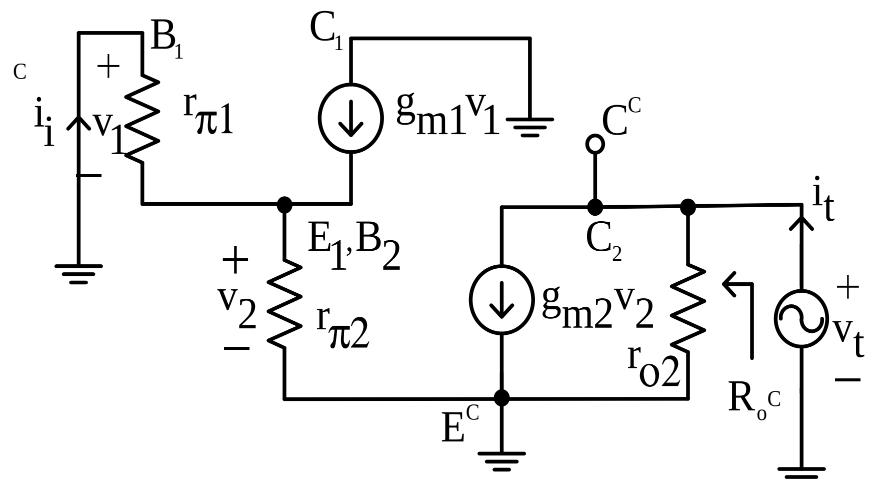
$i_c{}^c = \beta_o i_{e1} = \beta_o (1+\beta_o) i_b{}^c$

$\therefore \beta^c = \frac{i_c{}^c}{i_b{}^c} = \beta_o (1+\beta_o)$

This shows that the current gain of the composite transistor is approximately β_o^2.

To find output resistance, $r_o^{\ c}$:





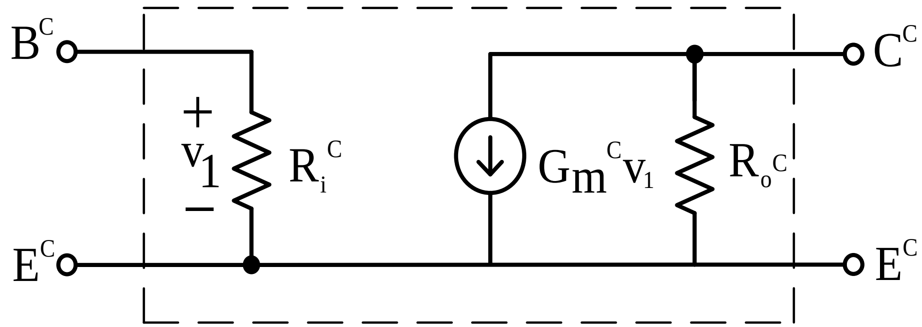
$$R_o^{\ c} = \left.\frac{v_t}{i_t}\right|_{v_i=0}$$

$$v_1 = v_2 = 0$$

$$g_{m2} v_2 = 0$$

$$R_o^{\ c} = r_o^{\ c} = r_{o2}$$

The small signal, two-port network equivalent for the CC-CE connection



$$R_i^{\,c} = r_\pi^{\,c} = r_{\pi1} + \left(\beta_o + 1\right) r_{\pi2}$$

$$G_m^{\,c} = g_m^{\,c} = \frac{g_{m2}}{1 + \left[\dfrac{r_{\pi1}}{\left(\beta_o + 1\right) r_{\pi2}}\right]}$$

$$R_o^{\,c} = r_o^{\,c} = r_{o2}$$

The Darlington pair

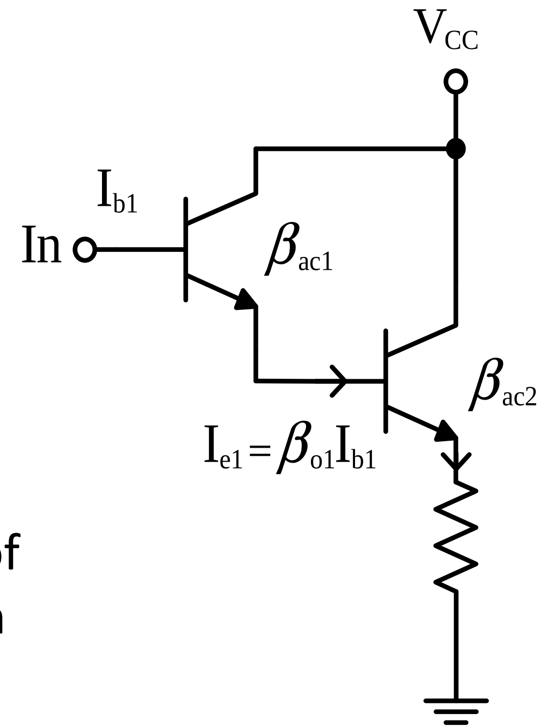
$$R_i \text{ for CE}: r_\pi = \frac{\beta_o}{g_m}$$

$$R_i \text{ for CB}: r_e = \frac{1}{g_m + \frac{1}{r_\pi}} = \frac{1}{g_m\left(1+\frac{1}{\beta_o}\right)} = \frac{\alpha_o}{g_m}$$

$$R_i \text{ for CC}: R_i = r_\pi + (\beta_o + 1)(R_L \| r_o)$$

$$R_i \text{ for emitter degeneration}: R_i = r_\pi + (1+\beta_o)R_E$$

$$R_i^c = r_\pi^c = r_{\pi 1} + (\beta_o + 1) r_{\pi 2}$$

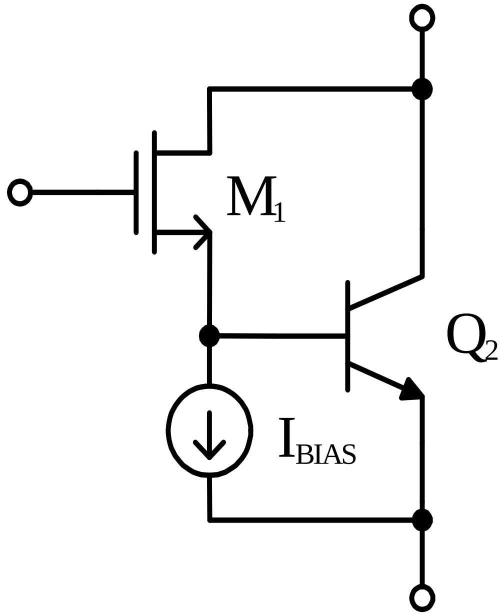


β_o is a major factor in determining the input resistance of an amplifier. The β_o of the transistor limits the maximum achievable input resistance that can be obtained from a common collector circuit.

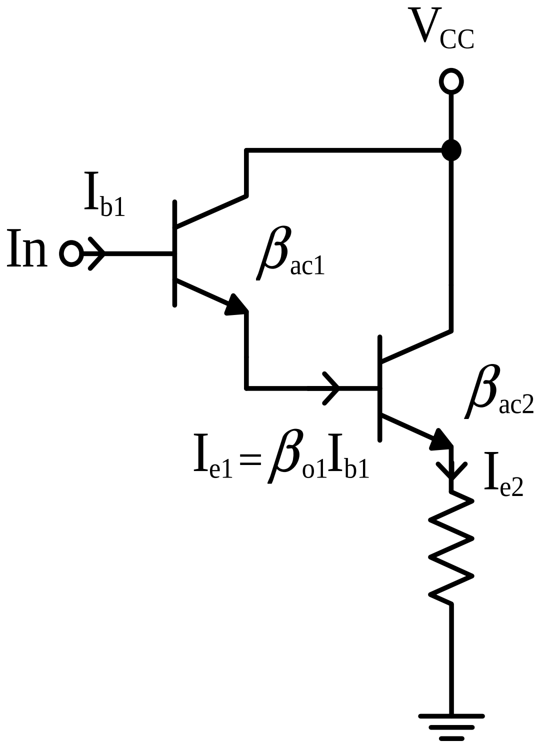
One way to boost the input resistance is to use a Darlington pair. The collectors of two transistors are connected, and the E of the first drives the B of the second.

Since Darlington-type connections are used to boost the effective current gain of BJT, it has no significant application in pure-MOS circuits.

However, in BiCMOS, it is used to apply the ∞ R_{in} of MOS and high G_m of BJT.



The Darlington pair cont'd



$$\beta_{ac} = \beta_{o}$$

$$I_e = \left(\beta_{ac} + 1\right) I_b$$

$$I_{e1} \approx \beta_{ac1} I_{b1}$$

$$I_{e1} = I_{b2}$$

$$I_{e2} \approx \beta_{ac2} I_{b2} = \beta_{ac2} I_{e1}$$

$$I_{e2} = \beta_{ac2} \beta_{ac1} I_{b1}$$

Effective current gain $\dfrac{I_{e2}}{I_{b1}} = \beta_{ac2} \beta_{ac1}$

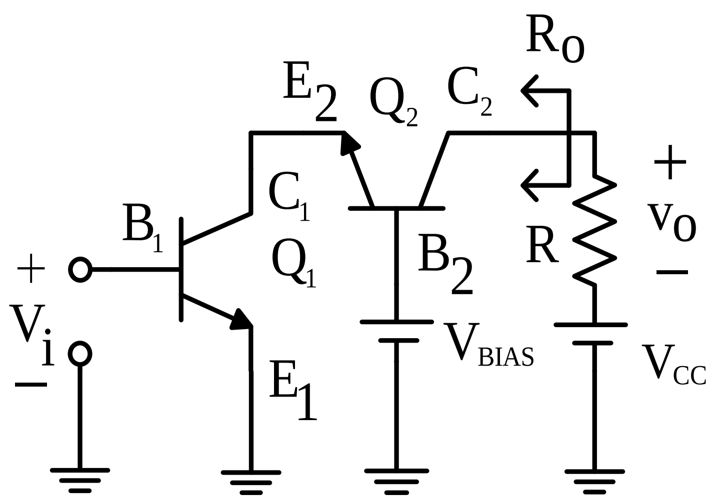
3.4.2 The Cascode Configuration

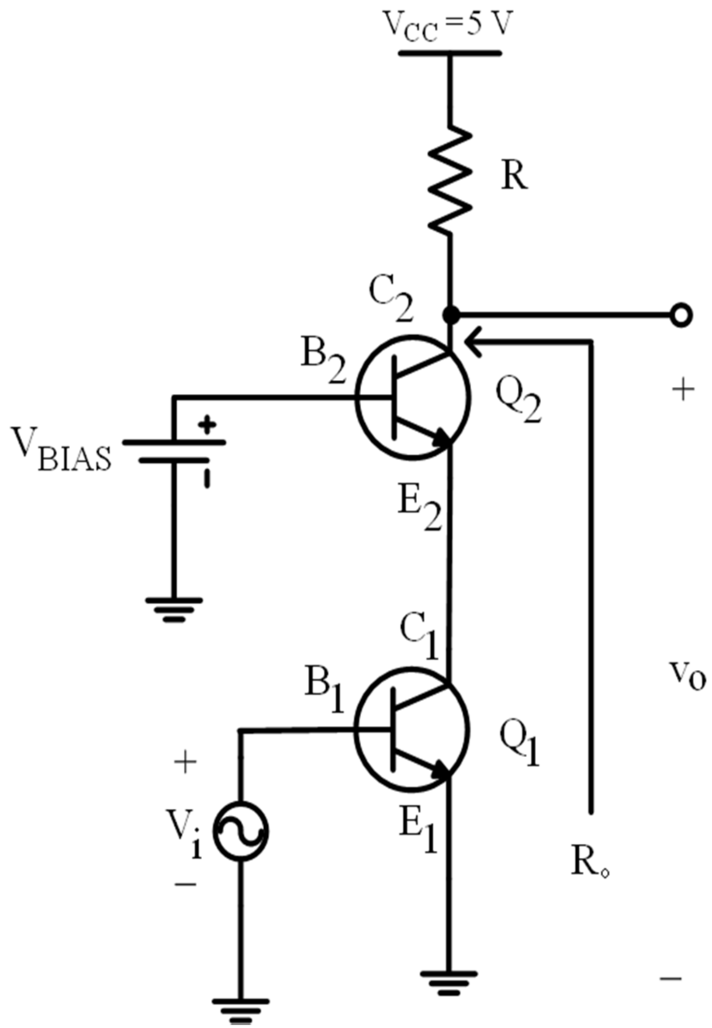
The cascode configuration is important mostly because it increases output resistance and reduces unwanted capacitive feedback in amplifiers, allowing operation at higher frequencies.

The high output resistance is particularly useful in achieving large amounts of voltage gain.

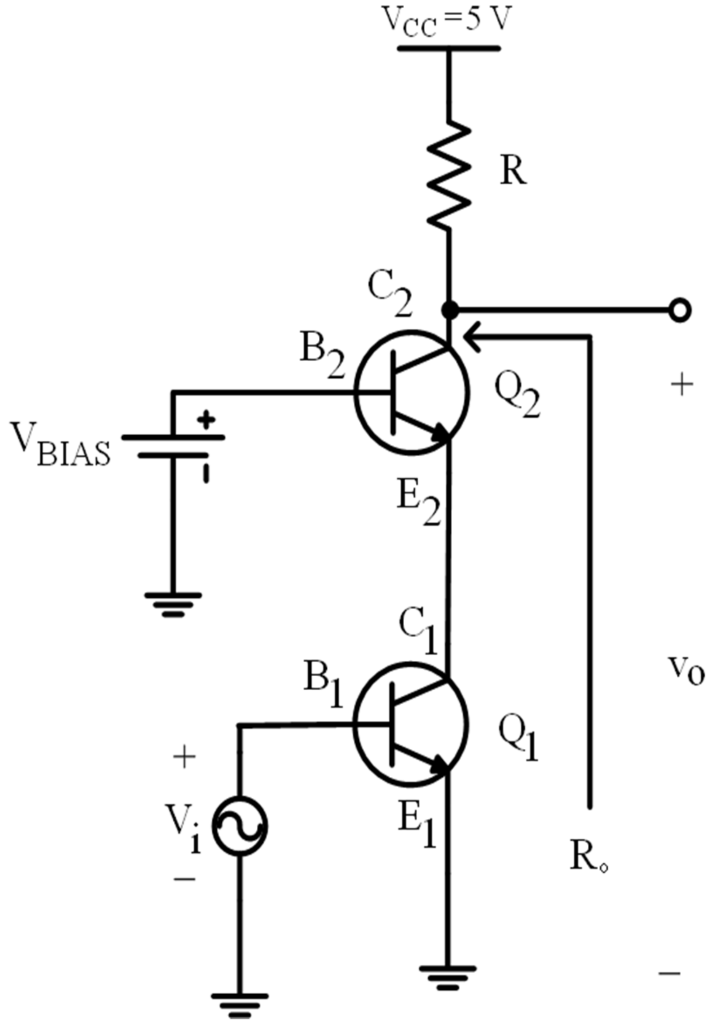
Bipolar Cascode

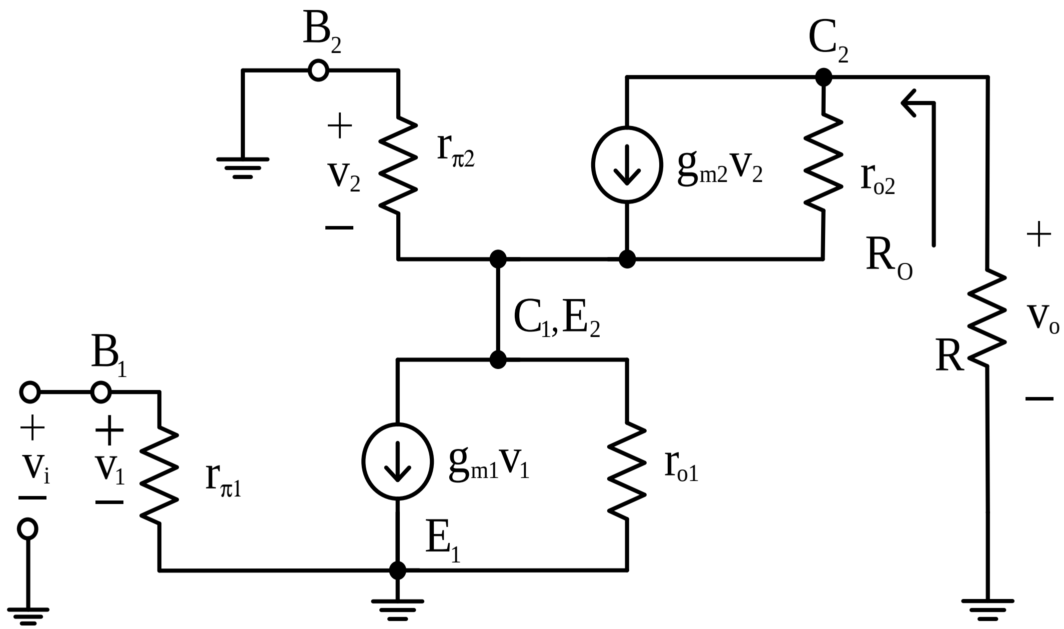
Cascode is a CE-CB amplifier.





Small-signal equivalent circuit for the cascode at low frequency



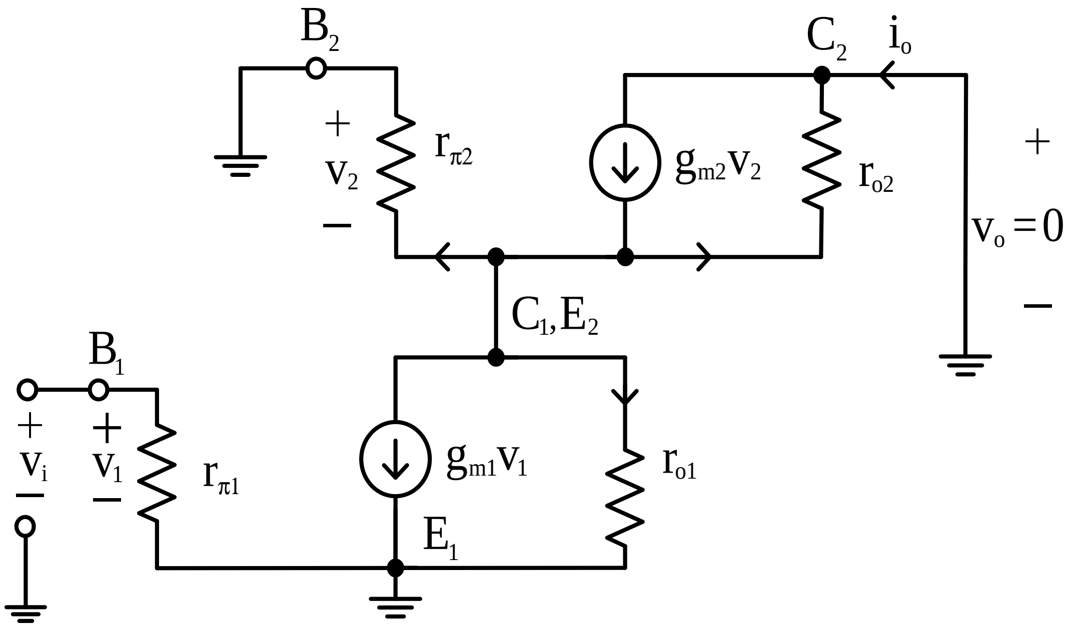


$$R_i = r_{\pi 1}$$

$$G_M = \left.\frac{i_o}{v_i}\right|_{v_o=0}$$

Small-signal equivalent circuit for low frequency

To determine G_M :

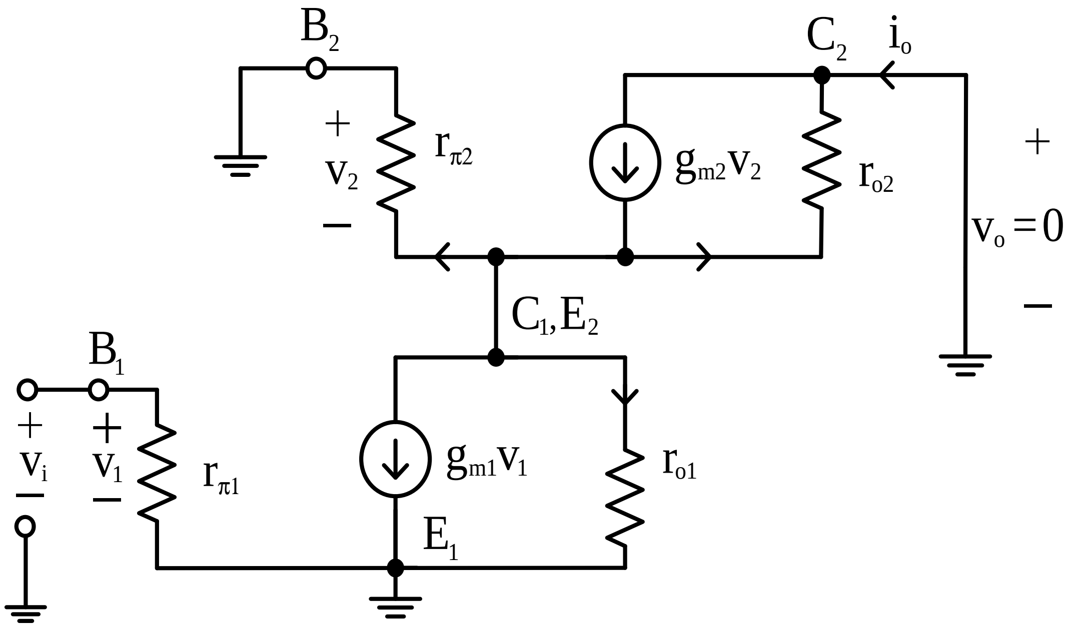


At node C_1 :

$$g_{m2}v_2 = g_{m1}v_1 - \frac{v_2}{r_{o1}} - \frac{v_2}{r_{o2}} - \frac{v_2}{r_{\pi 2}}$$

$$v_2\left(g_{m2} + \frac{1}{r_{o2}} + \frac{1}{r_{\pi 2}} + \frac{1}{r_{o1}}\right) = g_{m1}v_1$$

$$v_2 = \frac{g_{m1}v_1}{g_{m2} + \frac{1}{r_{o2}} + \frac{1}{r_{\pi 2}} + \frac{1}{r_{o1}}}$$



At node C_2 :

$$i_o + i_{r_{o2}} = g_{m2} v_2$$

$$i_o - \frac{v_2}{r_{o2}} = g_{m2} v_2$$

$$i_o = g_{m2} v_2 + \frac{v_2}{r_{o2}}$$

$$= \left(g_{m2} + \frac{1}{r_{o2}} \right) v_2$$

$$v_2 = \frac{g_{m1} v_1}{g_{m2} + \frac{1}{r_{o2}} + \frac{1}{r_{\pi 2}} + \frac{1}{r_{o1}}}$$

Since $V_1 = V_i$,

$$i_o = \left(g_{m2} + \frac{1}{r_{o2}} \right) \frac{g_{m1} v_i}{g_{m2} + \frac{1}{r_{o2}} + \frac{1}{r_{\pi 2}} + \frac{1}{r_{o1}}}$$

$$i_o = \left(g_{m2} + \frac{1}{r_{o2}}\right)\frac{g_{m1}v_i}{g_{m2} + \frac{1}{r_{o2}} + \frac{1}{r_{\pi2}} + \frac{1}{r_{o1}}}$$

$$G_M = \frac{i_o}{v_i} = \left(g_{m2} + \frac{1}{r_{o2}}\right)\frac{g_{m1}}{g_{m2} + \frac{1}{r_{o2}} + \frac{1}{r_{\pi2}} + \frac{1}{r_{o1}}}$$

Assuming r_{o1} and r_{o2} are very large,

$$G_M = \frac{i_o}{v_i} = \frac{g_{m2}g_{m1}}{g_{m2} + \frac{1}{r_{\pi2}}} = \frac{g_{m2}g_{m1}}{g_{m2} + \frac{g_{m2}}{\beta_{o2}}} = \frac{g_{m1}}{1 + \frac{1}{\beta_{o2}}} \approx g_{m1}$$