BJT Amplifiers: Part 2

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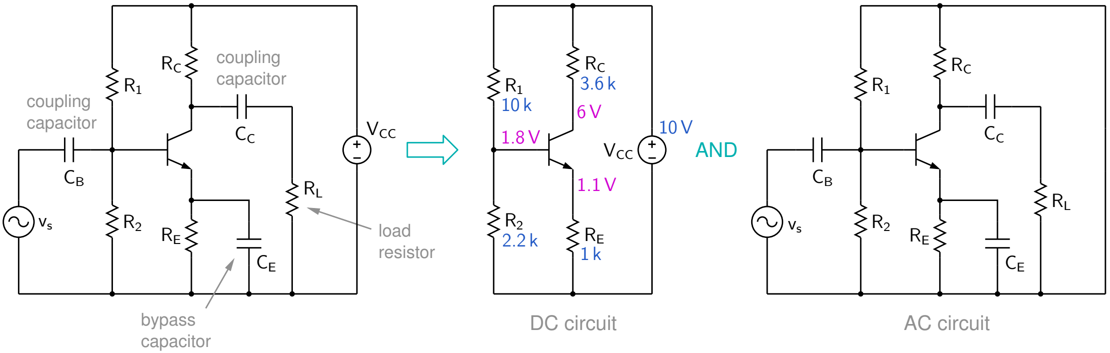
Common-emitter amplifier



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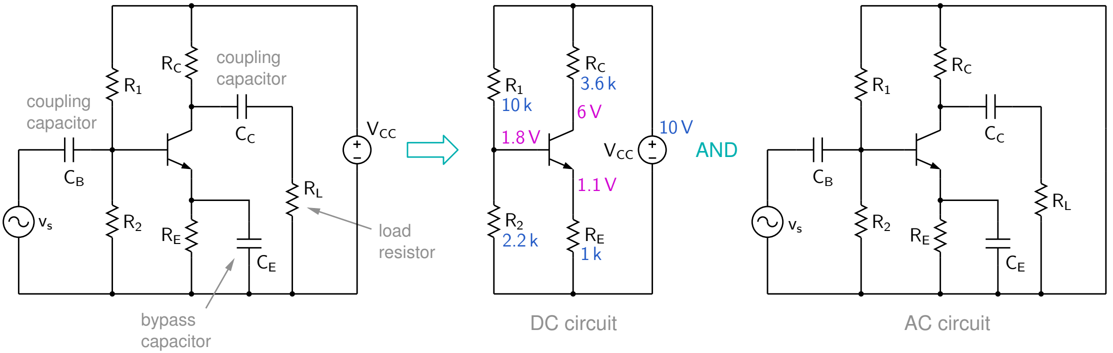

DC circuit

AC circuit

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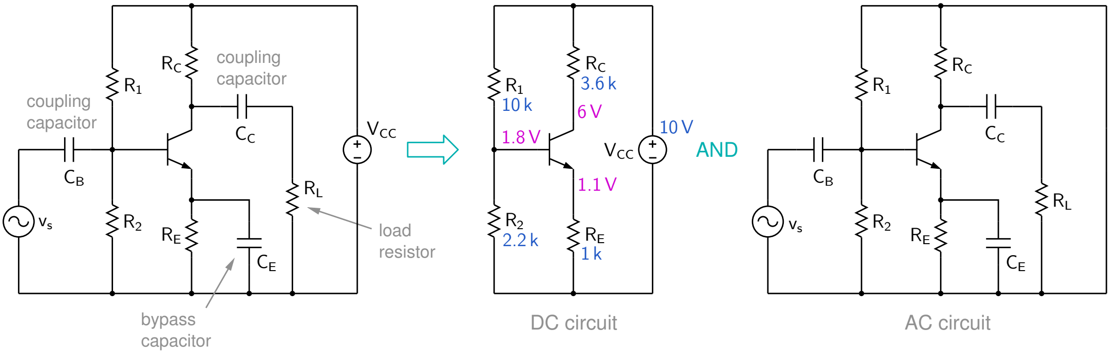

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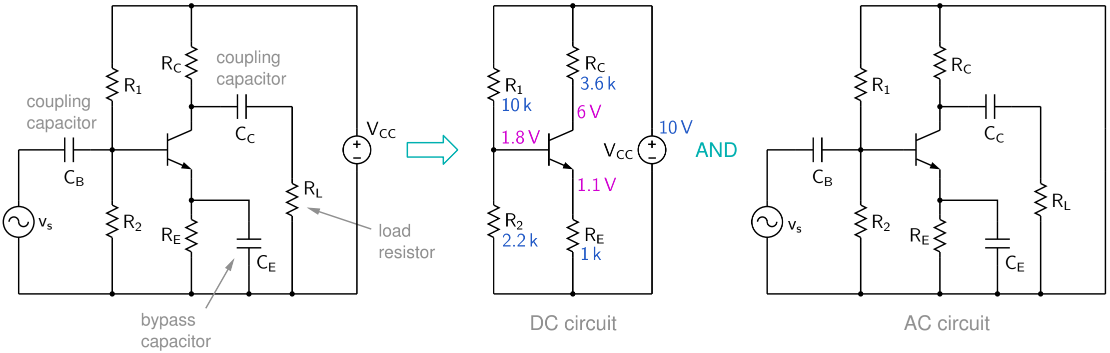

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* We now analyse the AC (small-signal) circuit to obtain v_b, v_e, v_c, i_c.
* We will then get the complete solution by simply adding the DC and AC results, e.g., $i_C(t) = I_C + i_c(t)$.
* We will assume that C_B, C_C, C_E are large enough so that, at the signal frequency (say, 1 kHz), they can be replaced by short circuits.

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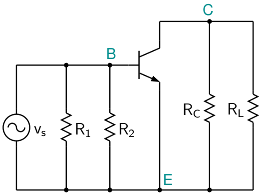

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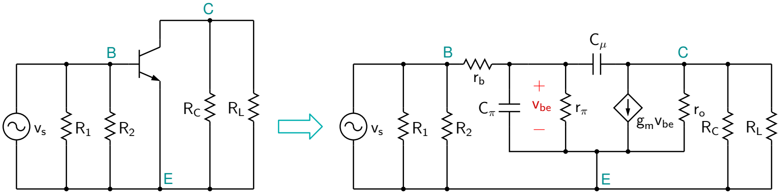

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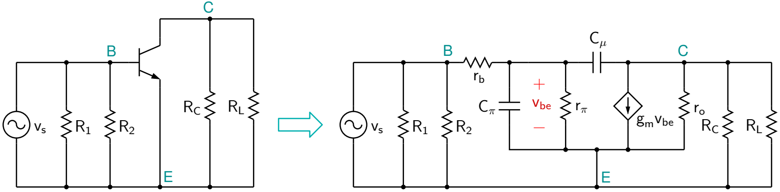

* The parasitic capacitances C_π and C_μ are in the pF range. At a signal frequency of 1 kHz, the impedance corresponding to these capacitances is

  $$\mathbf{Z} \sim \frac{-j}{\omega C} = \frac{-j}{2\pi \times 10^3 \times 10^{-12}} \sim -j\,100\,\mathrm{M}\Omega$$

  $\rightarrow$ C_π and C_μ can be replaced by open circuits.

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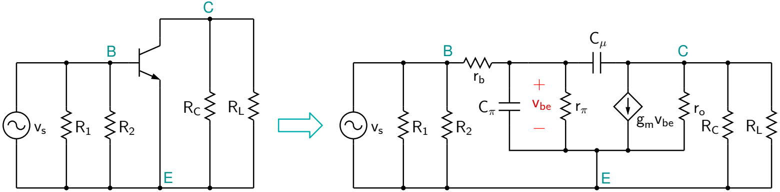

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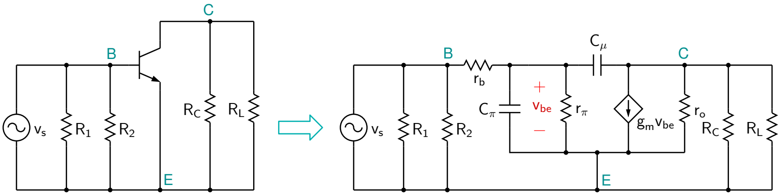

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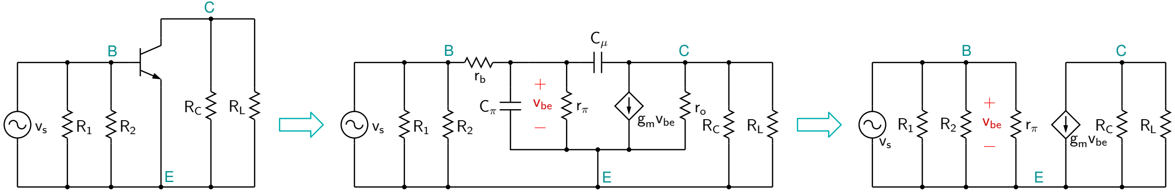
* The above considerations significantly simplify the AC circuit.



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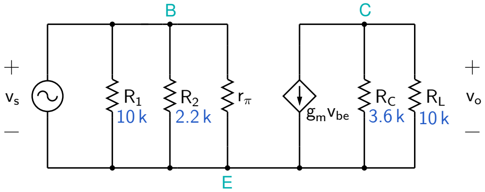

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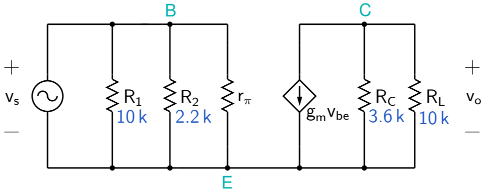

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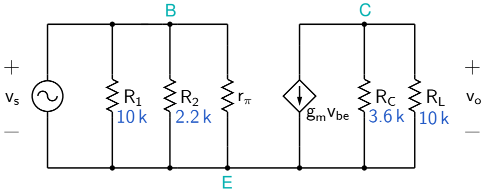

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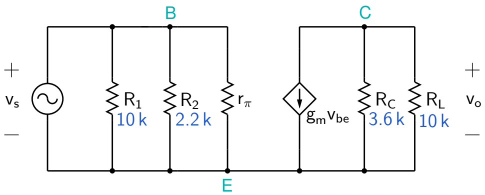

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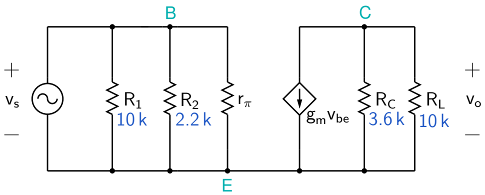

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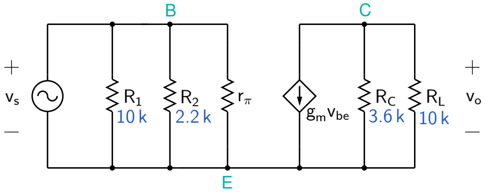

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For $v_s(t) = (2\,\mathrm{m}V)\, \sin \omega t$, the AC output voltage is,

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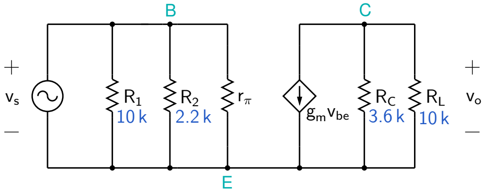

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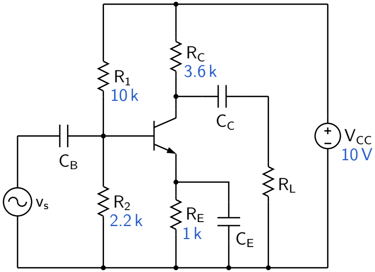
The AC collector current is,

$i_c = g_m\, v_{be} = g_m\, v_s = 42.5\,\mathrm{m}\mho \times (2\,\mathrm{m}V)\ \sin \omega t = 85\ \sin \omega t\ \mu A$.



For $v_s(t) = (2\,\mathrm{m}V)\,\sin\omega t$, we can now obtain expressions for the instantaneous currents and voltages:

$$v_C(t) = V_C + v_c(t) = V_C + v_o(t) = 6\;V - (225\,\mathrm{m}V)\,\sin\omega t\,.$$
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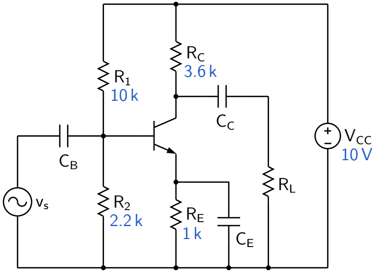

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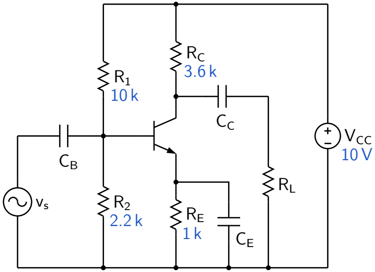
Note that the above procedure (DC + AC analysis) can be used *only if* the small-signal approximation (i.e., $|v_{be}| \ll V_T$) is valid. In the above example, the amplitude of v_{be} is 2 mV, which is much smaller than V_T (about 25 mV).



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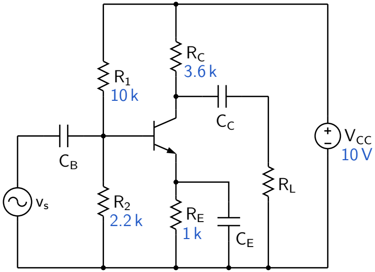

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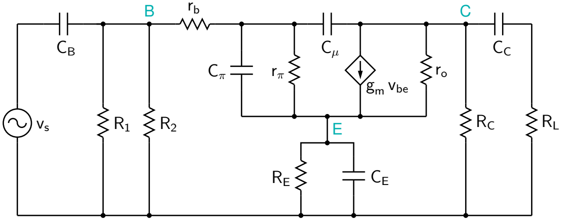
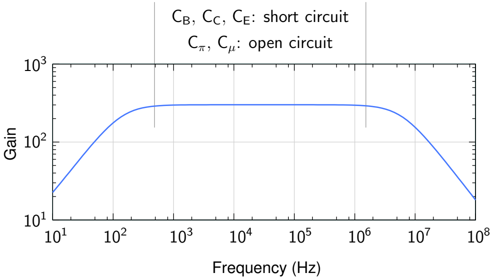
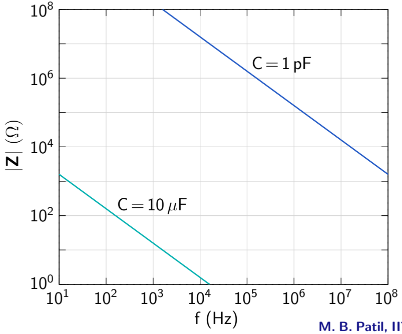
In practice, such a situation is anyway not prevalent (because it gives rise to distortion in the output voltage) except in special types of amplifiers.

Frequency response of common-emitter amplifier







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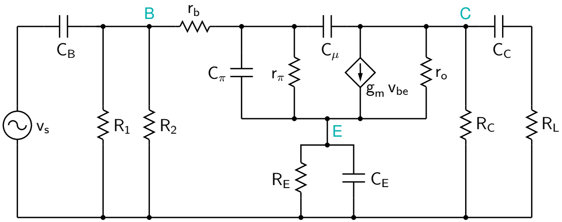

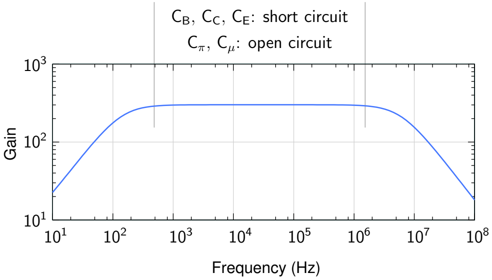

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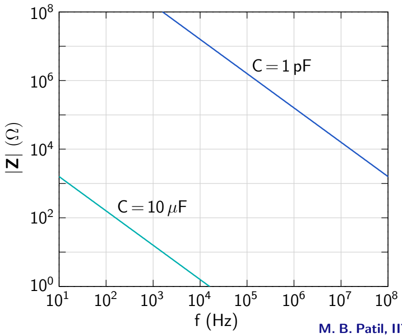

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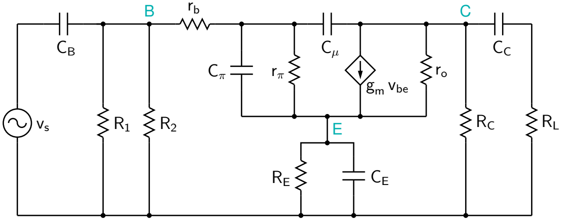

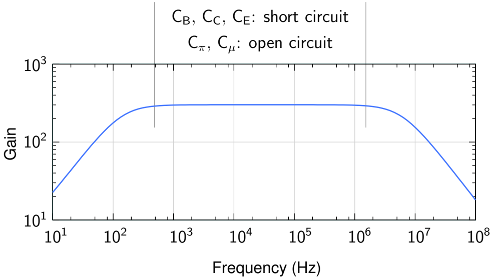

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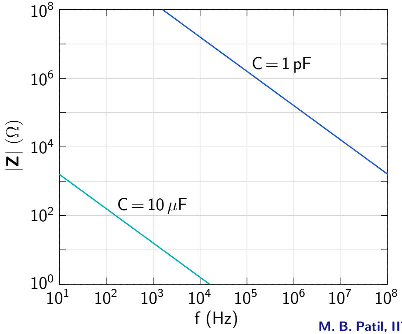

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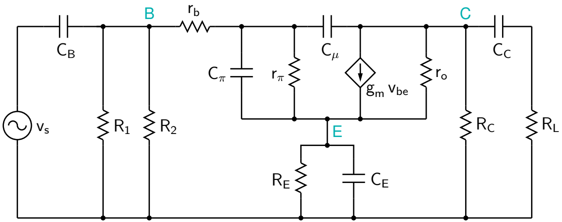

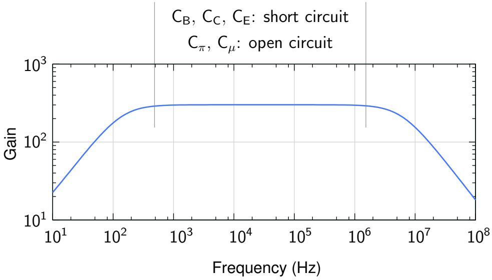

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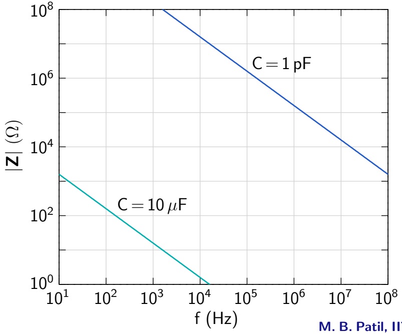
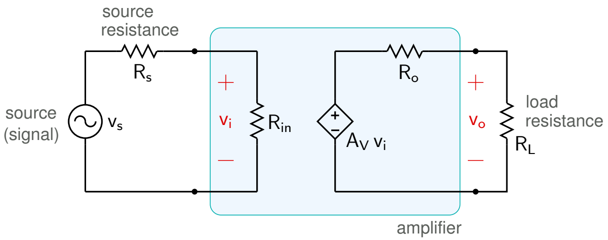
* In the "mid-band" range (which we have considered so far), the large capacitances behave like short circuits, and the small capacitances like open circuits. In this range, the gain is independent of frequency.



General representation of an amplifier



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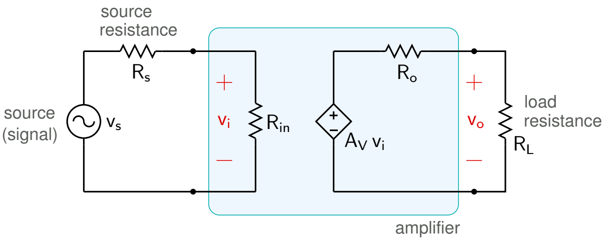

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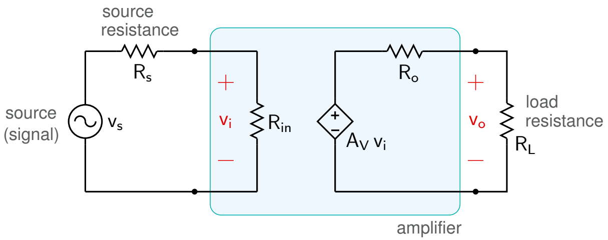

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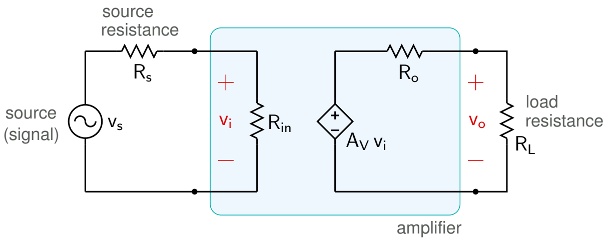

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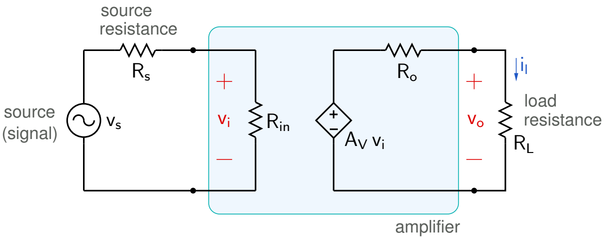
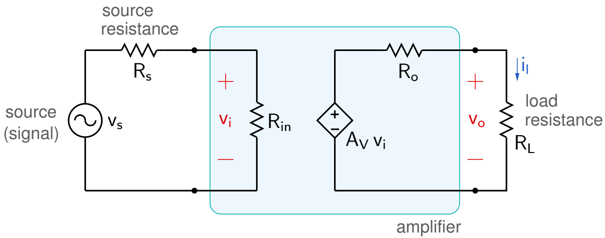
* The DC bias of the circuit can affect parameter values in the AC equivalent circuit (A_V, R_{in}, R_o). For example, for the common-emitter amplifier, $A_V \propto g_m = I_C/V_T$, I_C being the DC (bias) value of the collector current.
* Suppose we are given an amplifier as a "black box" and asked to find A_V, R_{in}, and R_o. What experiments would give us this information?

Voltage gain A_V



If $R_L \rightarrow \infty$, $i_l \rightarrow 0$, and $v_o \rightarrow A_V\,v_i$.

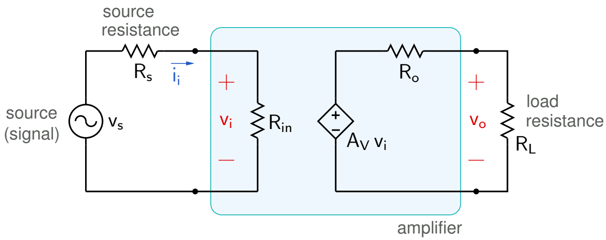
Voltage gain A_V



If $R_L \rightarrow \infty$, $i_l \rightarrow 0$, and $v_o \rightarrow A_V\, v_i$.

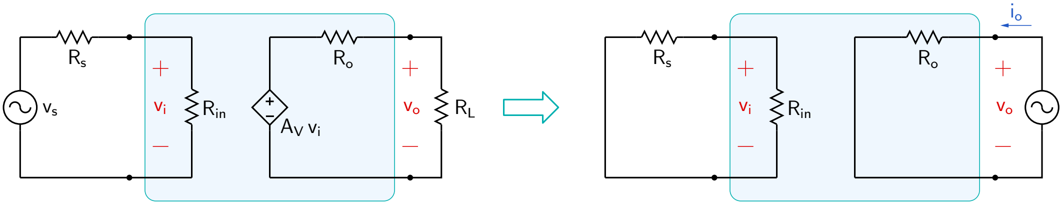
We can remove R_L (i.e., replace it with an open circuit), measure v_i and v_o, then use $A_V = v_o/v_i$.

Input resistance R_{in}



Measurement of v_i and i_i yields $R_{\text{in}} = v_i / i_i$.

Output resistance R_o



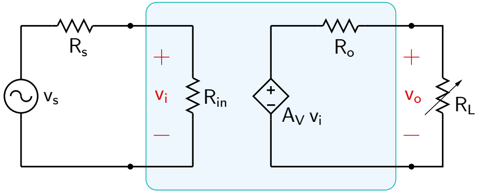
Method 1:

If $v_s \rightarrow 0$, $A_V\, v_i \rightarrow 0$.

Now, connect a test source v_o, and measure $i_o \rightarrow R_o = v_o/i_o$.

(This method works fine on paper, but it is difficult to use experimentally.)

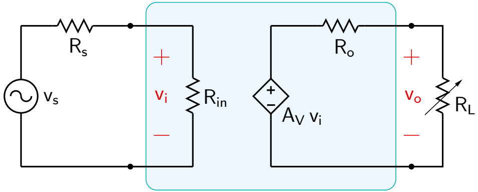
Output resistance R_o



Method 2:

$$v_o = \frac{R_L}{R_L + R_o} A_V \, v_i .$$

Output resistance R_o

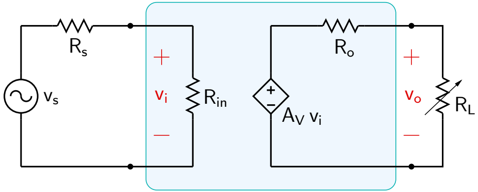


Method 2:

$$v_o = \frac{R_L}{R_L + R_o} A_V \, v_i .$$

If $R_L \rightarrow \infty$, $v_{o1} = A_V \, v_i$.

Output resistance R_o



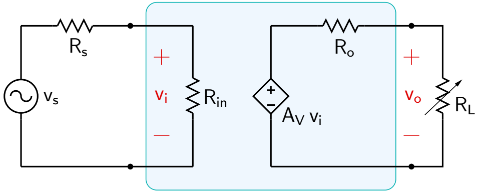
Method 2:

$$v_o = \frac{R_L}{R_L + R_o} A_V \, v_i .$$

If $R_L \rightarrow \infty$, $v_{o1} = A_V \, v_i$.

If $R_L = R_o$, $v_{o2} = \frac{1}{2} A_V \, v_i = \frac{1}{2} v_{o1}$.

Output resistance R_o



Method 2:

$$v_o = \frac{R_L}{R_L + R_o} A_V \, v_i .$$

If $R_L \to \infty$, $v_{o1} = A_V \, v_i$.

If $R_L = R_o$, $v_{o2} = \frac{1}{2} A_V \, v_i = \frac{1}{2} v_{o1}$.

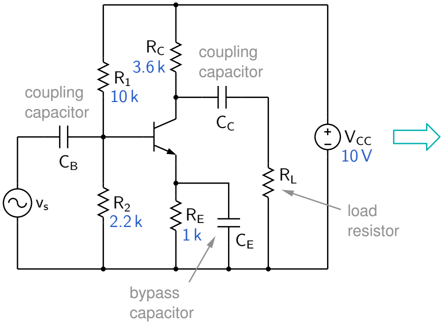
Procedure:

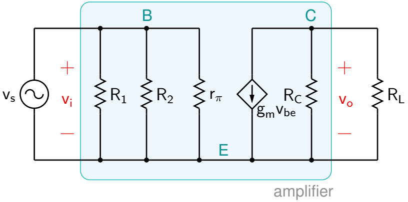
Measure v_{o1} with $R_L \to \infty$ (i.e., R_L removed).

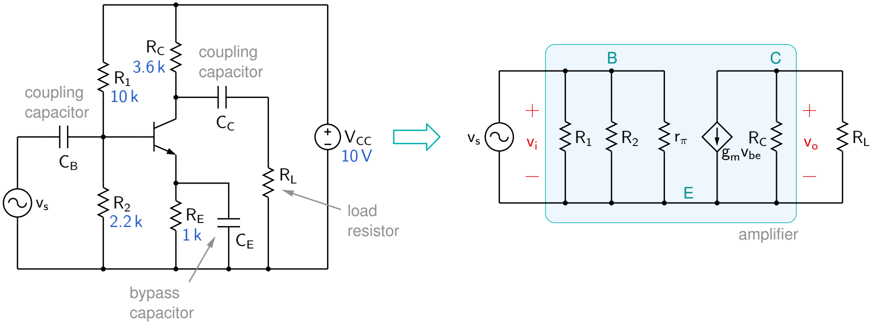
Vary R_L and observe v_o.

When v_o is equal to $v_{o1}/2$, measure R_L (after removing it).

R_o is the same as the measured resistance.

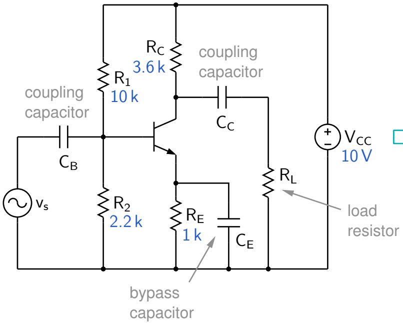

coupling
capacitor
R_C
$3.6\,k$
coupling
capacitor
R_1
$10\,k$
C_C
C_B
V_{CC}
$10\,V$
v_s
R_2
$2.2\,k$
R_E
$1\,k$
C_E
R_L
load
resistor
bypass
capacitor

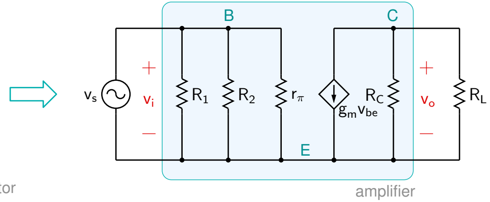

B
C
v_s
v_i
R_1
R_2
r_π
$g_m v_{be}$
R_C
v_o
R_L
E
amplifier



$$A_V = \frac{v_o}{v_i}, \text{ with } R_L \to \infty.$$

$$A_V = \frac{-g_m v_{be} R_C}{v_i} = -g_m R_C = -42.5\,\text{m℧} \times 3.6\,\text{k} = 153.$$





$$A_V = \frac{v_o}{v_i}, \text{ with } R_L \rightarrow \infty.$$

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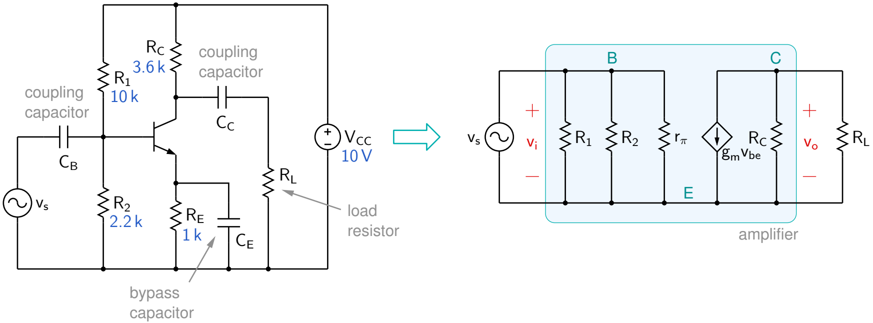
The input resistance of the amplifier is, by inspection, $R_{\text{in}} = (R_1 \parallel R_2) \parallel r_\pi$.

$r_\pi = \beta/g_m = 100/42.5\,\text{m}\mho = 2.35\,\text{k} \rightarrow R_{\text{in}} = 1\,\text{k}.$

Common-emitter amplifier



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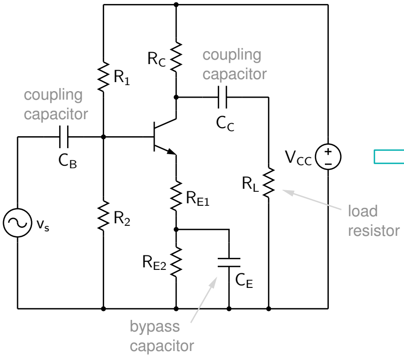
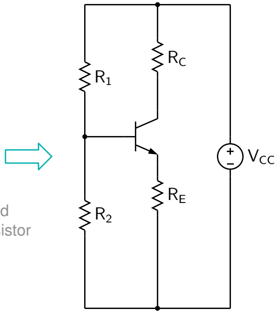
$r_\pi = \beta / g_m = 100/42.5\,\text{m℧} = 2.35\,\text{k} \rightarrow R_{\text{in}} = 1\,\text{k}$.

The output resistance is R_C (by "Method 1" seen previously).

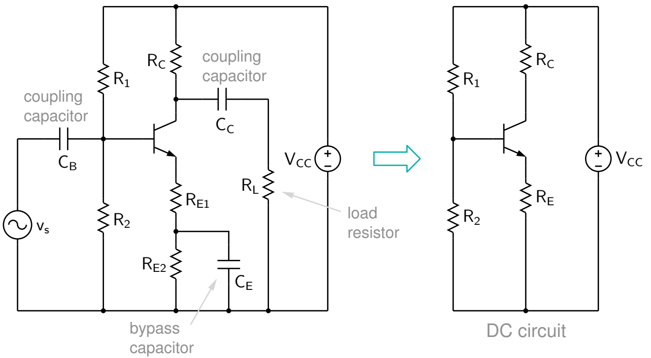
Common-emitter amplifier with partial bypass





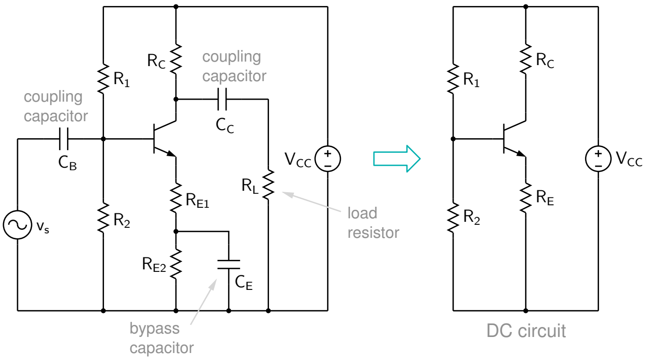
DC circuit

Common-emitter amplifier with partial bypass



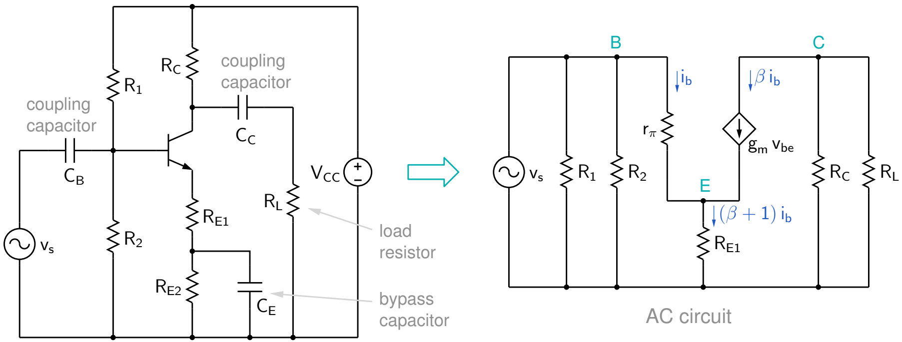
* For DC computation, C_E is open, and the DC analysis is therefore identical to our earlier amplifier, with $R_E \leftarrow R_{E1} + R_{E2}$.

Common-emitter amplifier with partial bypass



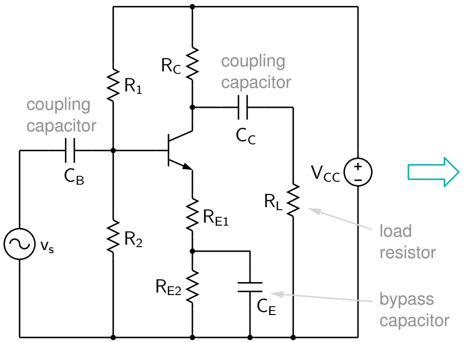
* For DC computation, C_E is open, and the DC analysis is therefore identical to our earlier amplifier, with $R_E \leftarrow R_{E1} + R_{E2}$.
* Bypassing a part of R_E (as opposed to all of it) does have an impact on the voltage gain (see next slide).

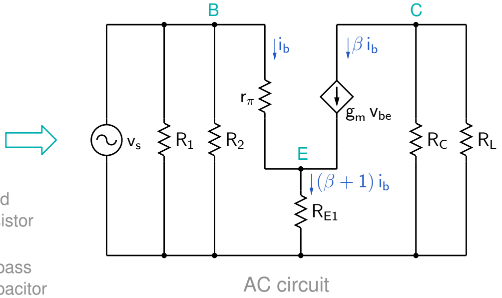
Common-emitter amplifier with partial bypass



Again, assume that, at the frequency of operation, C_B, C_C, C_E can be replaced by short circuits, and the BJT parasitic capacitances by open circuits.

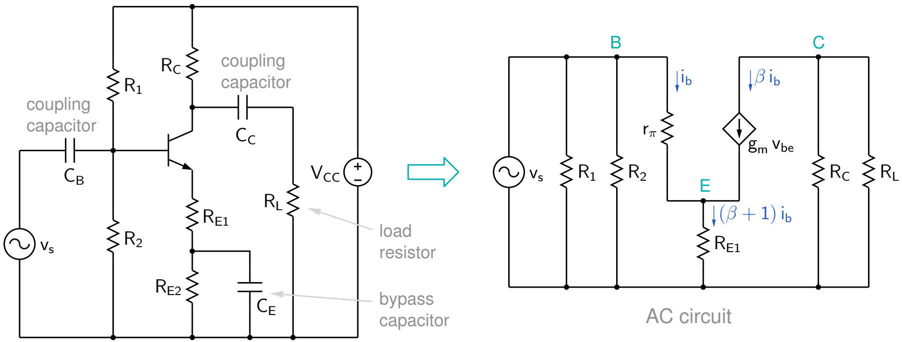
Common-emitter amplifier with partial bypass





Again, assume that, at the frequency of operation, C_B, C_C, C_E can be replaced by short circuits, and the BJT parasitic capacitances by open circuits.

$$v_s = i_b\, r_\pi + (\beta + 1)\, i_b\, R_{E1} \rightarrow i_b = \frac{v_s}{r_\pi + (\beta + 1)\, R_{E1}}.$$



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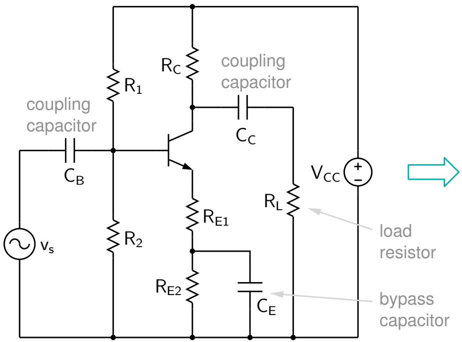
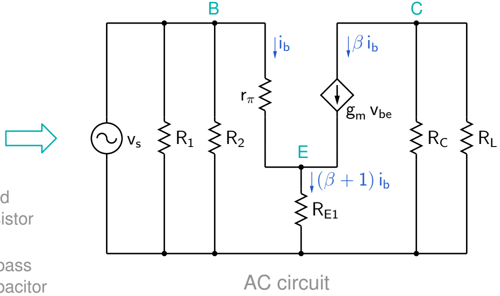
$$v_s = i_b\, r_\pi + (\beta+1)\, i_b\, R_{E1} \rightarrow i_b = \frac{v_s}{r_\pi + (\beta+1)\, R_{E1}}.$$

$$v_o = -\beta\, i_b \times (R_C \parallel R_L) \rightarrow \frac{v_o}{v_s} = -\frac{\beta\,(R_C \parallel R_L)}{r_\pi + (\beta+1)\, R_{E1}} \approx -\frac{(R_C \parallel R_L)}{R_{E1}} \text{ if } r_\pi \ll (\beta+1)\, R_{E1}.$$

Common-emitter amplifier with partial bypass





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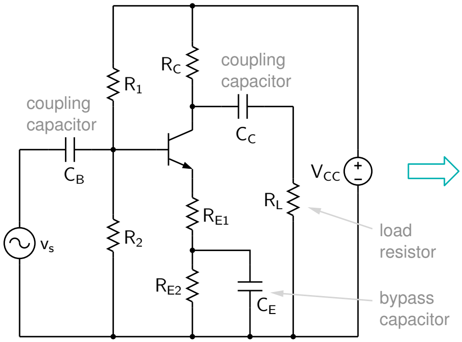
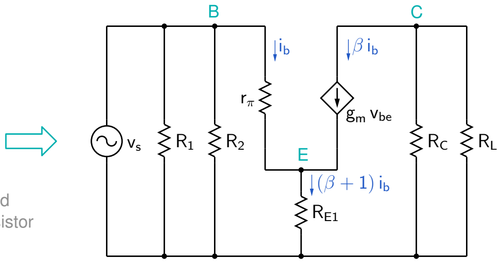
Note: R_{E1} gets multiplied by $(\beta+1)$.

Common-emitter amplifier with partial bypass

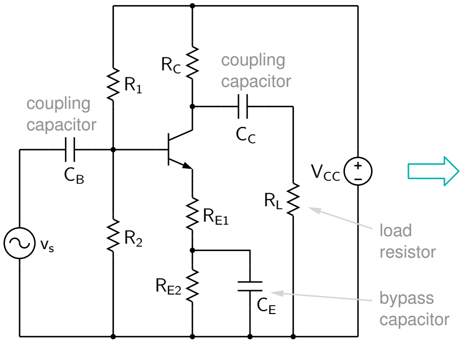


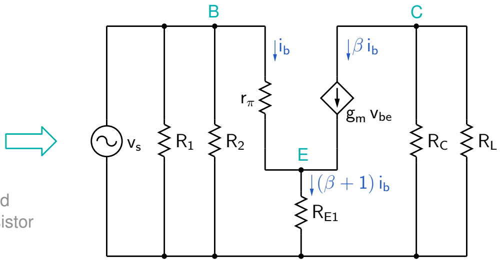


AC circuit

$$\frac{v_{be}}{v_s} = \frac{r_\pi\, i_b}{r_\pi\, i_b + R_E\,(\beta+1)\, i_b} = \frac{r_\pi}{r_\pi + R_E\,(\beta+1)}$$

Common-emitter amplifier with partial bypass





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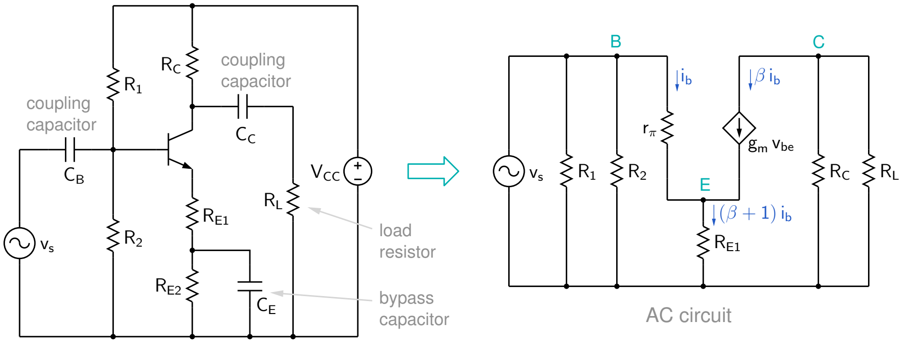
The small-signal condition, viz., $|v_{be}(t)| \ll V_T$ now implies

$$|v_s|\, \frac{r_\pi}{r_\pi + R_E\,(\beta+1)} \ll V_T \quad \text{or} \quad |v_s| \ll V_T \times \frac{r_\pi + R_E\,(\beta+1)}{r_\pi},$$ which is much larger than V_T.

Common-emitter amplifier with partial bypass



$$\frac{v_{be}}{v_s} = \frac{r_\pi\, i_b}{r_\pi\, i_b + R_E\,(\beta+1)\, i_b} = \frac{r_\pi}{r_\pi + R_E\,(\beta+1)}$$

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$\rightarrow$ Although the gain is reduced, partial emitter bypass allows larger input voltages to be applied without causing distortion in $v_o(t)$. (For comparison, we required $|v_s| \ll V_T$ for the CE amplifier.)