EE101: BJT circuits (Part 2)

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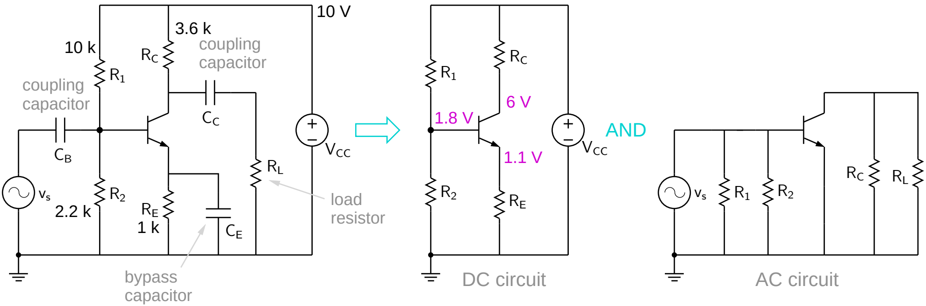
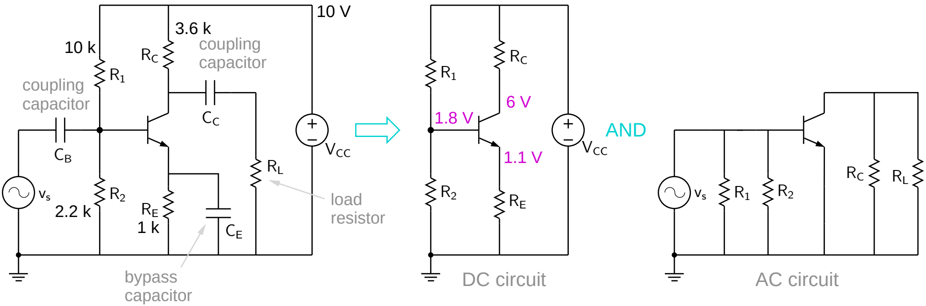
Common-emitter amplifier



* We have already analysed the DC (bias) circuit of this amplifier and found that $V_B = 1.8\ V$, $V_E = 1.1\ V$, $V_C = 6\ V$, and $I_C = 1.1\ mA$.



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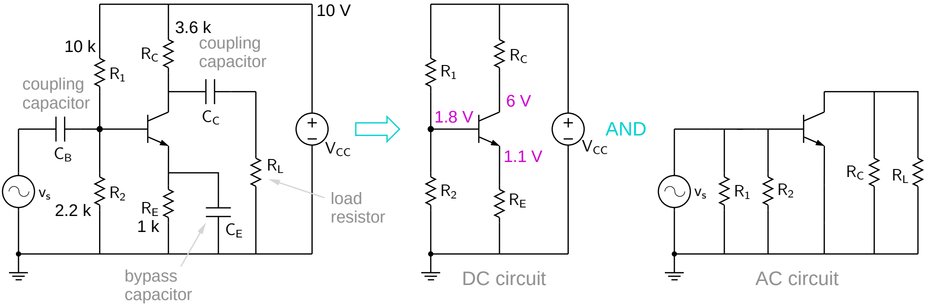

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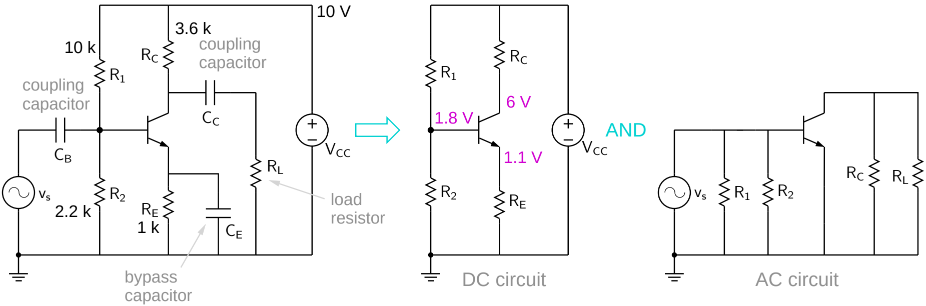

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* We will then get the complete solution by simply adding the DC and AC results, e.g., $i_C(t) = I_C + i_c(t)$.
* We will assume that C_B, C_C, C_E are large enough so that, at the signal frequency (say, 1 kHz), they can be replaced by short circuits.

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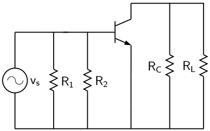

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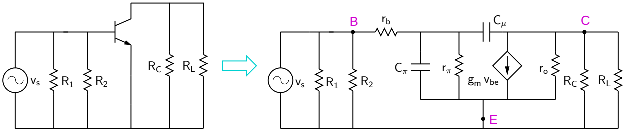

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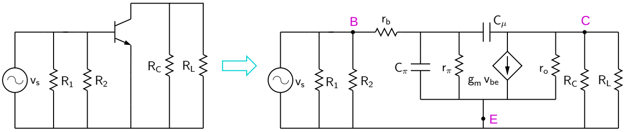
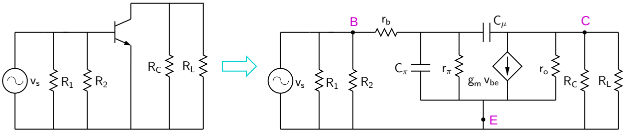


* The parasitic capacitances C_π and C_μ are in the pF range. At a signal frequency of 1 kHz, their impedance is $1/\omega C \sim 1/(2\pi \times 10^3 \times 10^{-12})$, i.e., $\sim 100\,\text{M}\Omega$.
  $\rightarrow$ C_π and C_μ can be replaced by open circuits.



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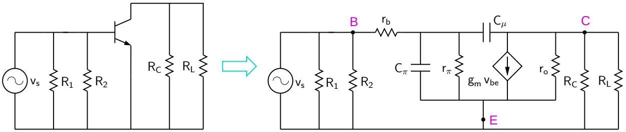

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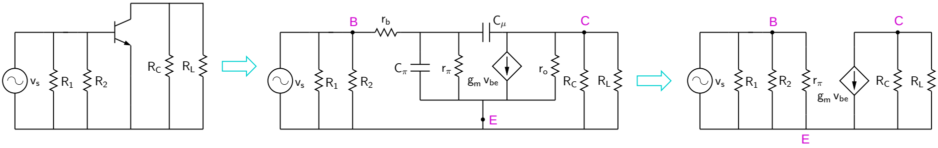

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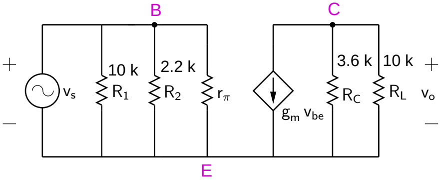
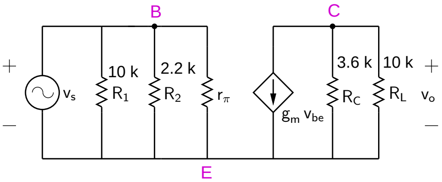


$v_o = -(g_m\, v_{be}) \times (R_C \parallel R_L) = -(g_m\, v_s) \times (R_C \parallel R_L)$



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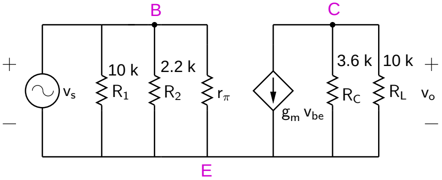
(superscript L is used because the gain includes the effect of R_L.)



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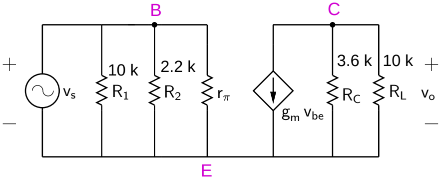

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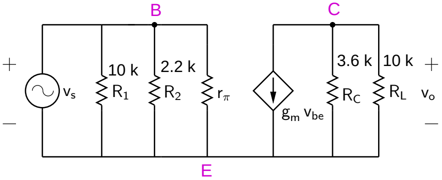

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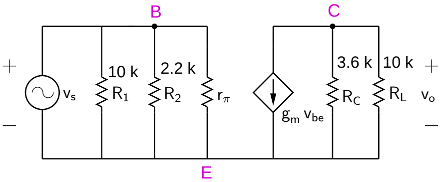

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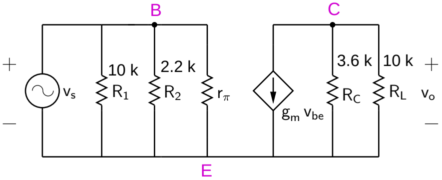
$v_o = A_V^L\, v_s = -(112.5)\,(2\,\mathrm{m}V)\,\sin\omega t = -(125\,\mathrm{m}V)\,\sin\omega t$



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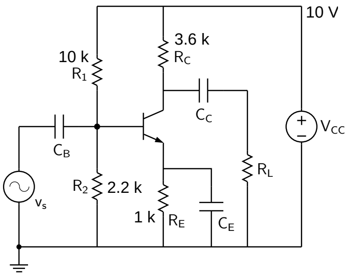
The AC collector current is,

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



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

$$v_C(t) = V_C + v_c(t) = V_C + v_o(t) = 6\ V - (125\,\text{m}V)\ \sin\omega t\,.$$
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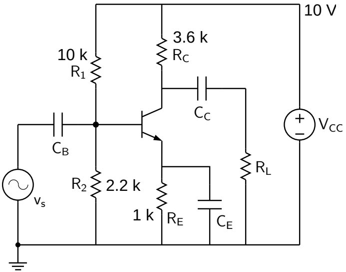

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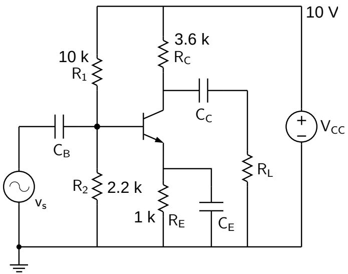
Note that the above procedure (DC + AC analysis) can be used *only if* the small-signal approximation (i.e., $|v_{be}| \ll V_T$) is valid. In the above example, the amplitude of v_{be} is 2 mV, which is much smaller than V_T.



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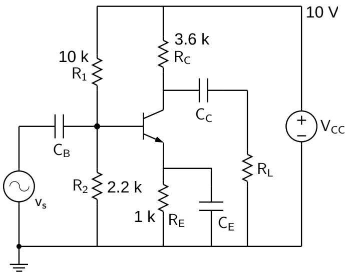
For $v_s(t) = (20\,\mathrm{m}V)\ \sin\omega t$, for example, the small-signal approximation will not hold, and a numerical simulation will be required to obtain the currents and voltages of interest.



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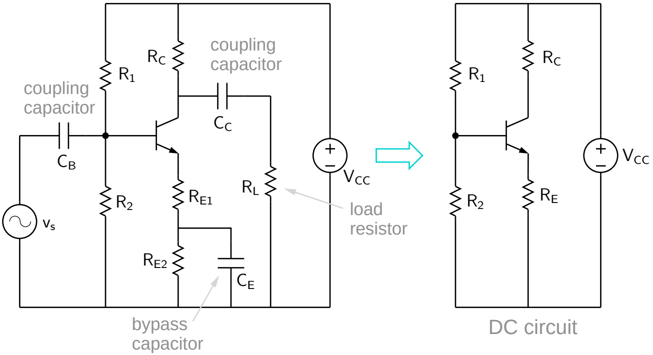
In practice, such a situation is anyway not prevalent (because it gives rise to distortion in the output voltage) except in special types of amplifiers.

Common-emitter amplifier with partial bypass



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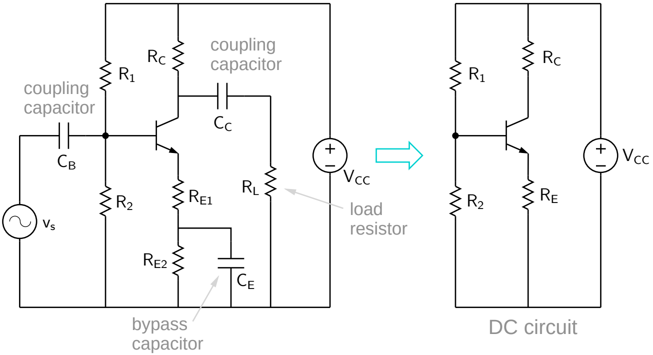

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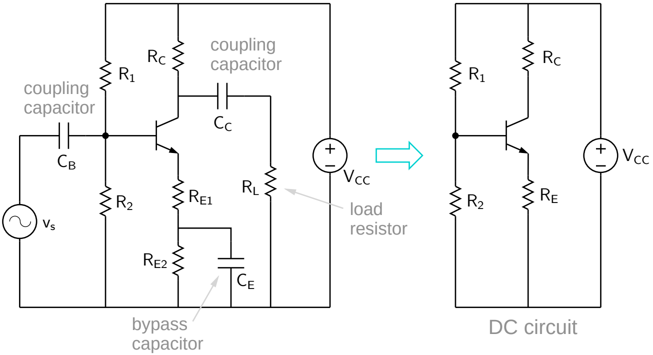

* For DC computation, C_E is open, and the DC analysis is therefore identical to our earlier amplifier, with $R_E \leftarrow R_{E1} + R_{E2}$.
* Bypassing a part of R_E (as opposed to all of it) does have an impact on the voltage gain (see next slide).

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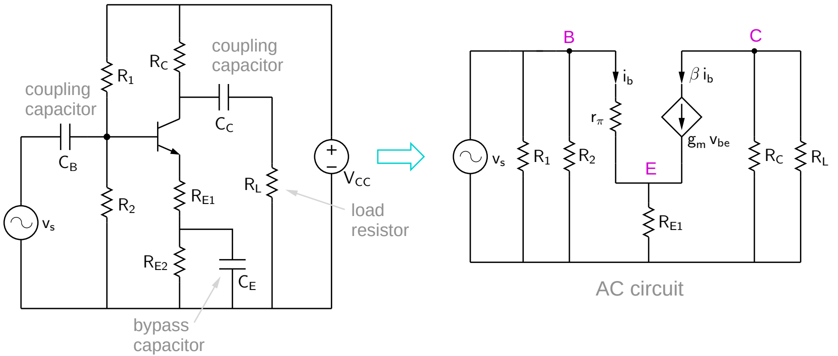

Again, assume that, at the frequency of operation, C_B, C_C, C_E can be replaced by short circuits, and the BJT parasitic capacitances by open circuits.

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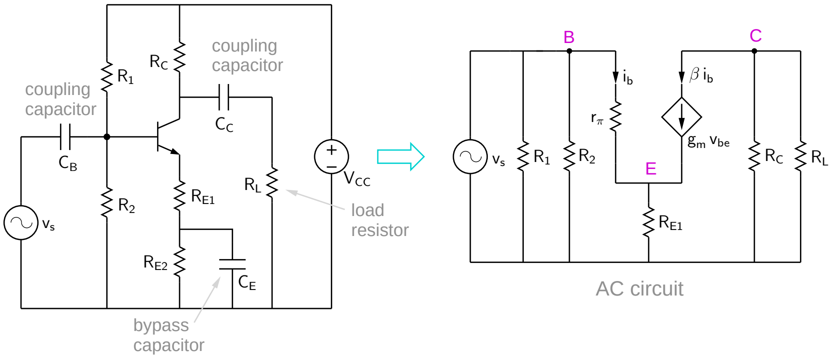

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$$v_s = v_{be} = i_b\, r_\pi + (\beta + 1)\, i_b\, R_{E1} \rightarrow i_b = \frac{v_s}{r_\pi + (\beta+1)\, R_{E1}}.$$

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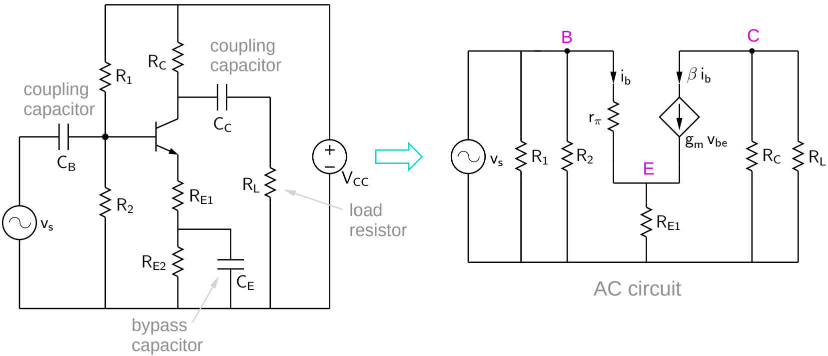

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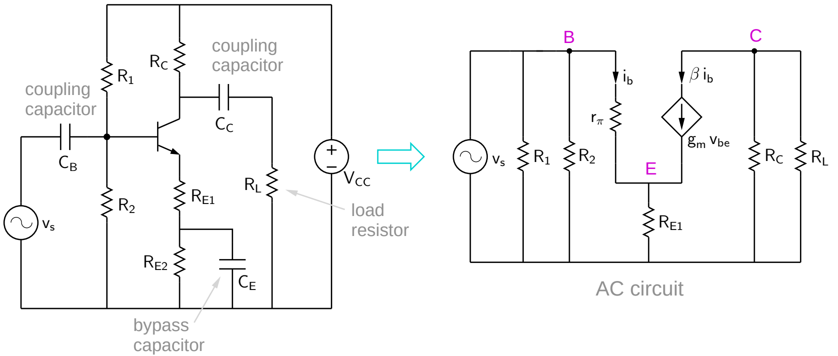

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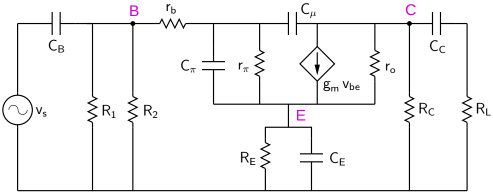
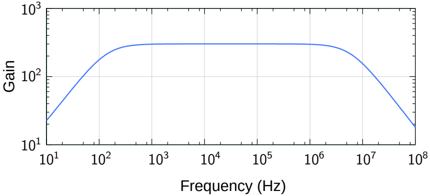
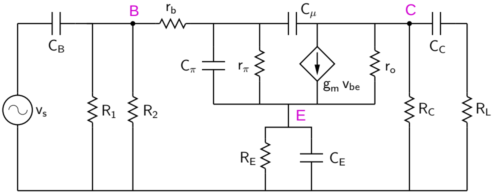
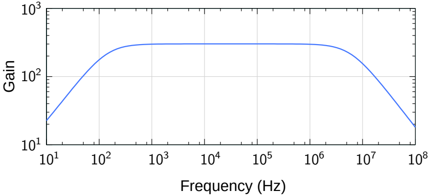
Note: R_{E1} gets multiplied by $(\beta+1)$.

Frequency response of common-emitter amplifier









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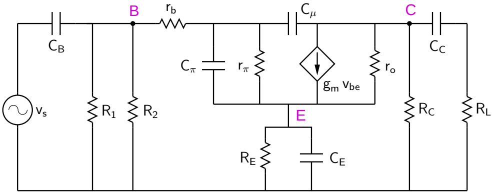

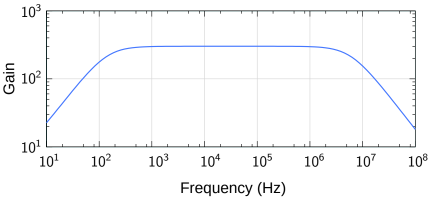

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* C_π, C_μ are small capacitances $\rightarrow 1/\omega C$ is perceptibly small only at high frequencies.

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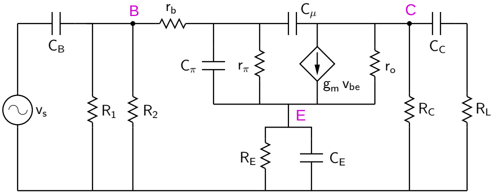

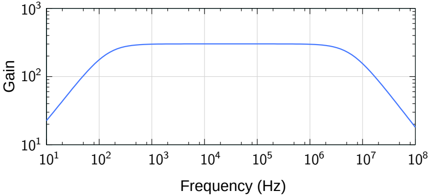

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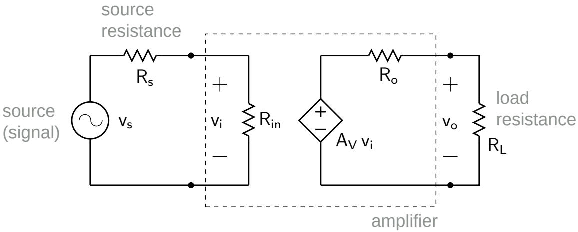
* C_π, C_μ are small capacitances $\rightarrow 1/\omega C$ is perceptibly small only at high frequencies.
* In the intermediate range (called "mid-band"), the large capacitances behave like short circuits, and the small capacitances behave like open circuits. In this range, the gain is independent of frequency.

General representation of an amplifier



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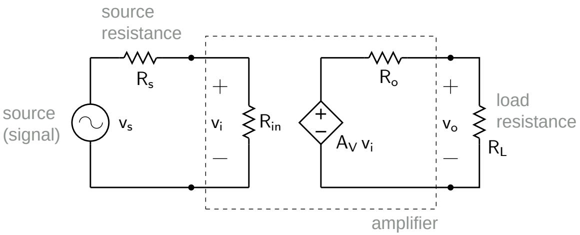

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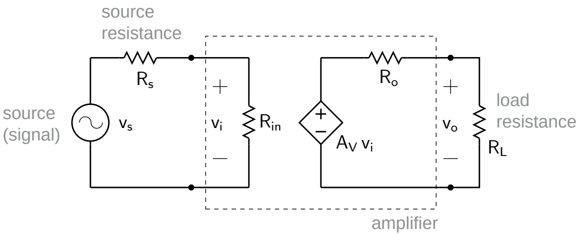

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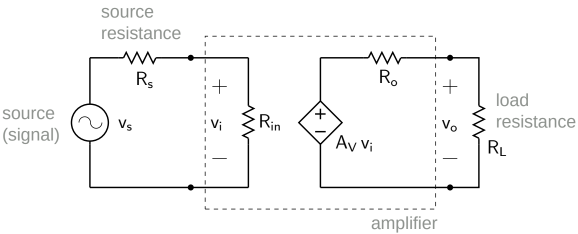

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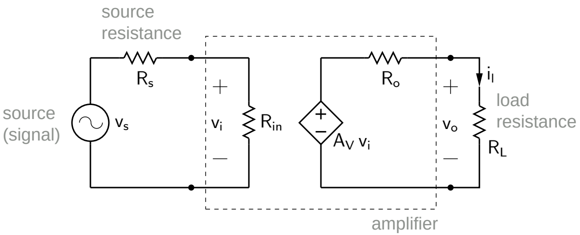
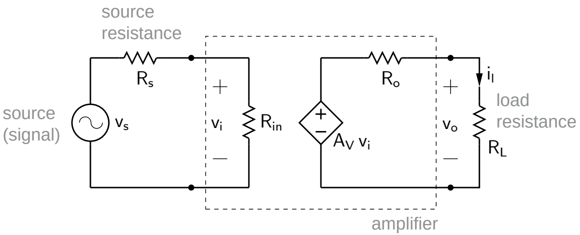
* Suppose we are given an amplifier as a "black box" and asked to find A_V, $R_{\rm in}$, and R_o. What experiments would give us this information?

Voltage gain A_V



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

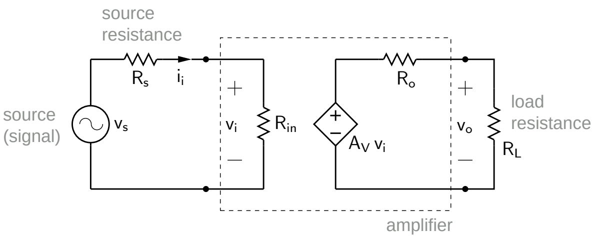
Voltage gain A_V



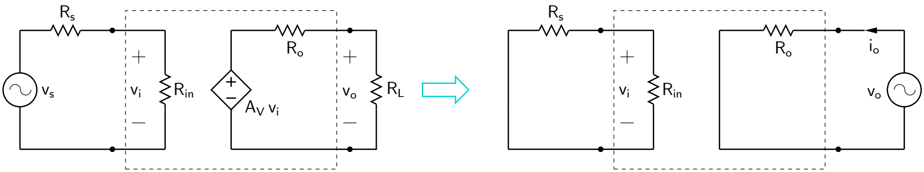
If $R_L \rightarrow \infty$, $i_l \rightarrow 0$, and $v_o \rightarrow A_V\, v_i$.

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 $R_{in} = v_i / i_i$.



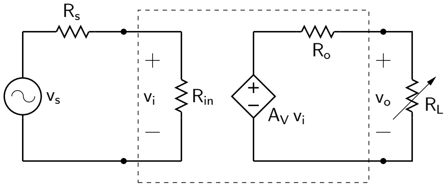
Method 1:

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

Now, connect a test source v_o, and measure i_o.

Clearly, $R_o = v_o/i_o$.

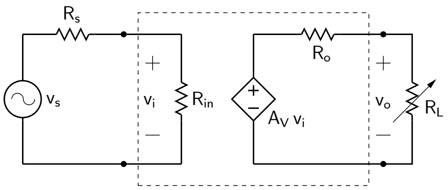
This method works fine on paper, but it is difficult to use experimentally.



Method 2:

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

Output resistance R_o



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

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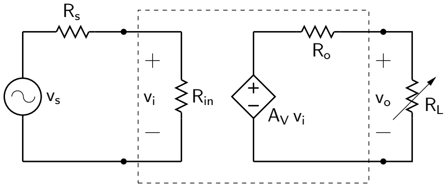

Method 2:

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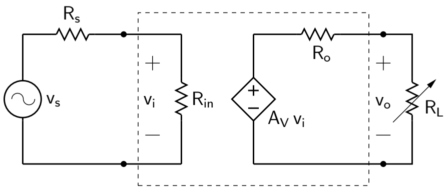
If $R_L \rightarrow \infty$, $v_{o1} = A_V \, v_i$.

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



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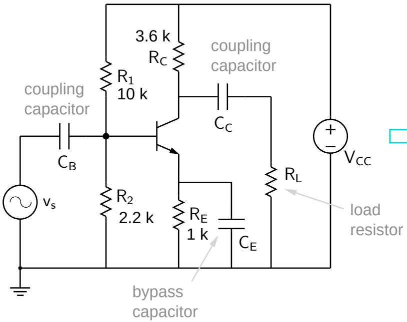
Procedure:

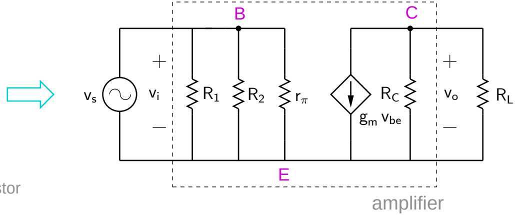
Measure v_{o1} with $R_L \rightarrow \infty$ (i.e., R_L removed).

Vary R_L to obtain $v_o = v_{o1}/2$.

The corresponding R_L is the same as R_o.

Common-emitter amplifier





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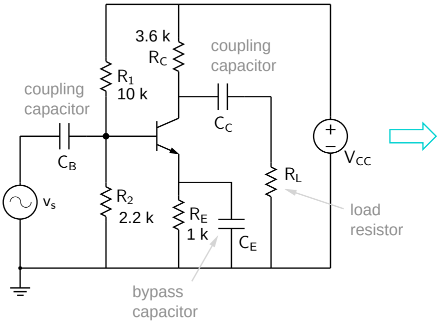

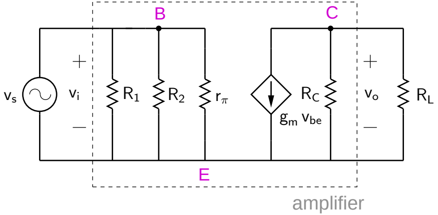

$$A_V = \frac{v_o}{v_i}, \text{ with } R_L \to \infty.$$

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

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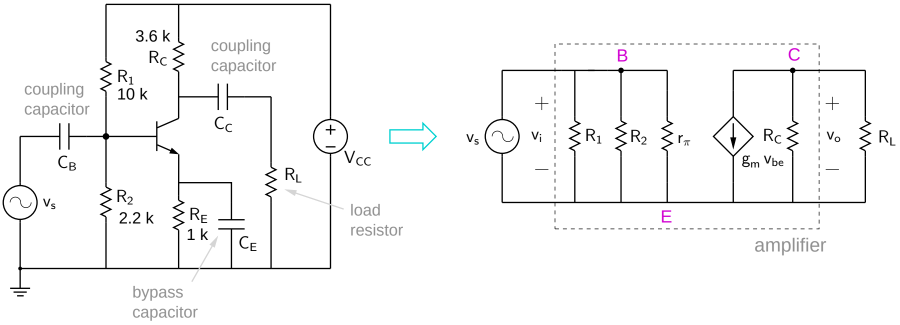

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The input resistance of the amplifier is, by inspection, $R_{\text{in}} = (R_1 \parallel R_2) \parallel r_\pi$.

$r_\pi = \beta / g_m = 100/42.5\,\text{m}\mho = 2.35\,\text{k} \rightarrow R_{\text{in}} = 1.24\,\text{k}.$

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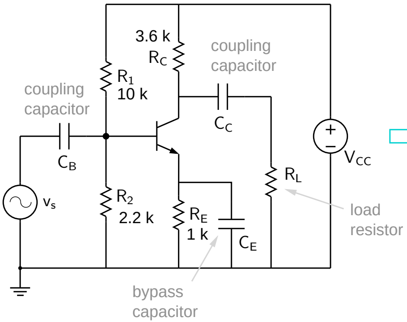

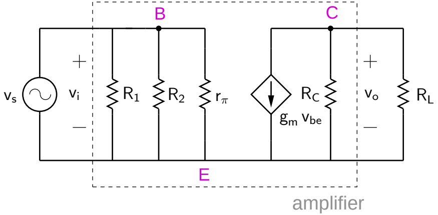

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The output resistance is R_C (by "Method 1" seen previously).