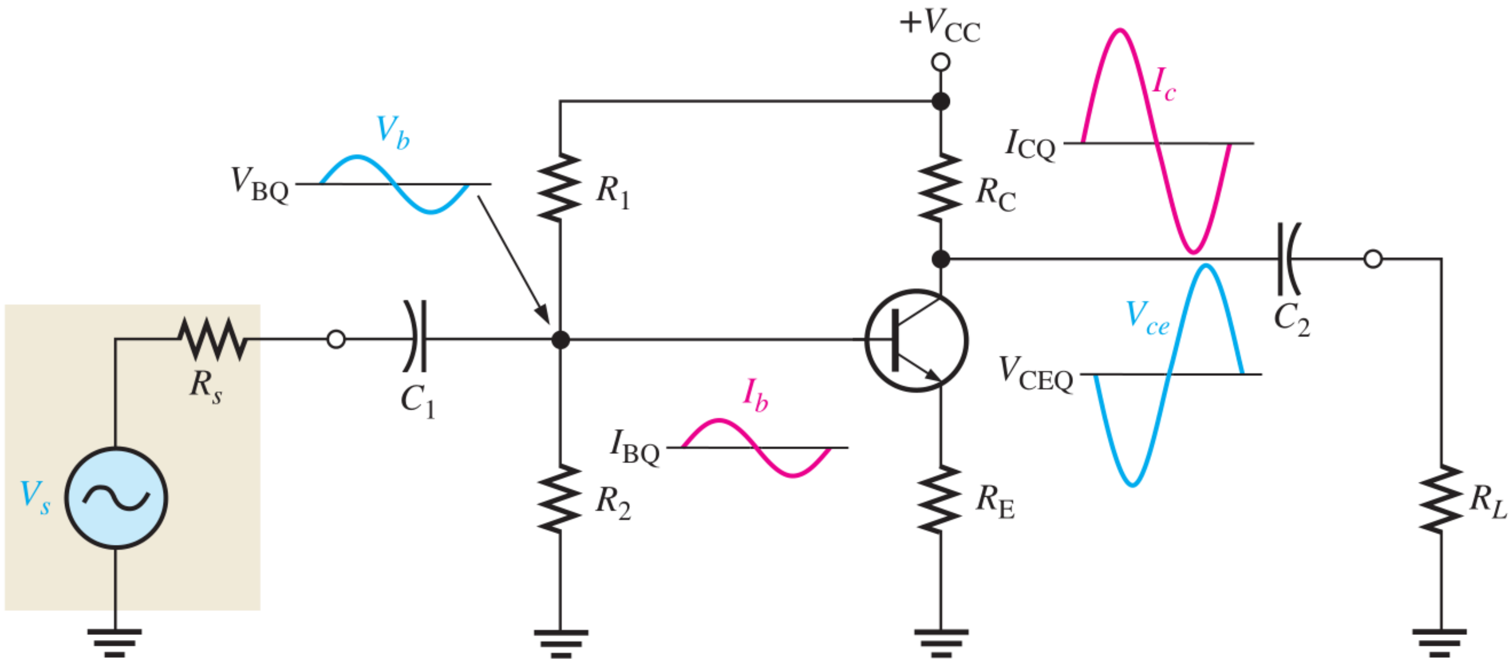
Basic Electronic Circuits
(IEC-103)

Lecture-19

Small Signal Analysis

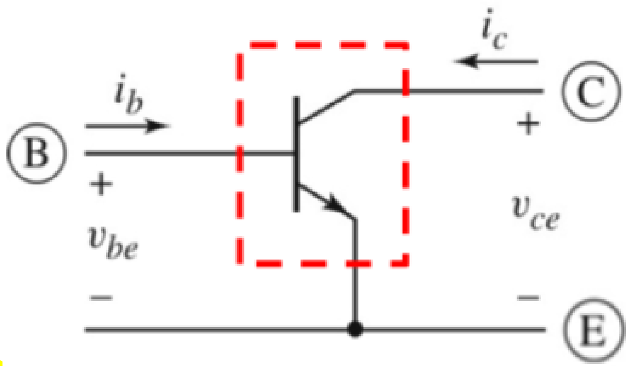
Basic Common Emitter Amplifier



Notation in Transistor Analysis

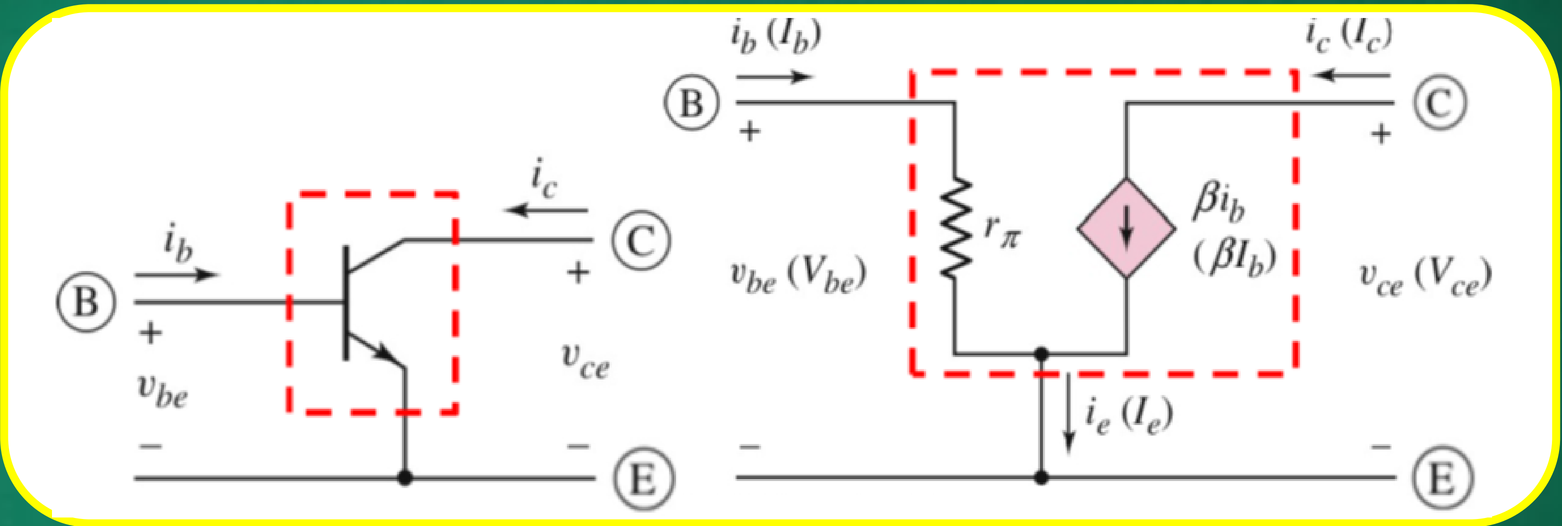
S. No	Variable	Instantaneous AC	DC	Total
1	Emitter Current	i_e	I_E	i_E
2	Collector Current	i_c	I_C	i_C
3	Base Current	i_b	I_B	i_B
4	Collector-emitter Voltage	v_{ce}	V_{CE}	v_{CE}
5	Emitter-base Voltage	v_{eb}	V_{EB}	v_{EB}

Small Signal Hybrid-π Equiv. Circuit



BJT as a 2 port network

Small Signal Hybrid-π Equiv. Circuit



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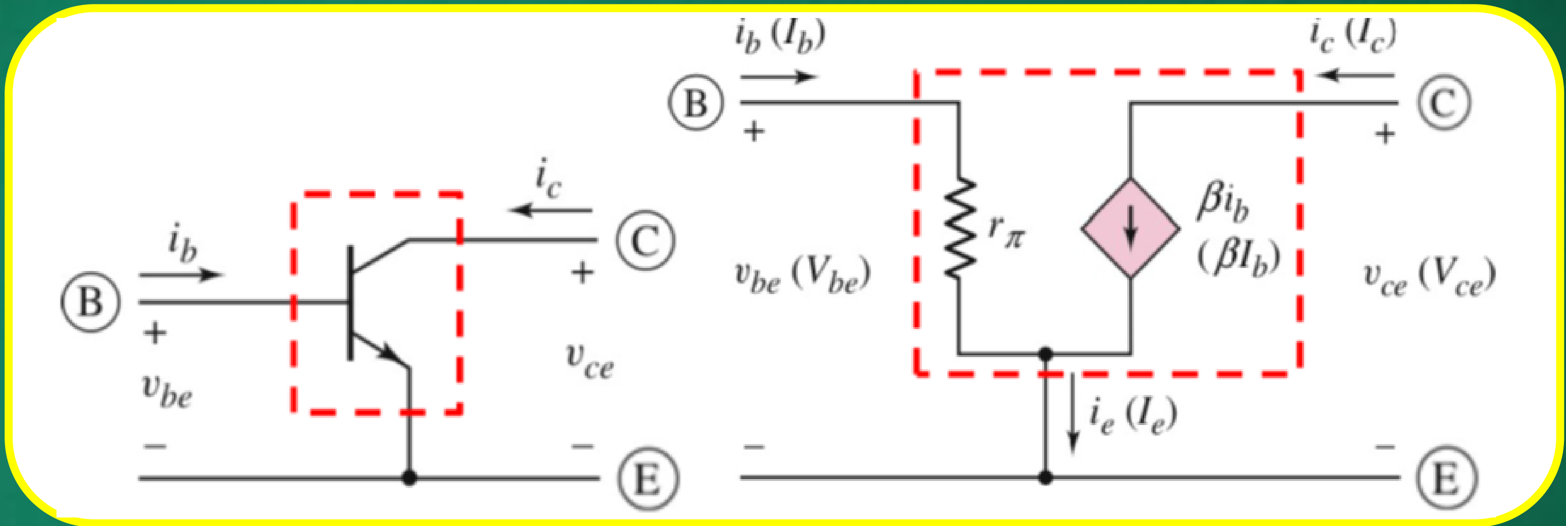

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$$\beta = Common\ emitter\ current\ gain = \ i_c/i_b$$

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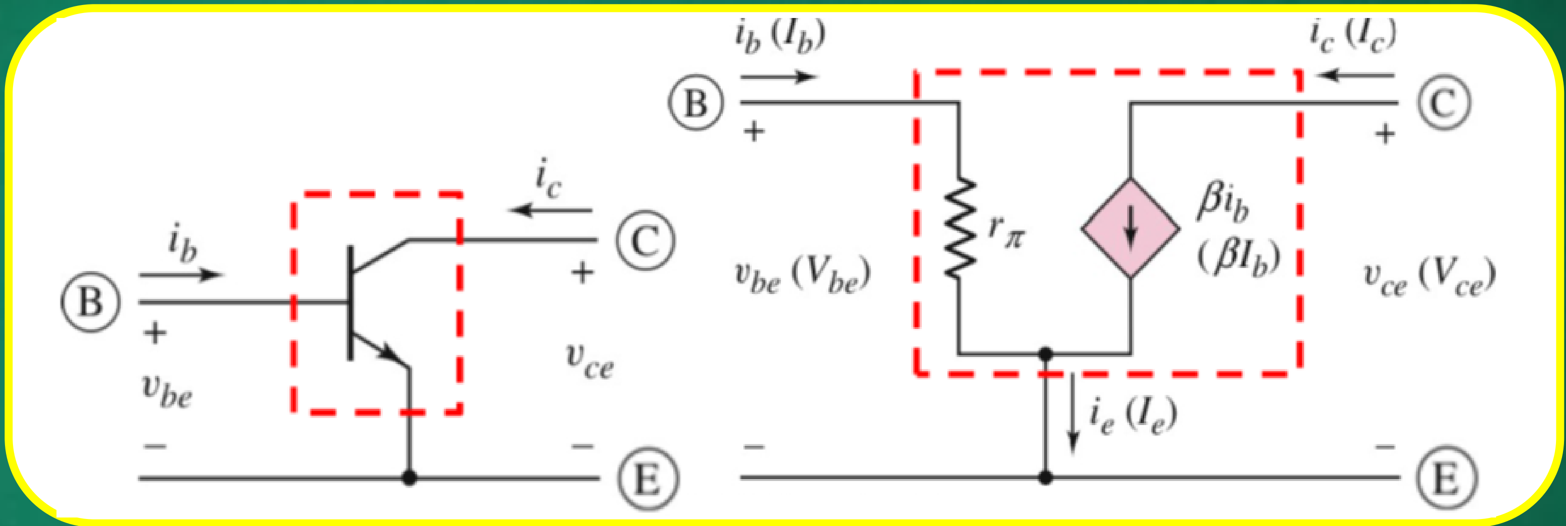


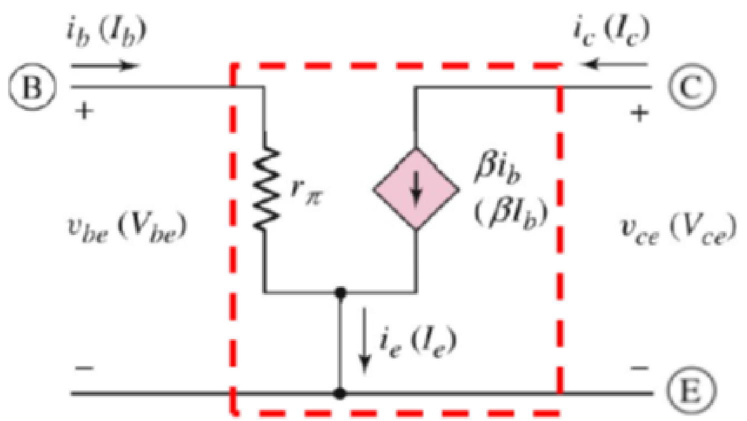
BJT as a 2 port network

Small signal hybrid π equivalent circuit

$\beta = Common\ emitter\ current\ gain = \ i_c / i_b$

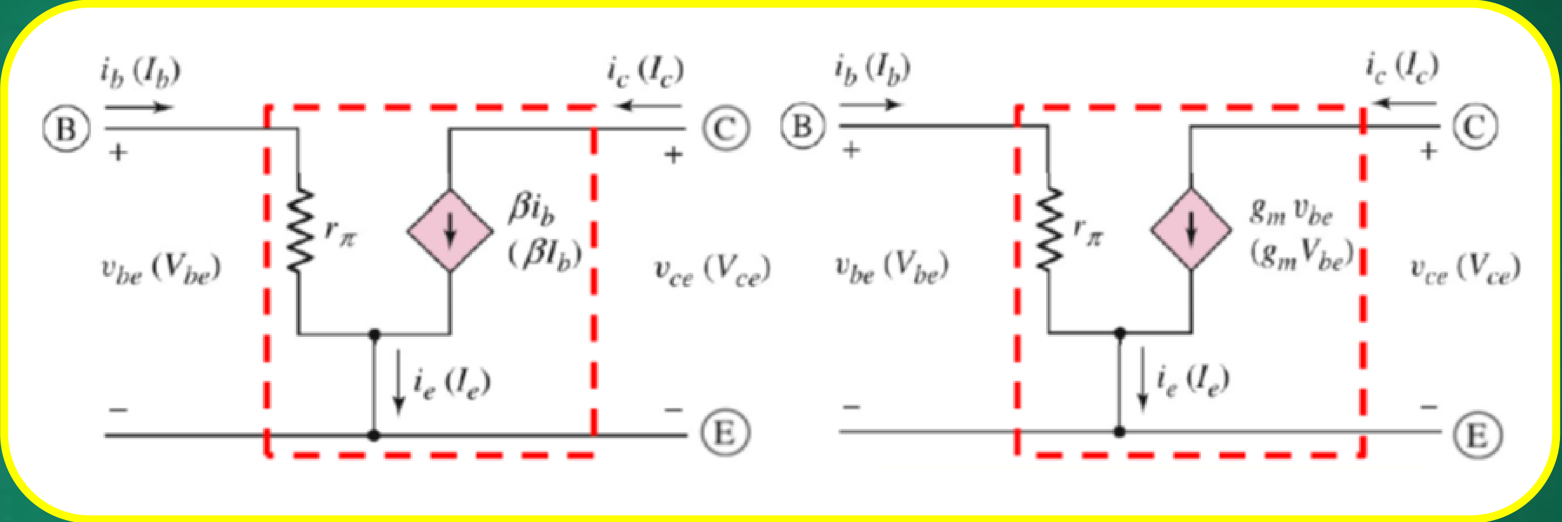
$\boldsymbol{r}_\pi = v_{be}/i_b = V_T/I_{BQ}$
$= \beta V_T/I_{CQ} = small\ signal\ resistance, where\ V_T\ is\ the\ thermal\ voltage$

Small Signal Hybrid-π Equiv. Circuit



With current gain parameter

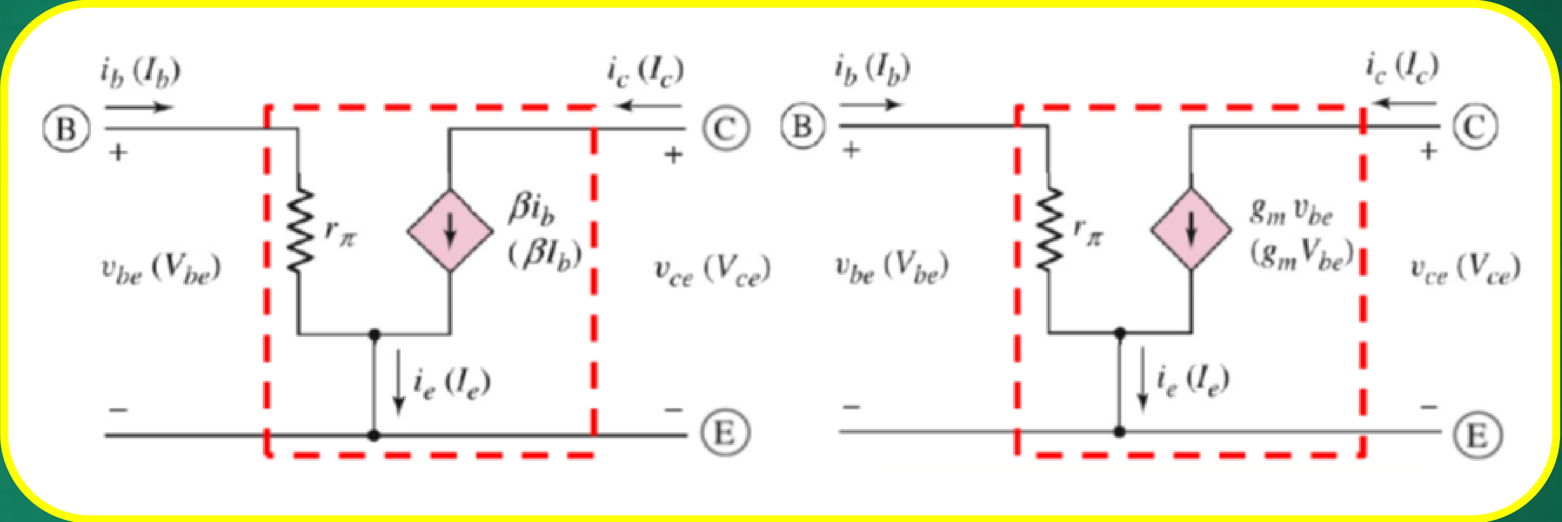
Small Signal Hybrid-π Equiv. Circuit



With current gain parameter

With transconductance parameter

Small Signal Hybrid-π Equiv. Circuit



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$$g_m = \beta / r_\pi = I_{CQ}/V_T \ = transconductance$$

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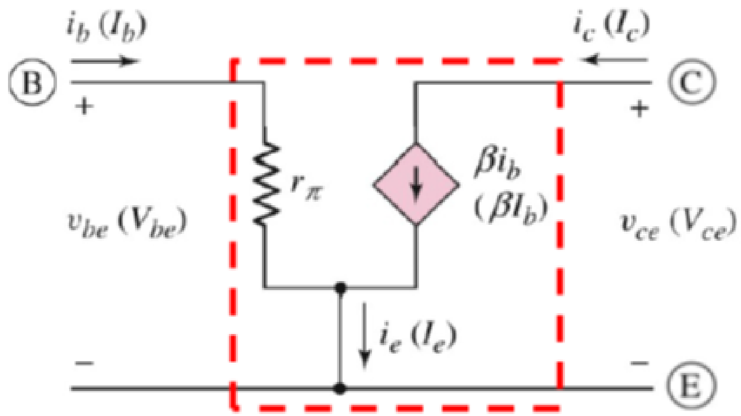
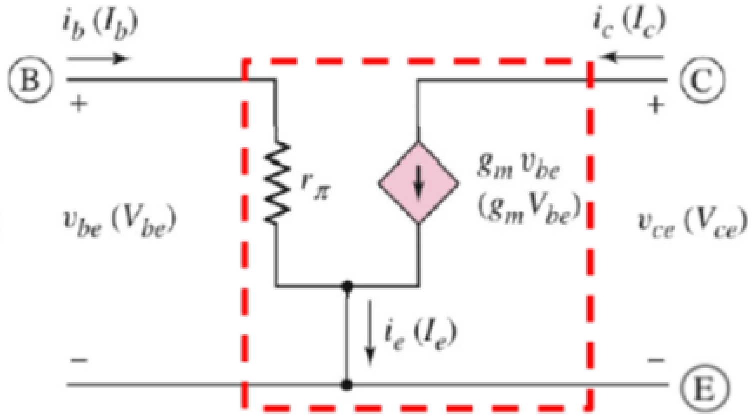


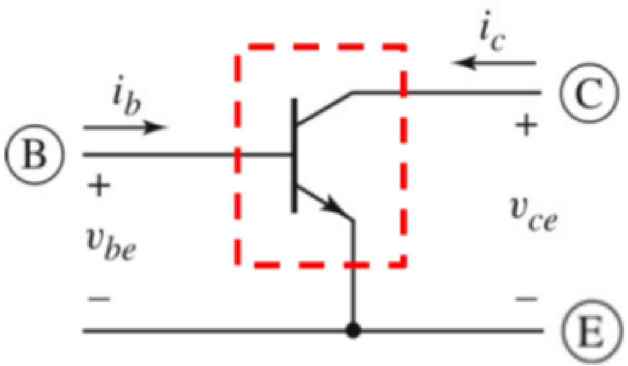


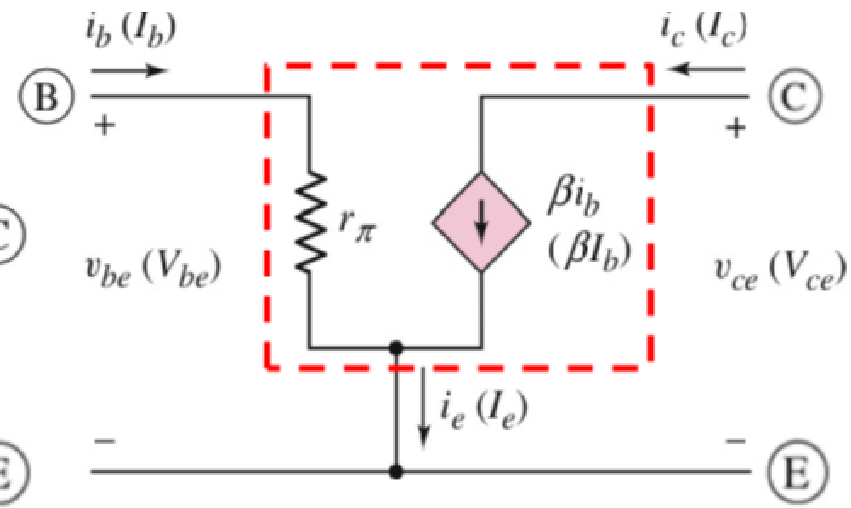
With current gain parameter | **With transconductance parameter**

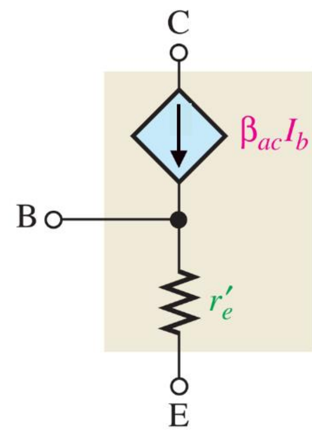
$$g_m = \beta / r_\pi = I_{CQ}/V_T \; = transconductance$$

i_c is assumed to be independent of v_{ce} which is not the case in practice and the assumption will be released later to include the "Early effect"

Another Representation







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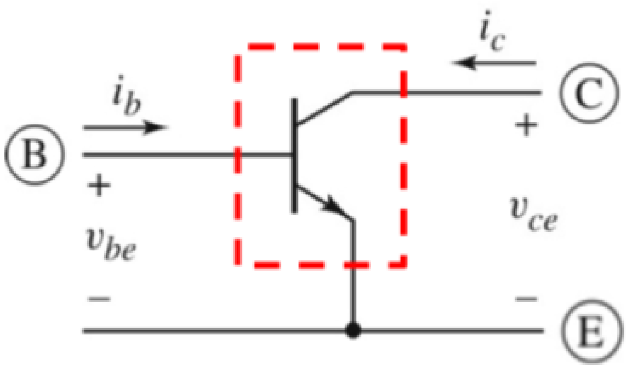
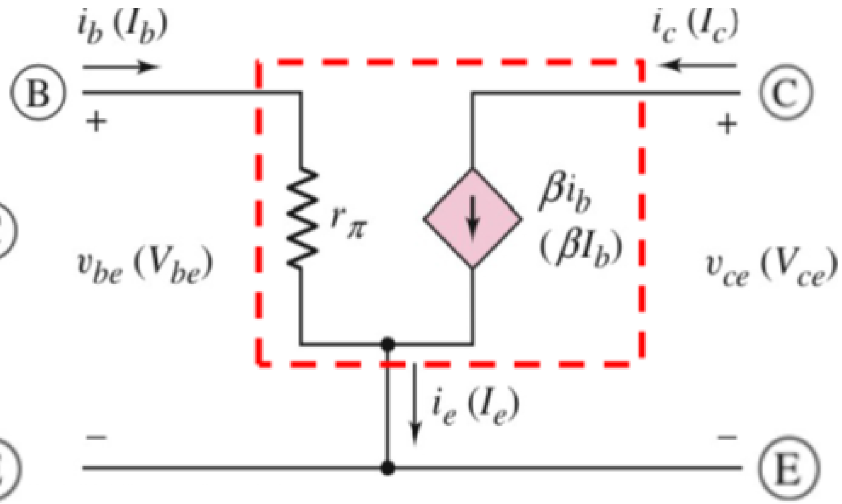
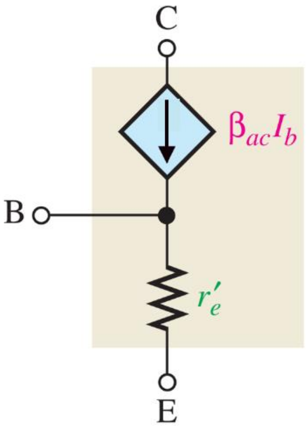




$$r_e = \frac{25\text{mV}}{I_E}$$



DC and AC Load Lines

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- Load line is drawn on the characteristic curve (current vs voltage) in a nonlinear device like diode or transistor.

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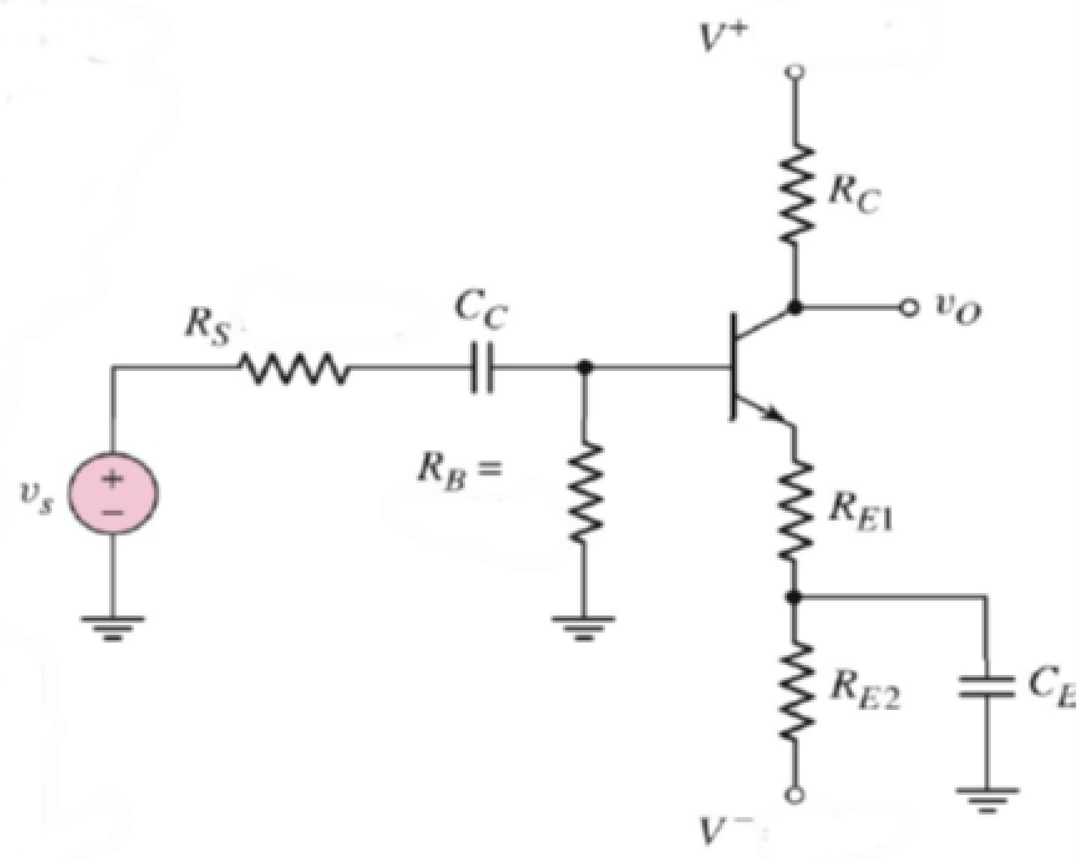
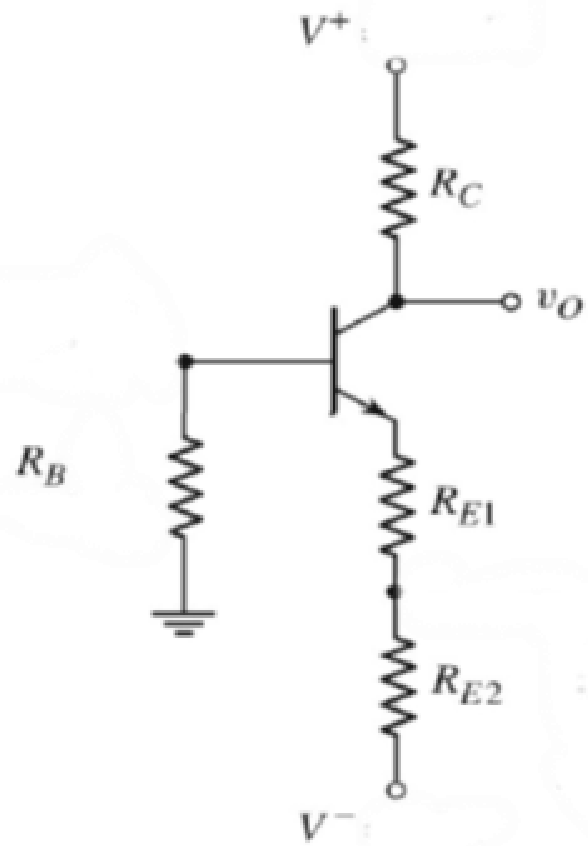
- ❑ AC load line is a straight line with a slope equal to the AC impedance passing through the Q pint.

DC And AC Load Line



DC Equivalent Circuit



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$$V_{CE}(off) = V^{+} - V^{-}$$

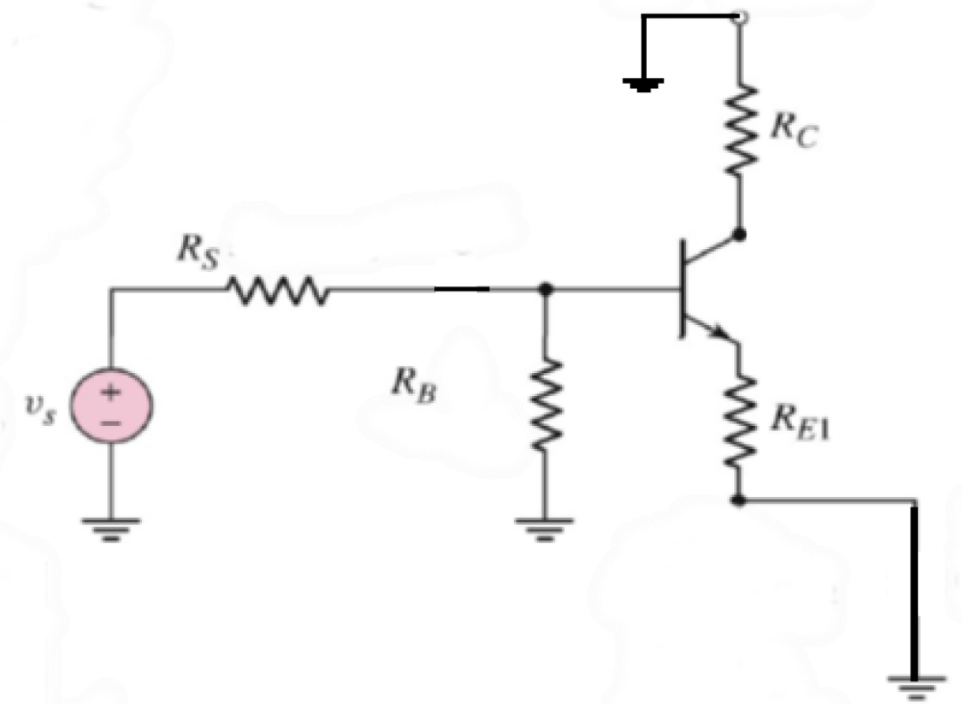
$$I_C(sat) = \frac{V^{+} - V^{-}}{R_C + R_{E1} + R_{E2}}$$

DC and AC Load Lines

Slope of the DC load line

$$-\frac{1}{R_C + R_{E1} + R_{E2}}$$

AC Equivalent Circuit



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Slope of the DC load line

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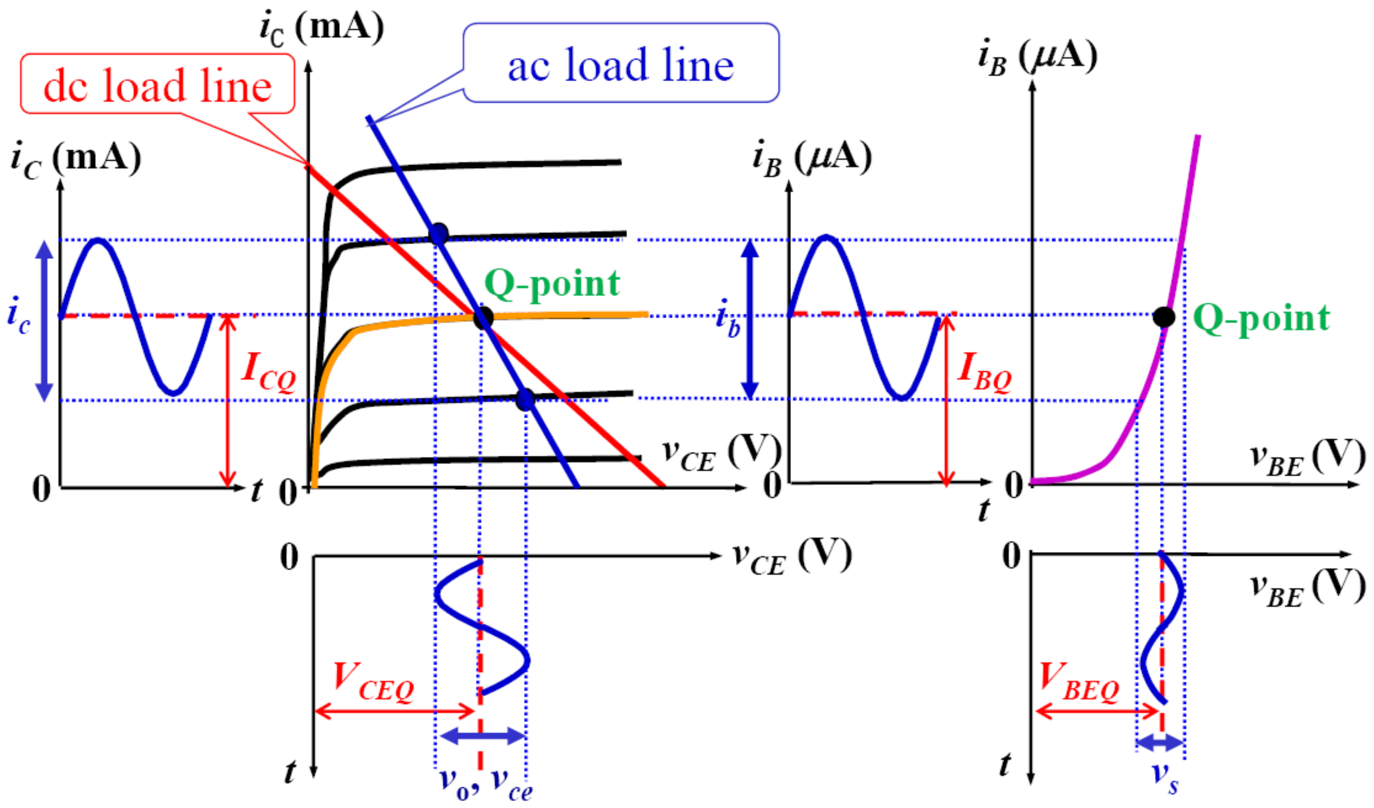
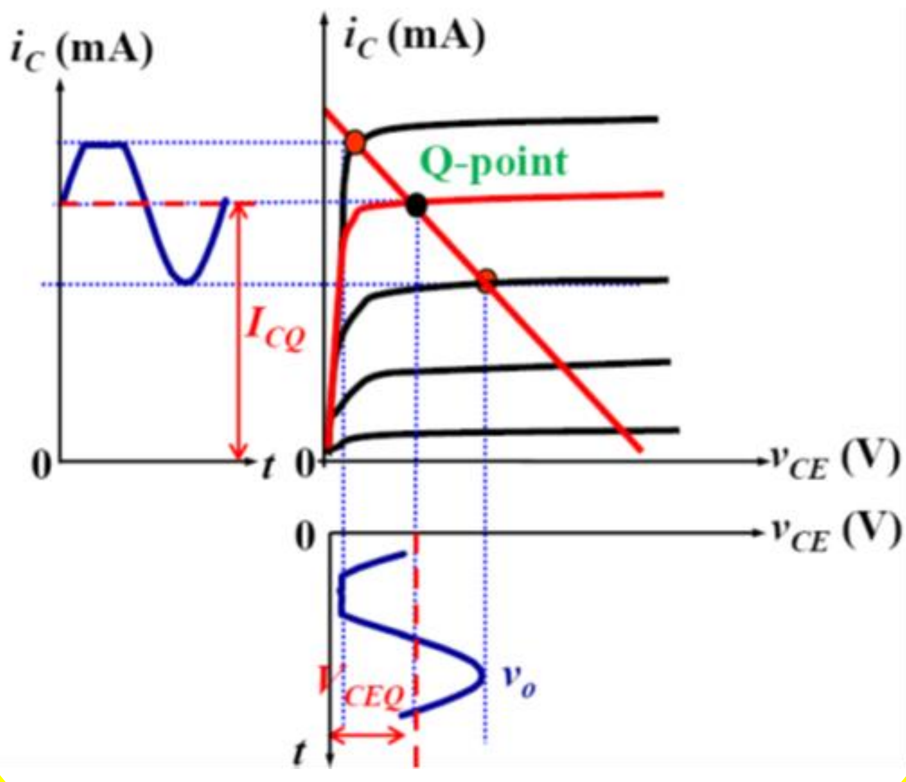
Max. Output Symmetrical Swing



Saturation



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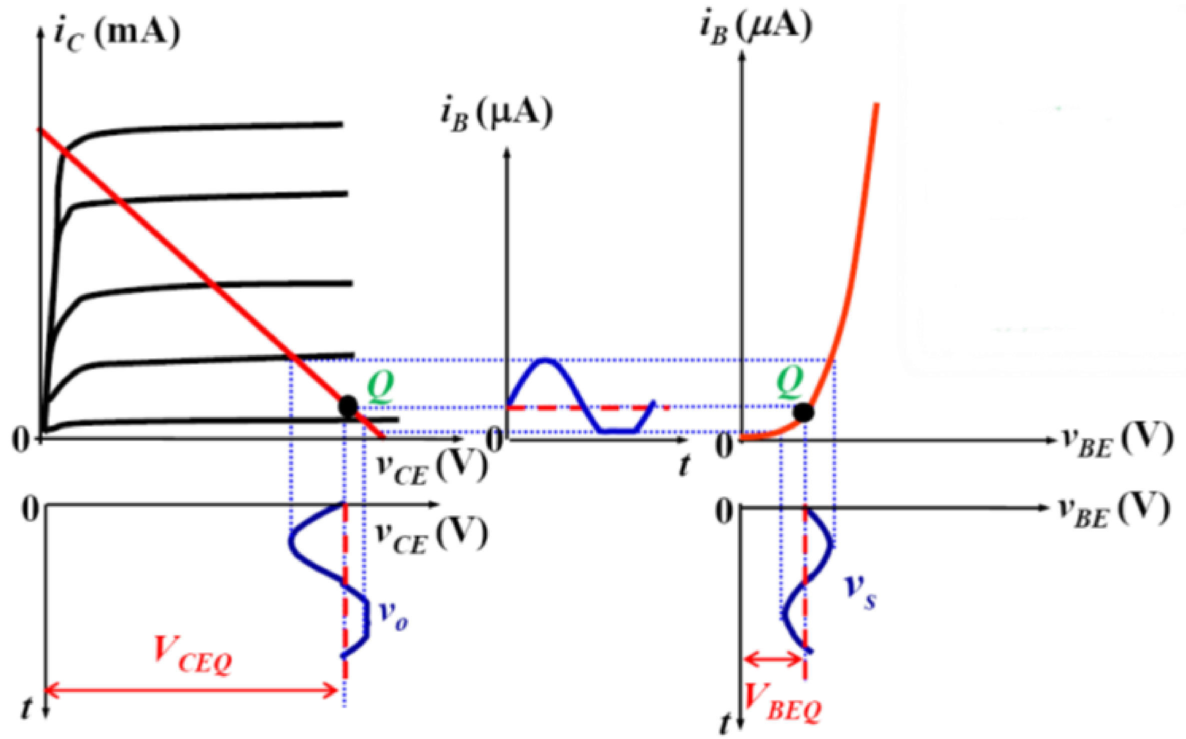
- If the Q-point is set too high, the BJT gets into saturation and a reduction of I_{BQ} is required.

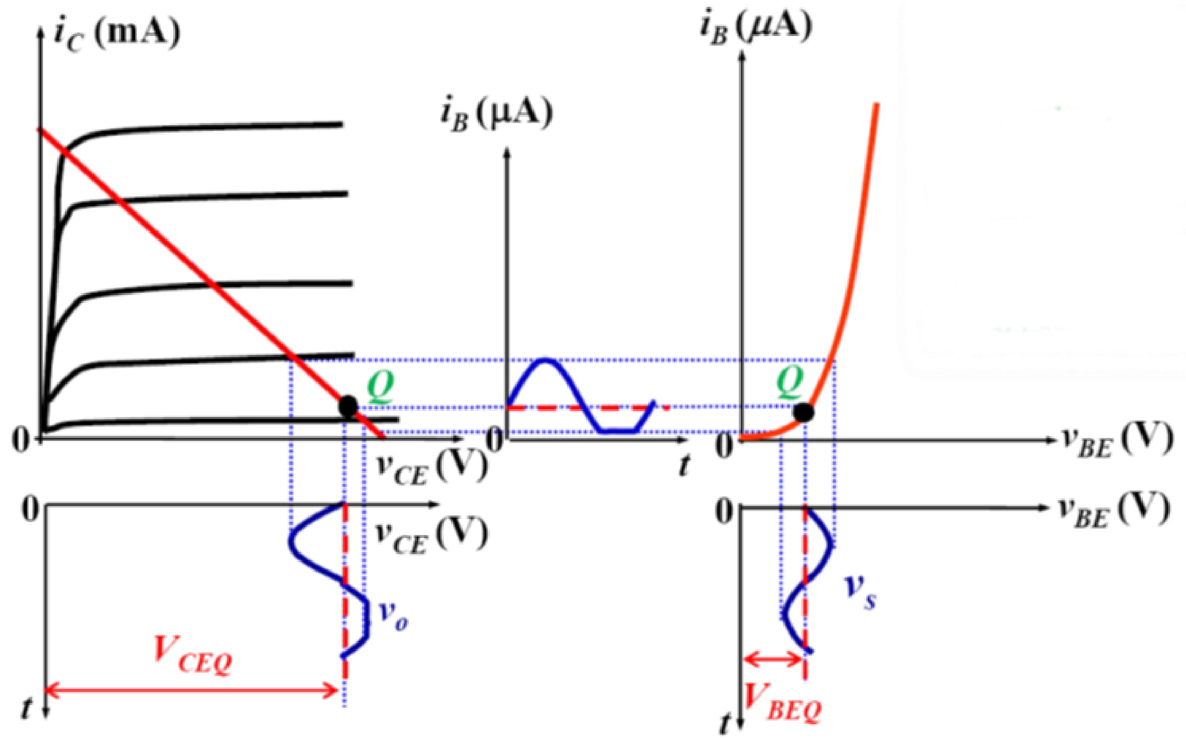
- Even with a proper Q-point setting, if the signal amplitude is too large, distortion will also result, and a reduction of signal amplitude is required.

Cutoff



i_C (mA)
0
v_{CE} (V)
Q
0
v_{CE} (V)
v_o
V_{CEQ}
t
i_B (μA)
0
t
i_B (μA)
Q
0
v_{BE} (V)
0
v_{BE} (V)
v_s
V_{BEQ}
t

Cutoff



❑ If the Q-point is too low, the BJT gets into cutoff, and an increase in I_{BQ} is required.

Multistage Amplifiers

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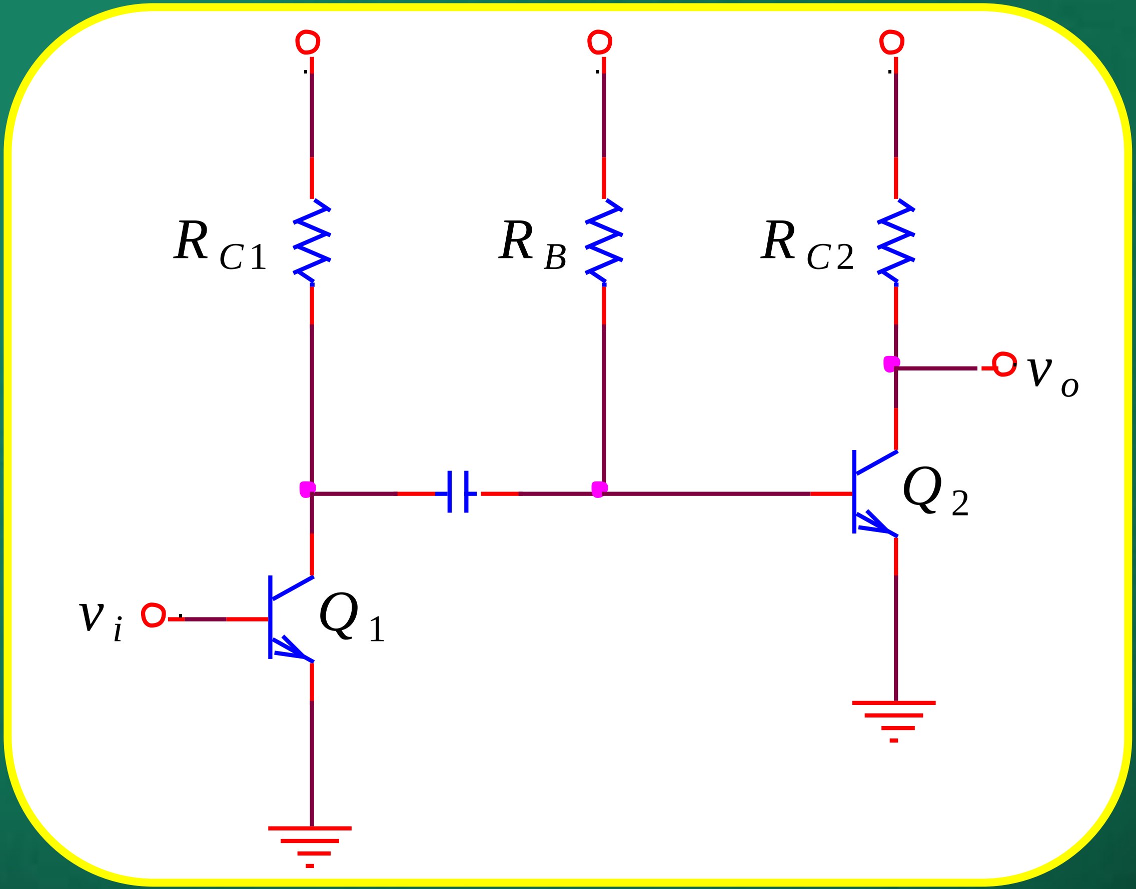
- Solution – transistor amplifier circuits can be connected in series or cascaded amplifiers

- This is done either to increase the overall small-signal voltage gain or provide an overall voltage gain greater than 1 with a very low output resistance

Multistage Amp Configuration

Cascade/RC coupling



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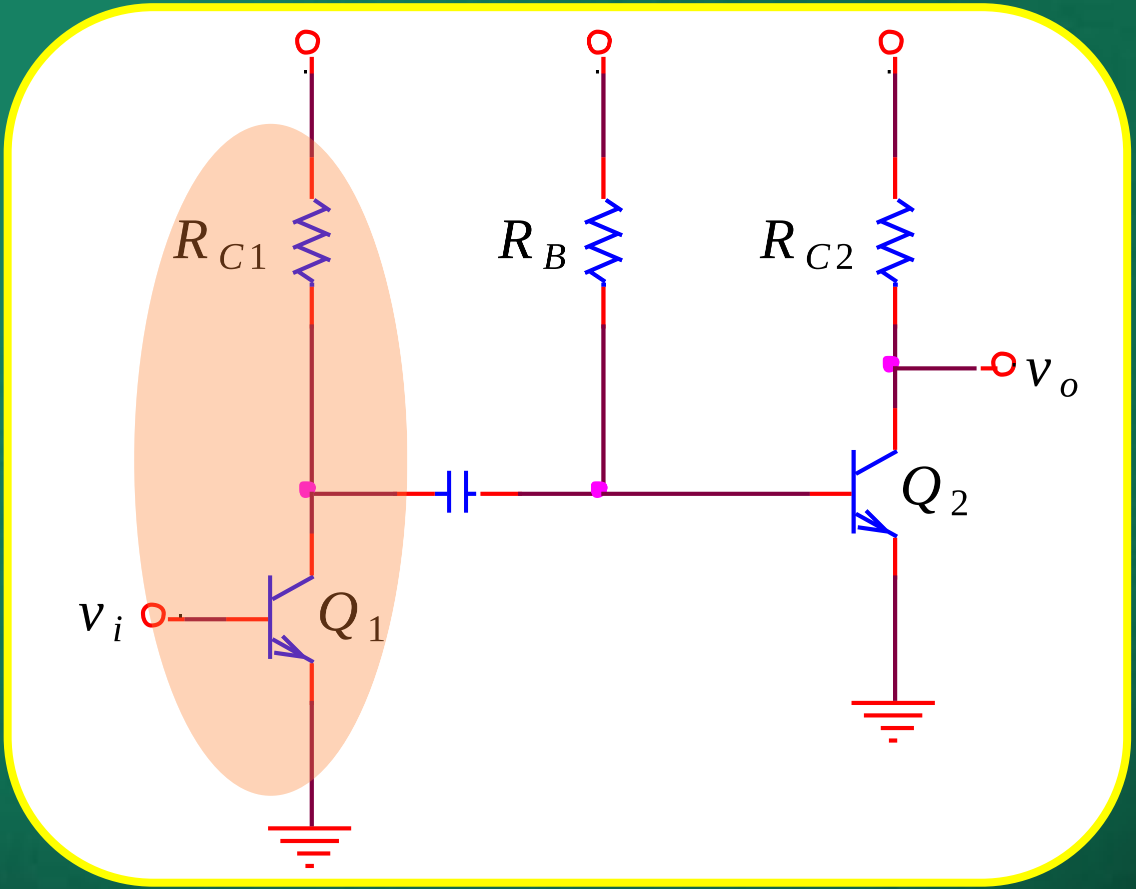

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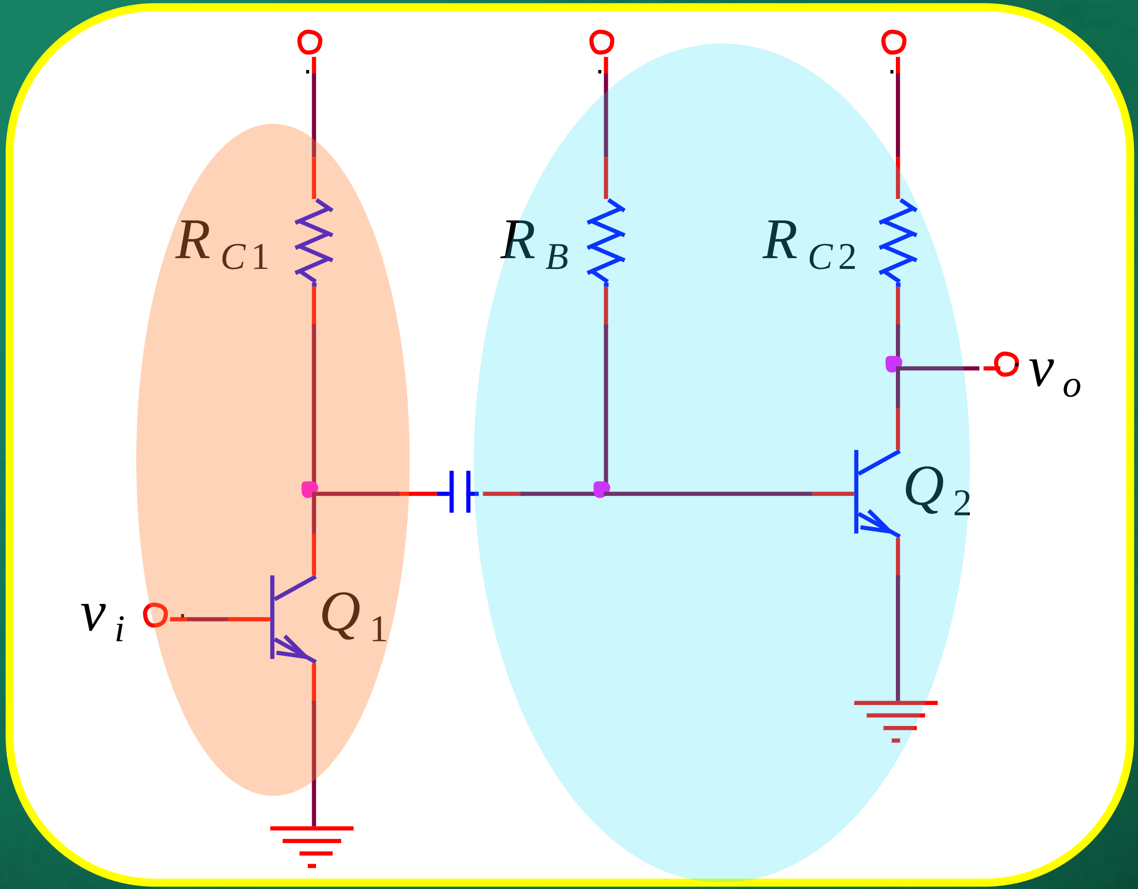
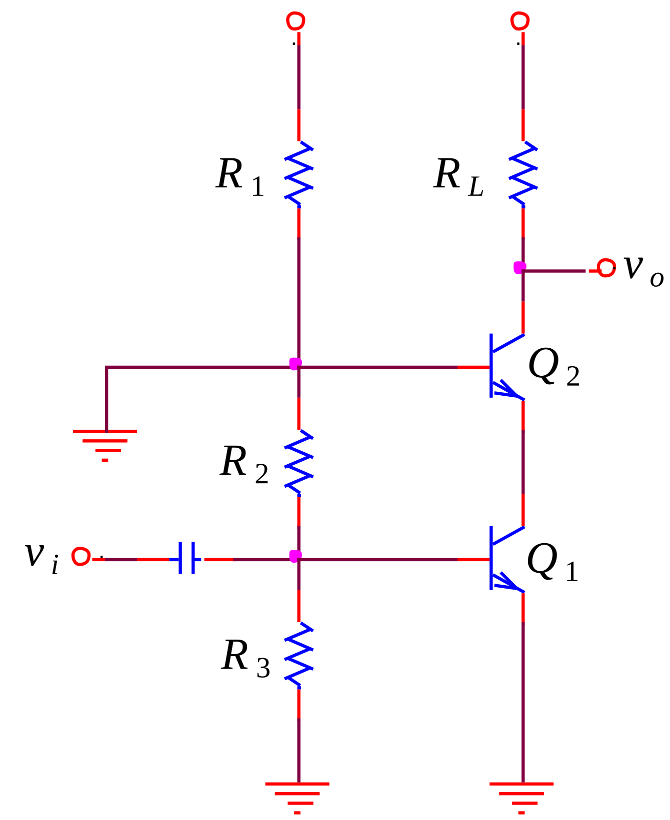


Multistage Amp Configuration

Cascode



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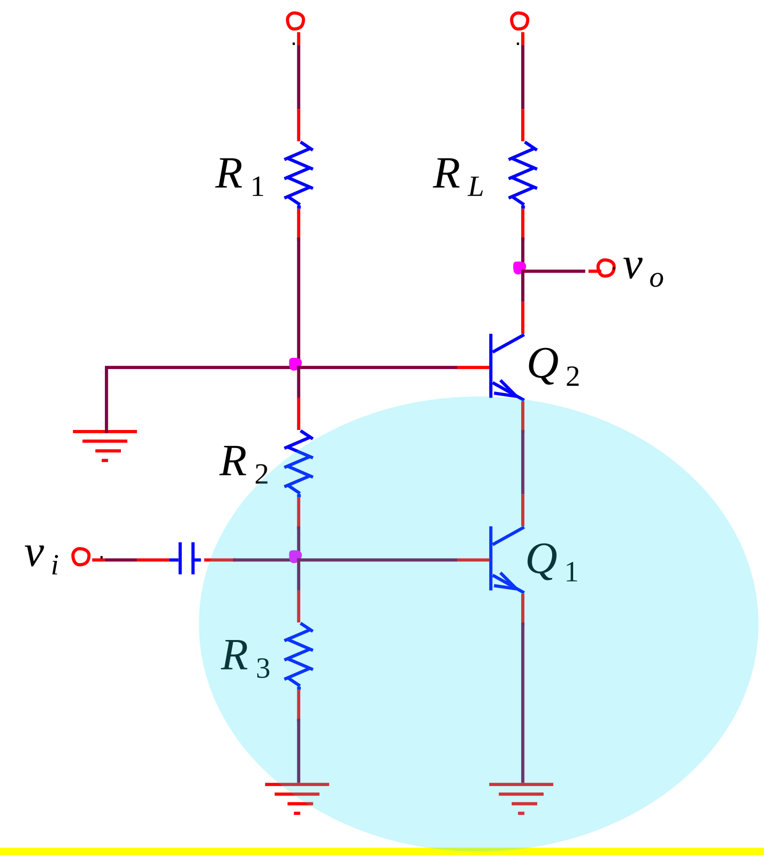

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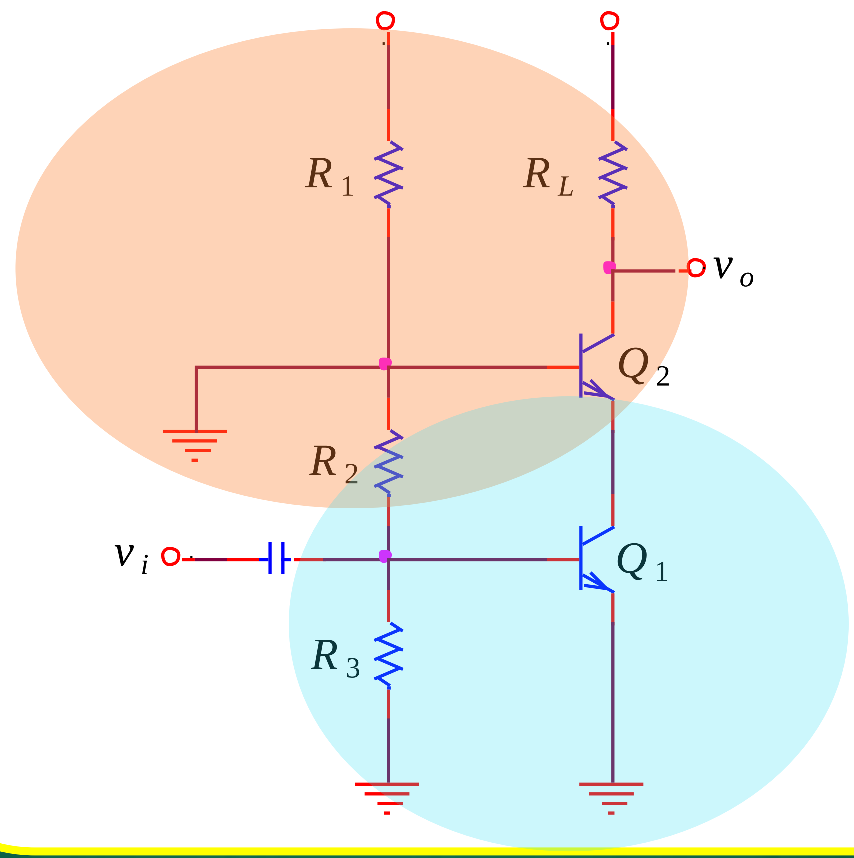
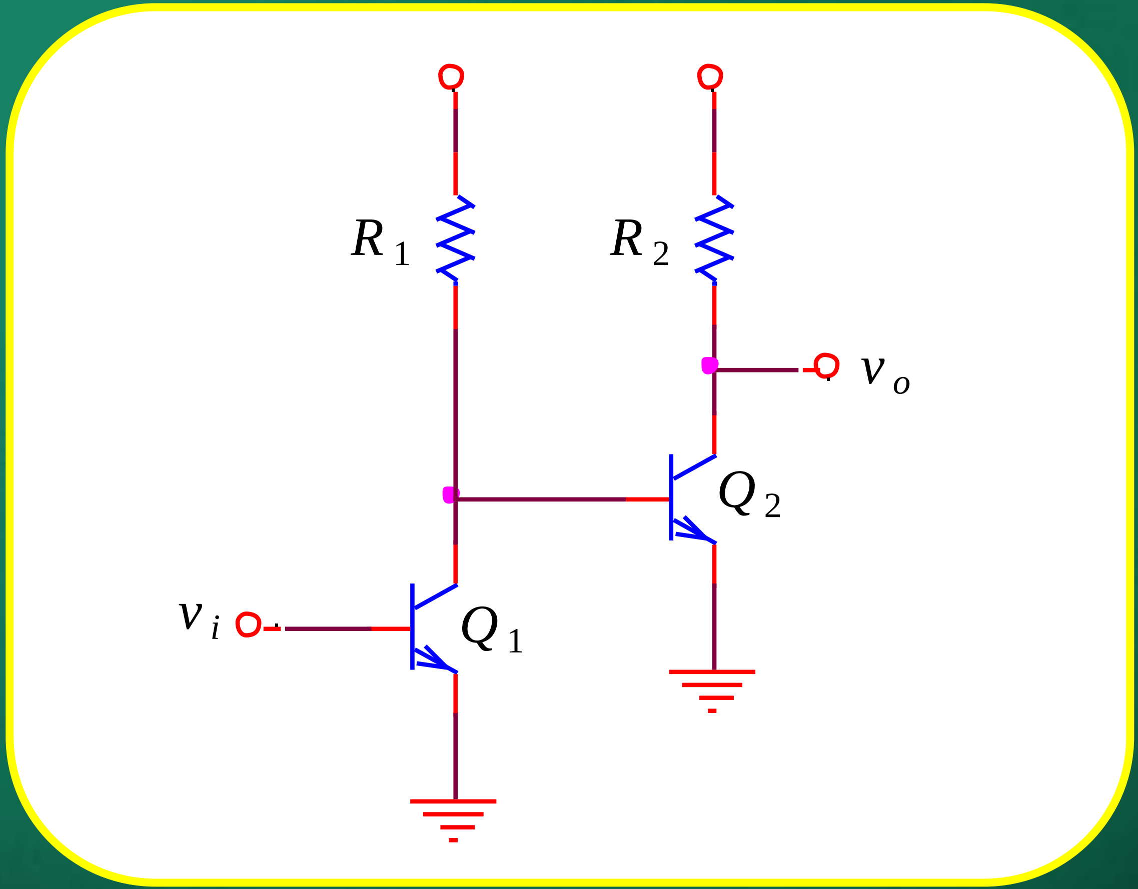


Multistage Amp Configuration

Darlington/Direct coupling



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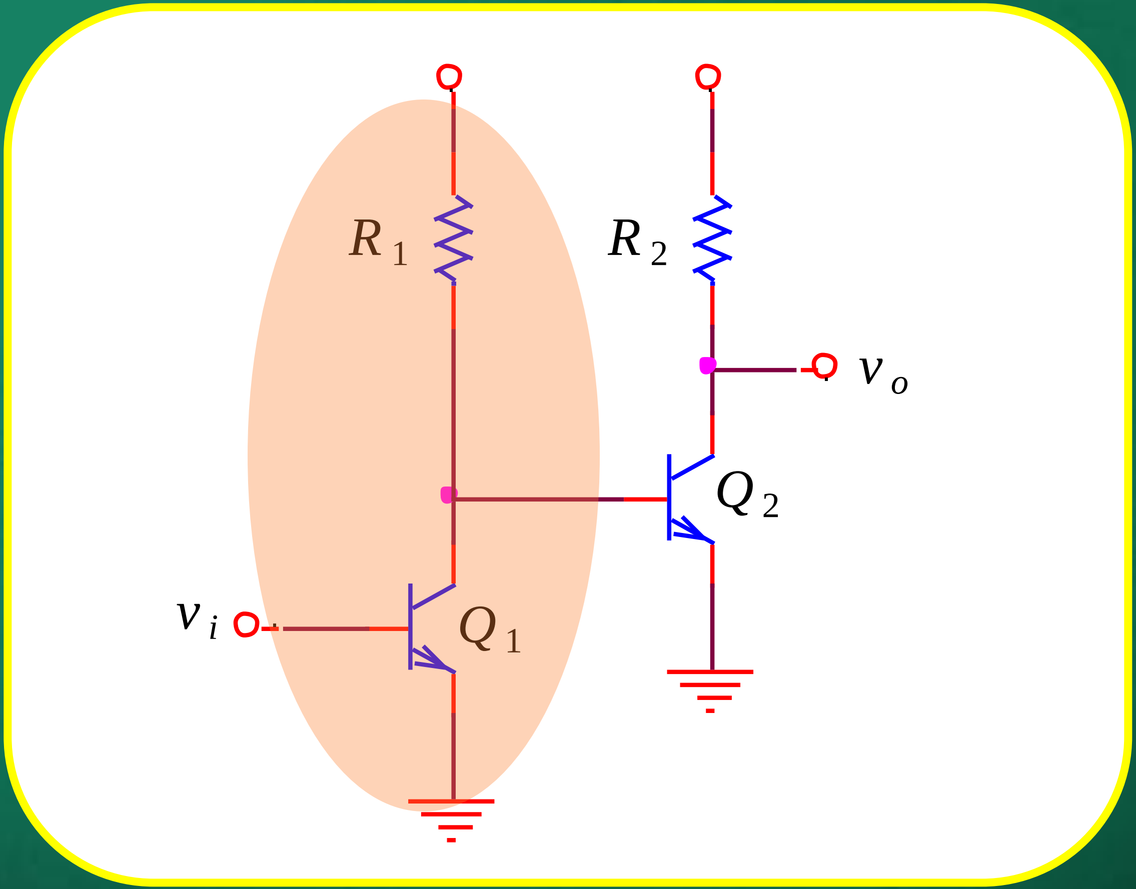

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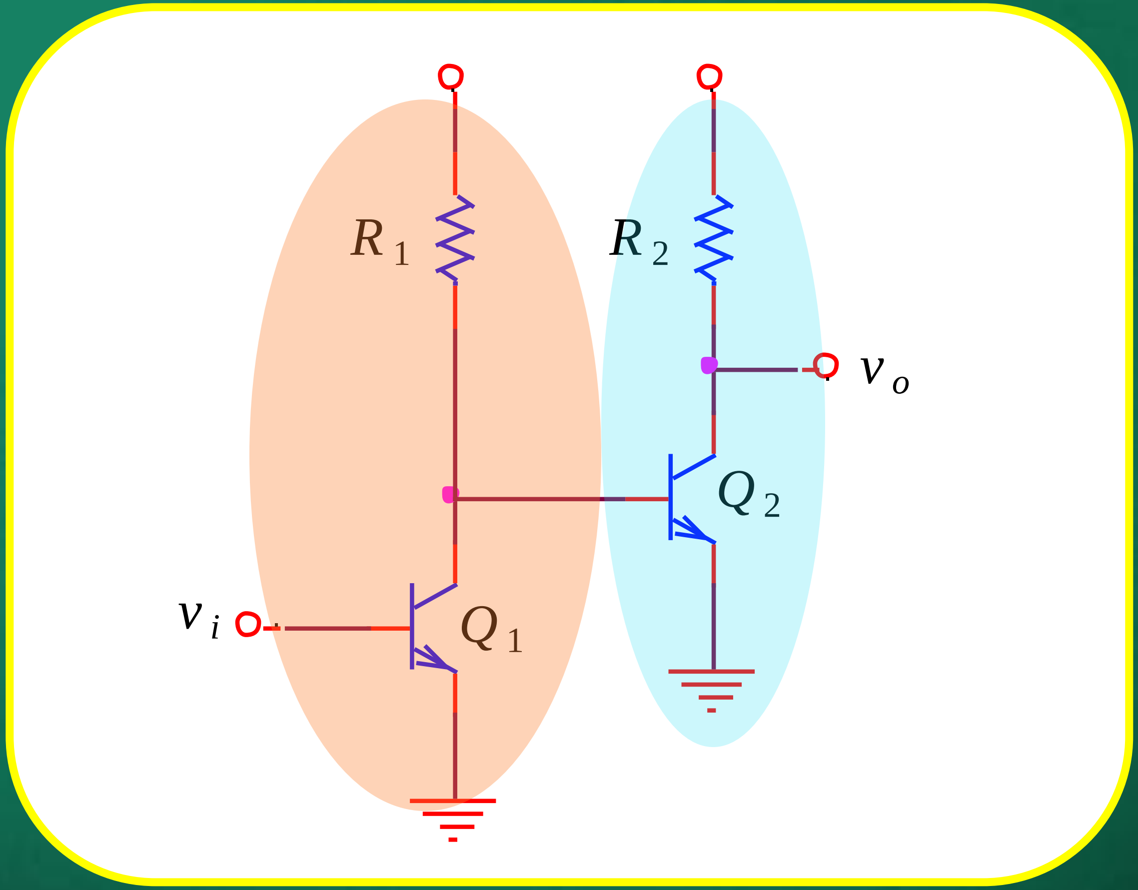
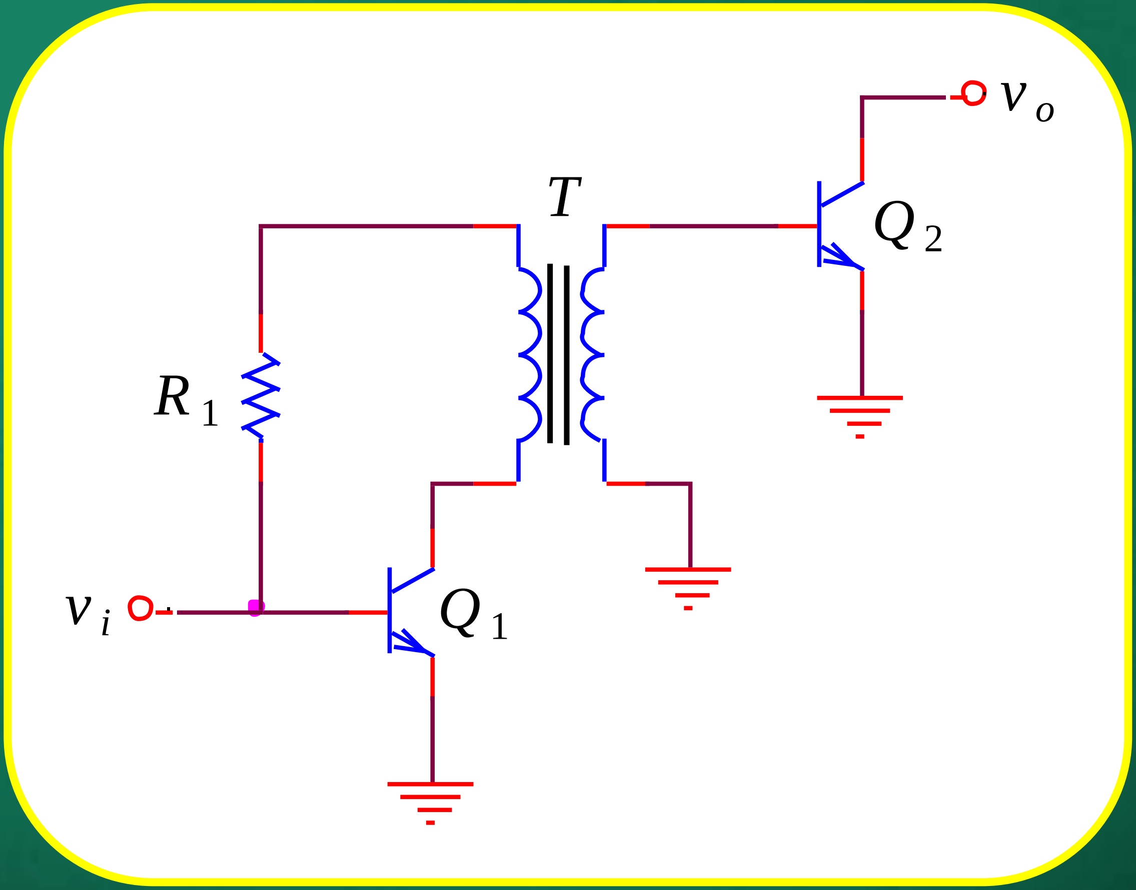


Multistage Amp Configuration

Transformer coupling



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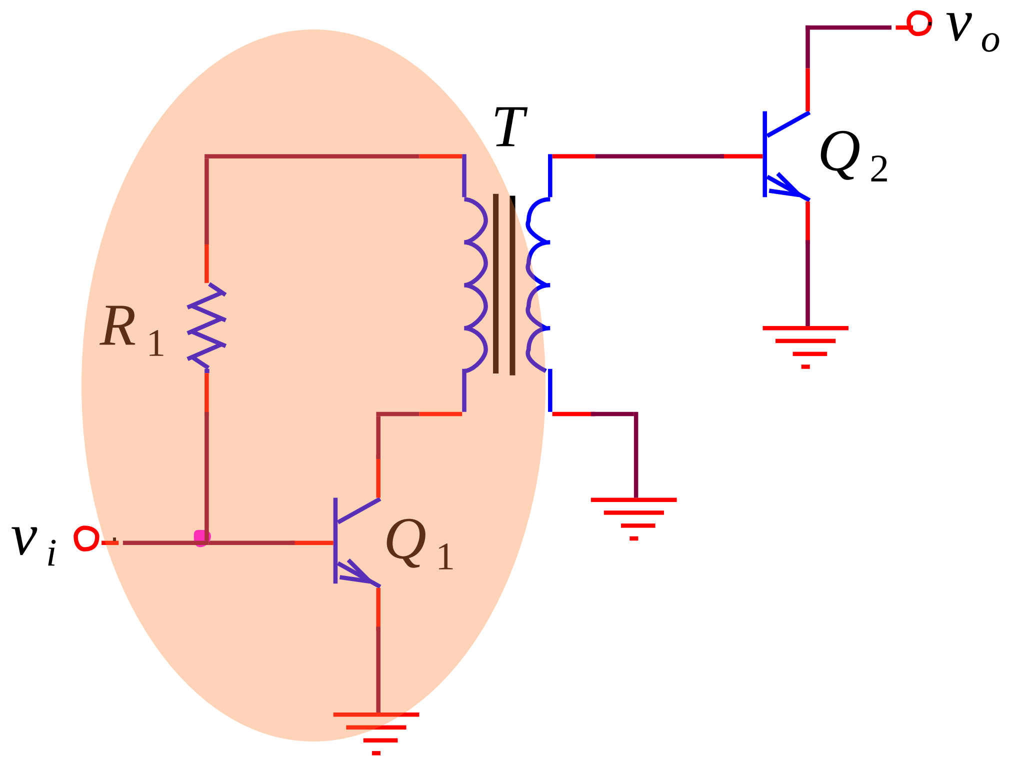

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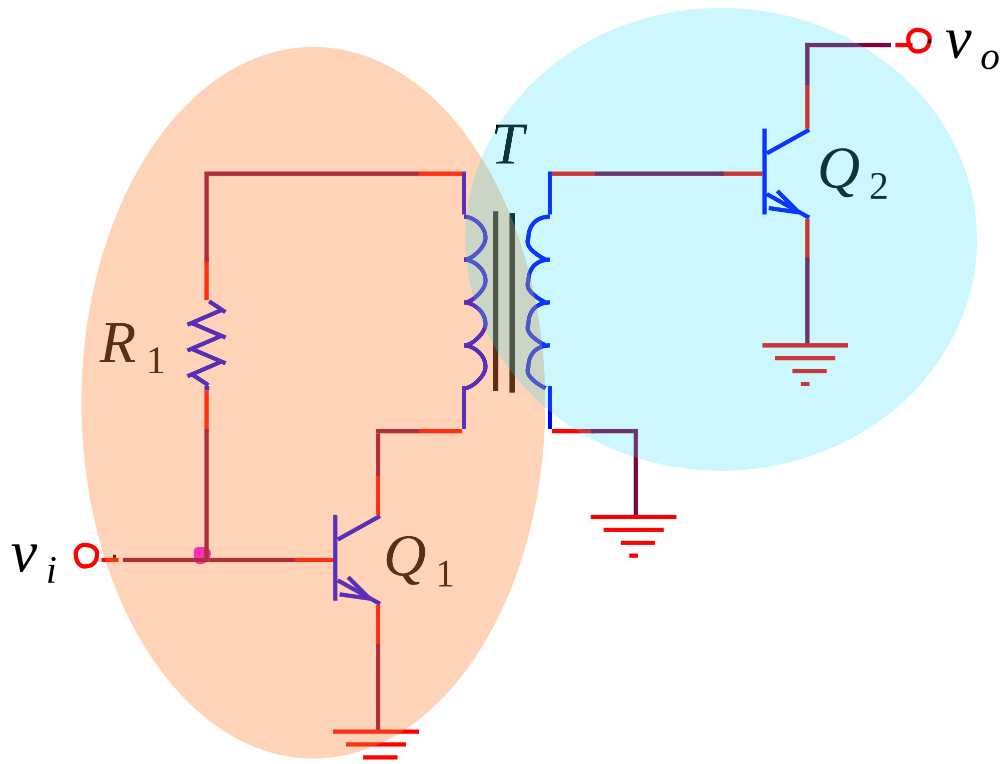

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- Coupling a signal from one stage to the another stage and block dc voltage from one stage to the another stage.

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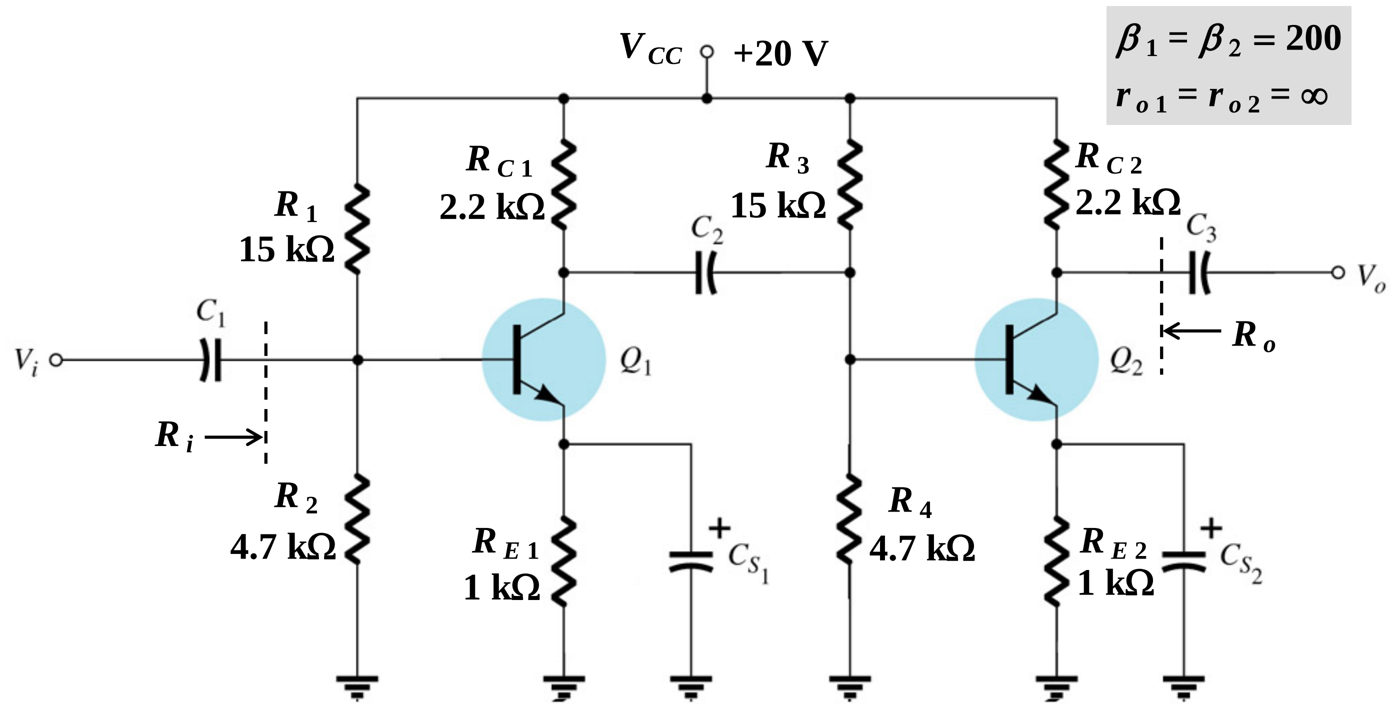
- Coupling a signal from one stage to the another stage and block dc voltage from one stage to the another stage.
- The signal developed across the collector resistor of each stage is coupled into the base of the next stage.
- The overall gain = product of the individual gain.

Example

Draw the AC equivalent circuit and calculate A_v, R_i, and R_o.



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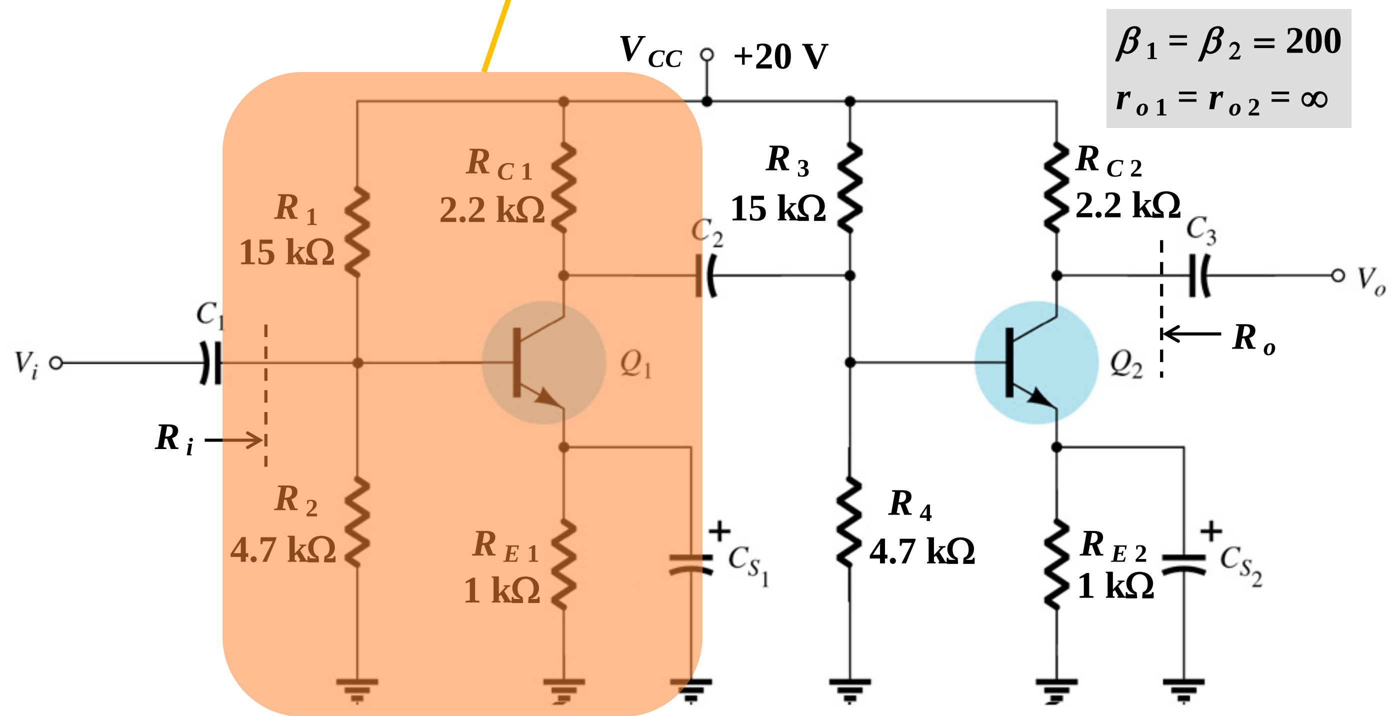
1st Stage



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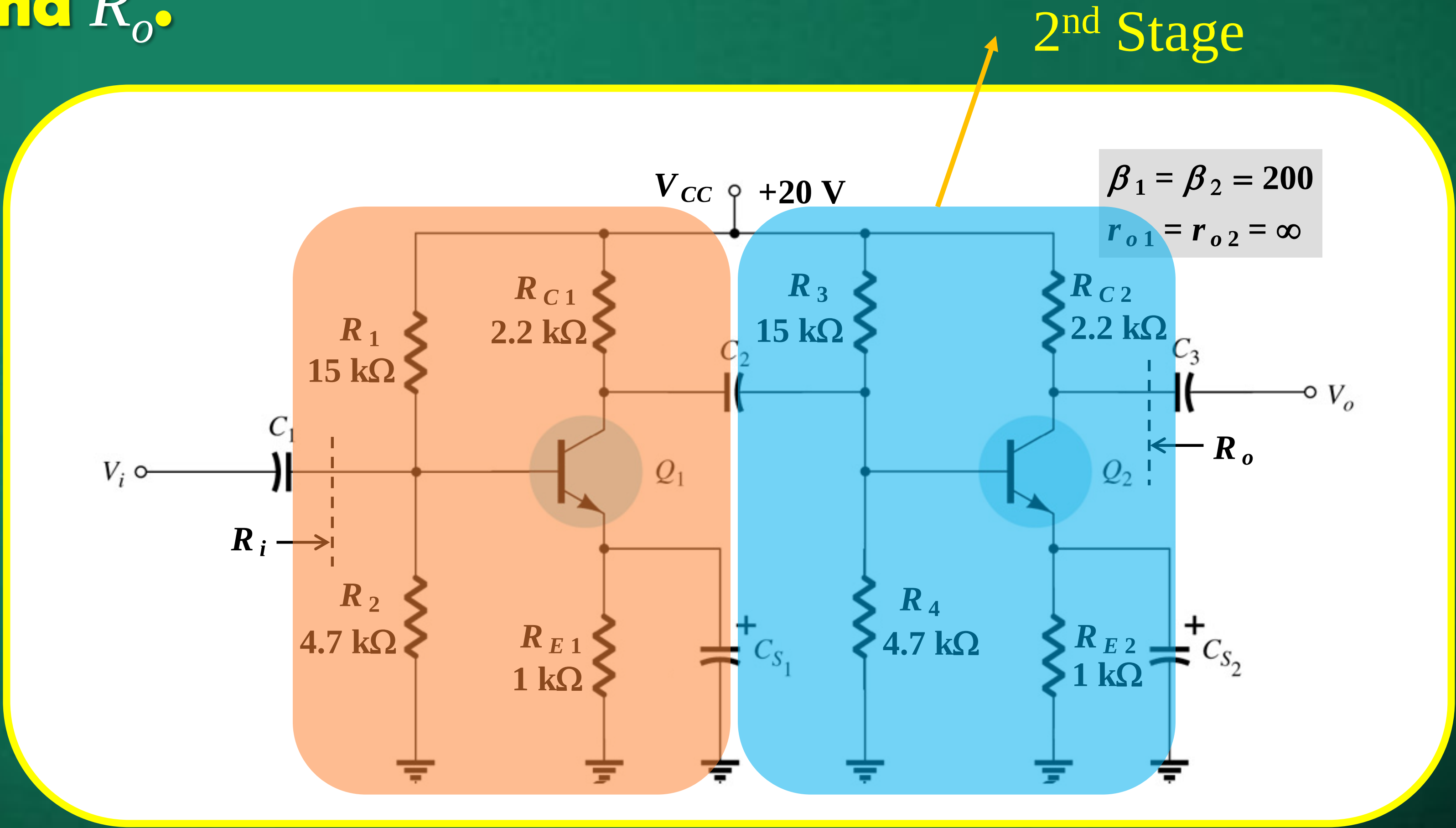
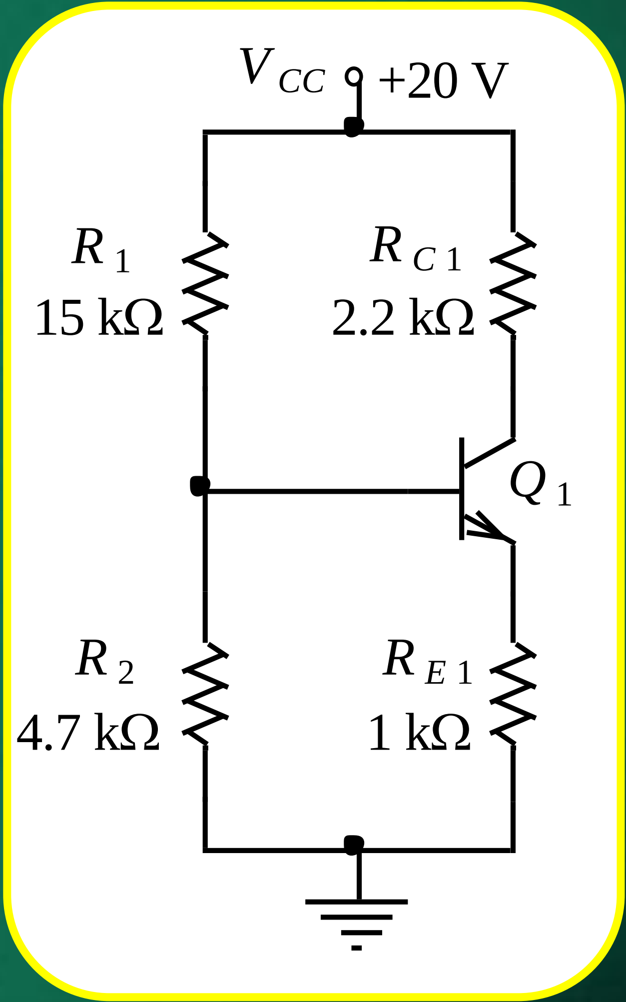


Example (continued)

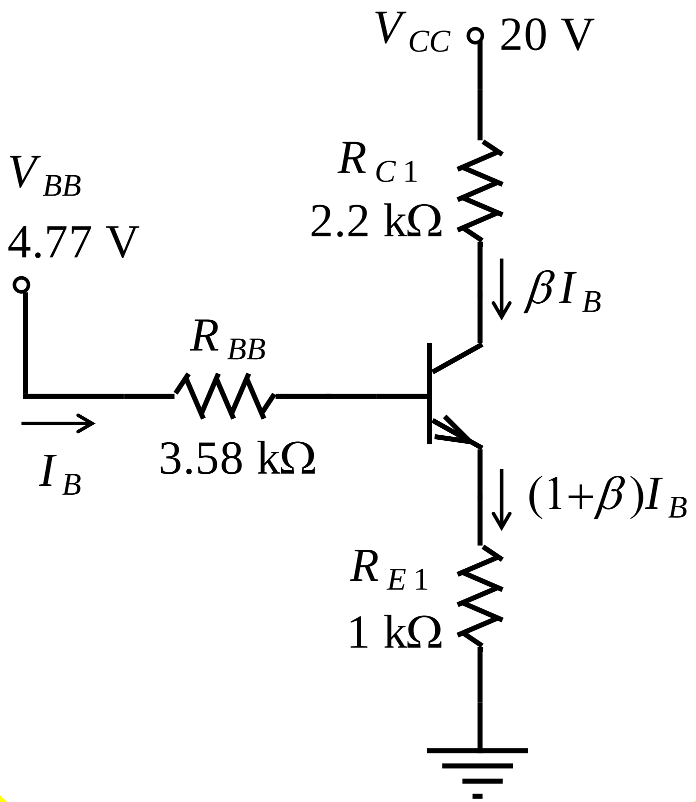
DC analysis

The circuit under DC condition (stage 1 and 2 are identical)



Example (continued)

Applying Thévenin's theorem, the circuit becomes



$$I_{BQ1} = I_{BQ2} = 19.89\ \mu\text{A}$$

$$I_{CQ1} = I_{CQ2} = 3.979\ \text{mA}$$

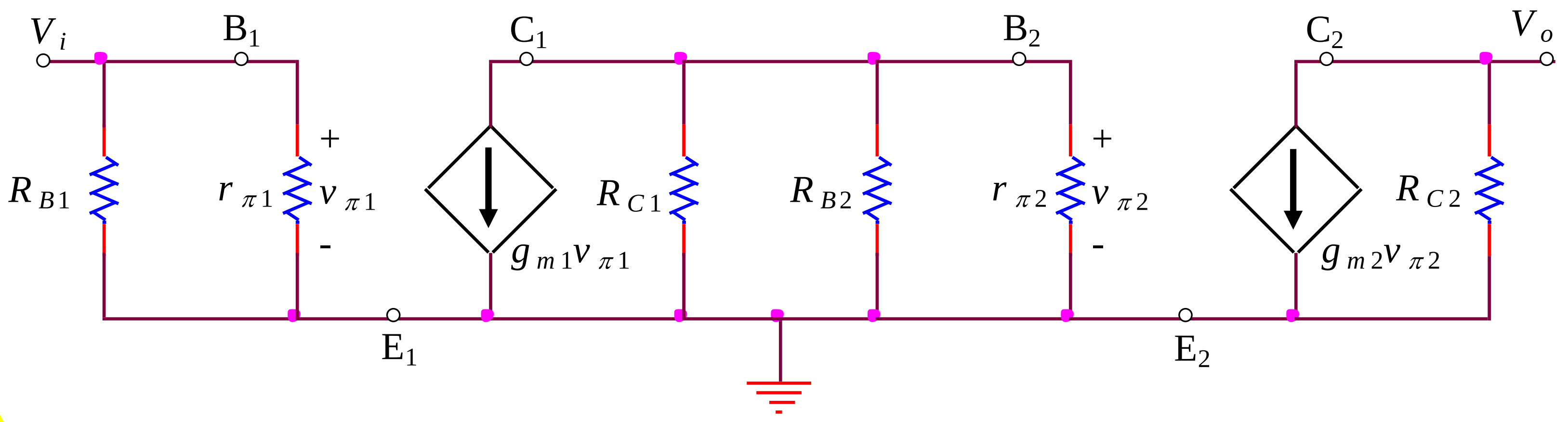
$$r_{\pi 1} = r_{\pi 2} = 1.307\ \text{k}\Omega$$

$$g_{m1} = g_{m2} = 0.153\ \text{A/V}$$

Example (continued)

AC analysis

The small-signal equivalent circuit



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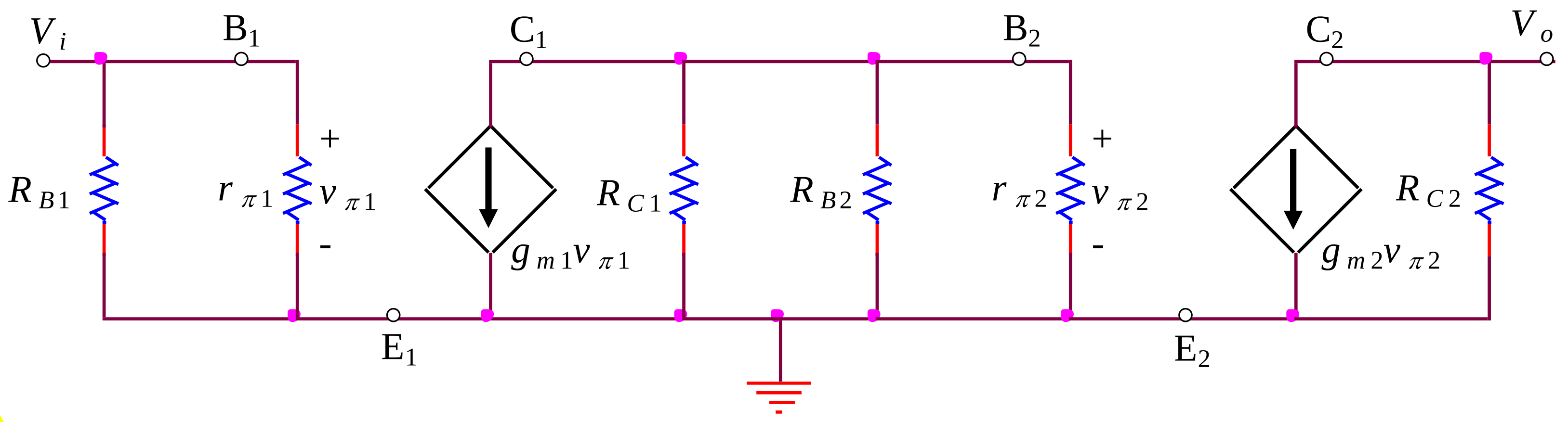

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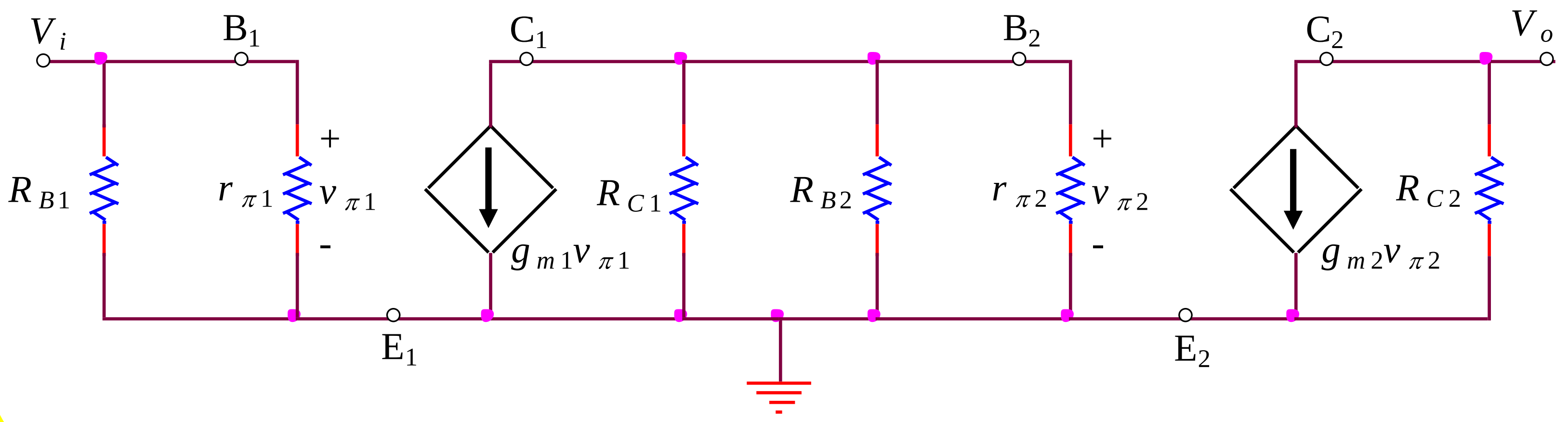

$$R_{B1} = R_1 // R_2$$

$$R_{B2} = R_3 // R_4$$

Example (continued)

$$\boxed{V_o = -g_{m2} v_{\pi 2} R_{C2}}$$

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$$A_2 = \frac{V_o}{v_{\pi 2}} = -g_{m2} R_{C2}$$

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$$v_{\pi 2} = -g_{m1} v_{\pi 1} \left(R_{C1} \, // \, R_{B2} \, // \, r_{\pi 2} \right)$$

Example (continued)

$$V_o = -g_{m2} v_{\pi 2} R_{C2}$$

$$A_2 = \frac{V_o}{v_{\pi 2}} = -g_{m2} R_{C2}$$

$$v_{\pi 2} = -g_{m1} v_{\pi 1} \left(R_{C1} // R_{B2} // r_{\pi 2} \right)$$

$$= -g_{m1} V_i \left(R_{C1} // R_{B2} // r_{\pi 2} \right)$$

$$\left[v_{\pi 1} = V_i \right]$$

Example (continued)

$$V_o = -g_{m2} v_{\pi 2} R_{C2}$$

$$A_2 = \frac{V_o}{v_{\pi 2}} = -g_{m2} R_{C2}$$

$$v_{\pi 2} = -g_{m1} v_{\pi 1} \left(R_{C1} \,//\, R_{B2} \,//\, r_{\pi 2} \right)$$

$$= -g_{m1} V_i \left(R_{C1} \,//\, R_{B2} \,//\, r_{\pi 2} \right)$$

$$\left[v_{\pi 1} = V_i \right]$$

$$A_1 = \frac{v_{\pi 2}}{V_i} = -g_{m2} \left(R_{C1} \,//\, R_{B2} \,//\, r_{\pi 2} \right)$$

Example (continued)

The small-signal voltage gain

$$A = A_1 A_2 = g_{m1} g_{m2} R_{C2} \left(R_{C1} \,//\, R_{B2} \,//\, r_{\pi 2} \right)$$

Example (continued)

The small-signal voltage gain

$$A = A_1 A_2 = g_{m1} g_{m2} R_{C2} \left(R_{C1} \,//\, R_{B2} \,//\, r_{\pi 2} \right)$$

Substituting values

$$R_{B1} = R_{B2} = R_3 \,//\, R_4 = 15 \,//\, 4.7 = 3.579\ \mathrm{k\Omega}$$

$$R_{C1} \,//\, R_{B2} \,//\, r_{\pi 2} = 2.2 \,//\, 3.579 \,//\, 1.307 = 667\ \Omega$$

$$A = 0.153 \times 0.153 \times 2200 \times 667 = 34350\ \mathrm{V/V}$$

Example (continued)

The input resistance

$$R_{in} = R_{B1} \,//\, r_{\pi 1} = 3.579 \,//\, 1.307 = 0.957\ \text{k}\Omega$$

Example (continued)

The input resistance

$$R_{in} = R_{B1} \,//\, r_{\pi 1} = 3.579 \,//\, 1.307 = 0.957 \text{ k}\Omega$$

The output resistance

$$R_o = R_{C2} = 2.2 \text{ k}\Omega$$