

EE101: BJT circuits (Part 3)

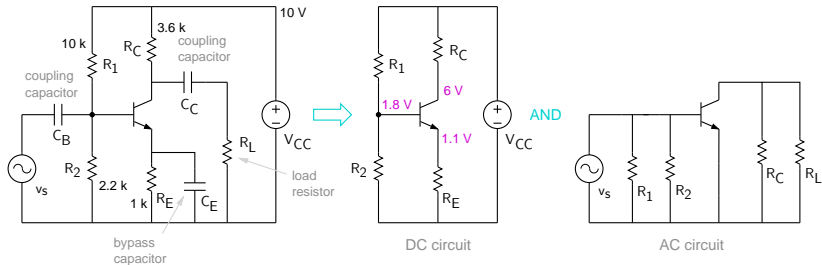


M. B. Patil

mbpatil@ee.iitb.ac.in

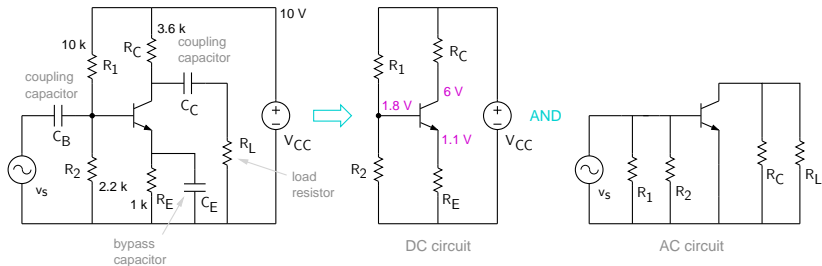
Department of Electrical Engineering
Indian Institute of Technology Bombay

Common-emitter amplifier



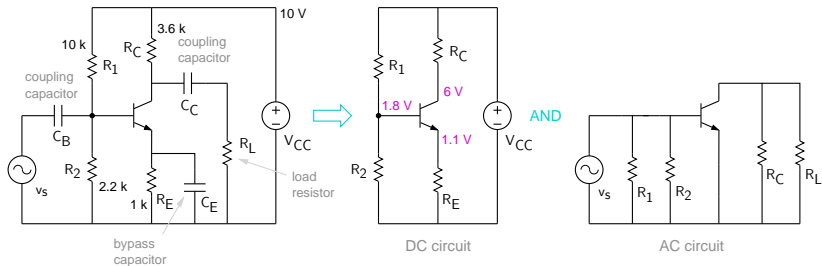
- * We have already analysed the DC (bias) circuit of this amplifier and found that $V_B = 1.8\text{ V}$, $V_E = 1.1\text{ V}$, $V_C = 6\text{ V}$, and $I_C = 1.1\text{ mA}$.

Common-emitter amplifier



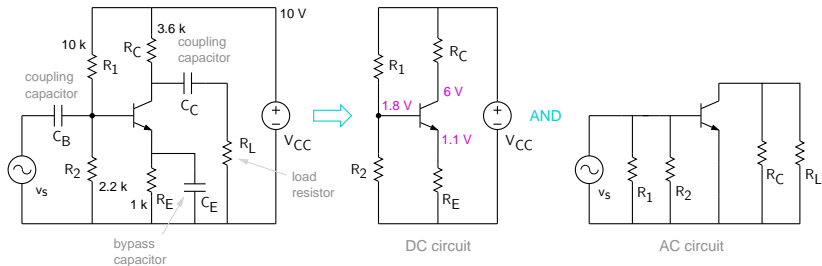
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Common-emitter amplifier



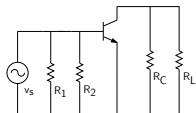
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Common-emitter amplifier

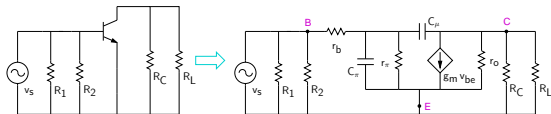


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- * We will then get the complete solution by simply adding the DC and AC results, e.g., $i_C(t) = I_C + i_c(t)$.
- * We will assume that C_B , C_C , C_E are large enough so that, at the signal frequency (say, 1 kHz), they can be replaced by short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

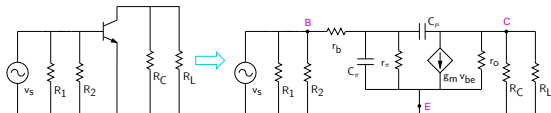
Common-emitter amplifier



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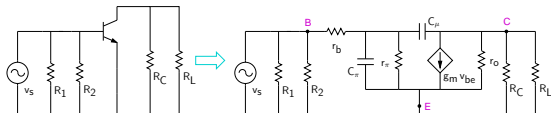


Common-emitter amplifier



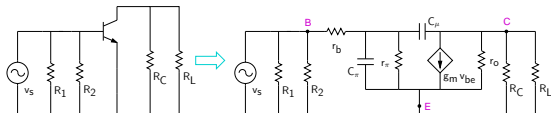
- * The parasitic capacitances C_π and C_μ are in the pF range. At a signal frequency of 1 kHz, their impedance is $1/\omega C \sim 1/(2\pi \times 10^3 \times 10^{-12})$, i.e., $\sim 100 \text{ M}\Omega$.
→ C_π and C_μ can be replaced by open circuits.

Common-emitter amplifier



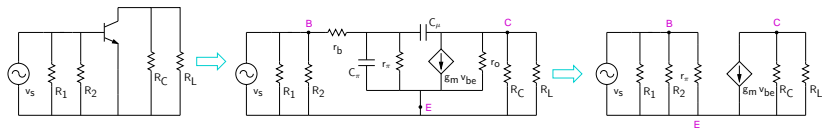
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Common-emitter amplifier



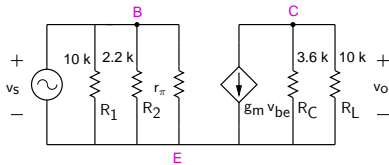
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Common-emitter amplifier



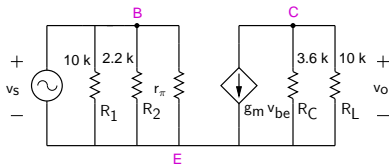
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Common-emitter amplifier



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

Common-emitter amplifier

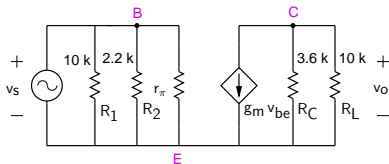


$$v_o = -(g_m v_{be}) \times (R_C \parallel R_L) = -(g_m v_s) \times (R_C \parallel R_L)$$

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

Common-emitter amplifier



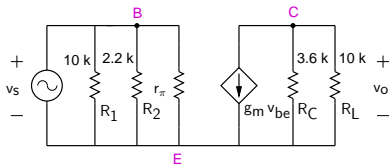
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Common-emitter amplifier



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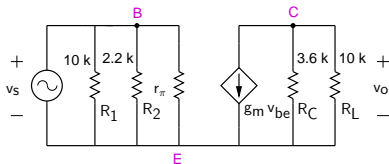
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Common-emitter amplifier



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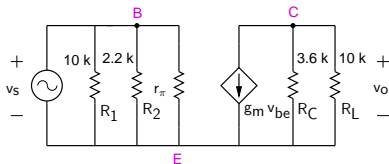
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Common-emitter amplifier



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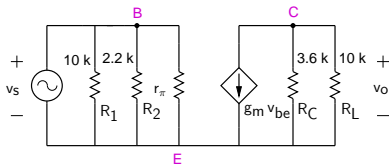
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For $v_s(t) = (2 \text{ mV}) \sin \omega t$, the AC output voltage is,

$$v_o = A_V^L v_s = -(112.5)(2 \text{ mV}) \sin \omega t = -(125 \text{ mV}) \sin \omega t$$

Common-emitter amplifier



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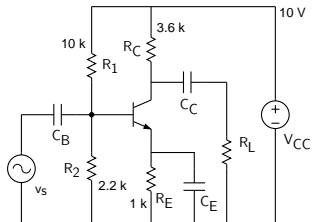
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The AC collector current is,

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

Common-emitter amplifier

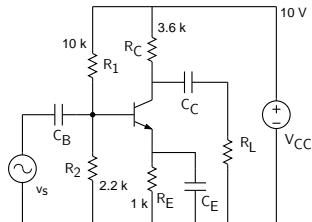


For $v_s(t) = (2 \text{ mV}) \sin \omega t$, we can now obtain expressions for the instantaneous currents and voltages:

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

$$i_C(t) = I_C + i_c(t) = 1.1 \text{ mA} - 0.085 \sin \omega t \text{ mA} .$$

Common-emitter amplifier



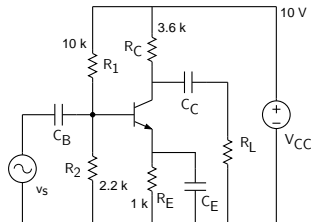
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Note that the above procedure (DC + AC analysis) can be used *only if* the small-signal approximation (i.e., $|v_{be}| \ll IV_T$) is valid. In the above example, the amplitude of v_{be} is 2 mV, which is much smaller than V_T .

Common-emitter amplifier



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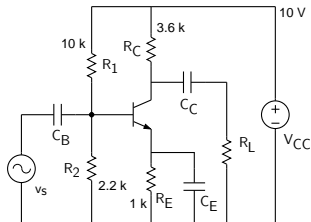
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For $v_s(t) = (20 \text{ mV}) \sin \omega t$, for example, the small-signal approximation will not hold, and a numerical simulation will be required to obtain the currents and voltages of interest.

Common-emitter amplifier



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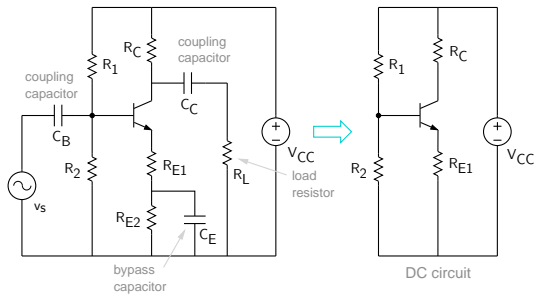
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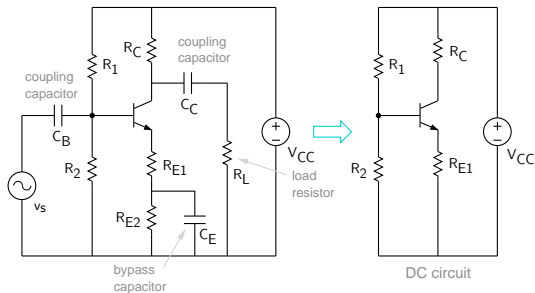
For $v_s(t) = (20 \text{ mV}) \sin \omega t$, for example, the small-signal approximation will not hold, and a numerical simulation will be required to obtain the currents and voltages of interest.

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

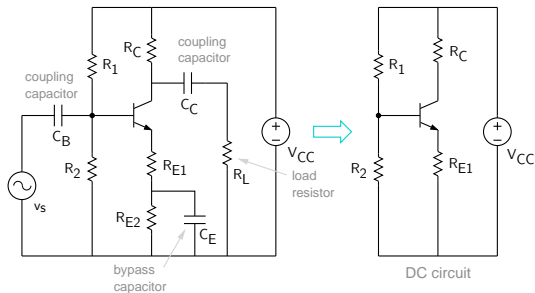


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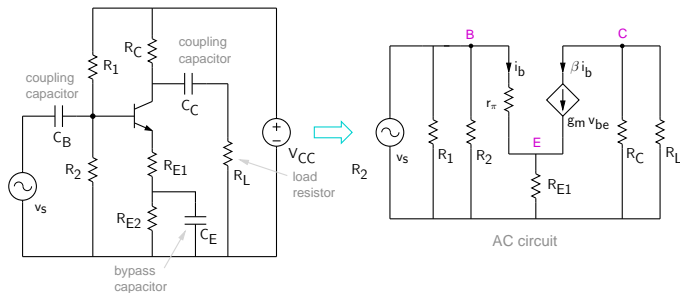
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Common-emitter amplifier with partial bypass



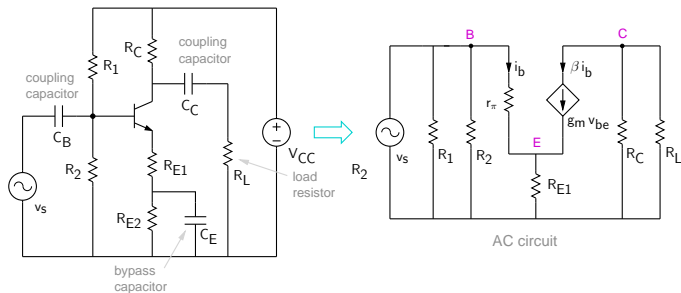
- * For DC computation, C_E is open, and the DC analysis is therefore identical to our earlier amplifier, with $R_E \leftarrow R_{E1} + R_{E2}$.
- * Bypassing a part of R_E (as opposed to all of it) does have an impact on the voltage gain (see next slide).

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.

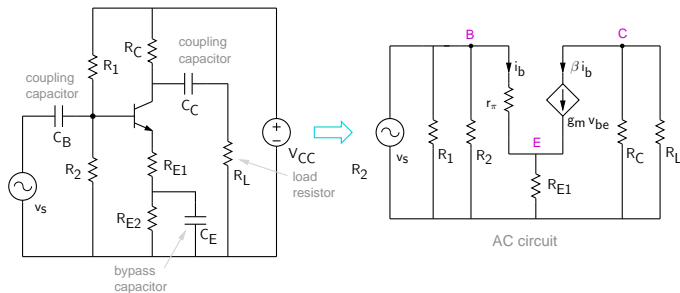
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$$v_s = v_{be} = i_b r_\pi + (\beta + 1) i_b R_{E1} \rightarrow i_b = \frac{v_s}{r_\pi + (\beta + 1) R_{E1}}.$$

Common-emitter amplifier with partial bypass

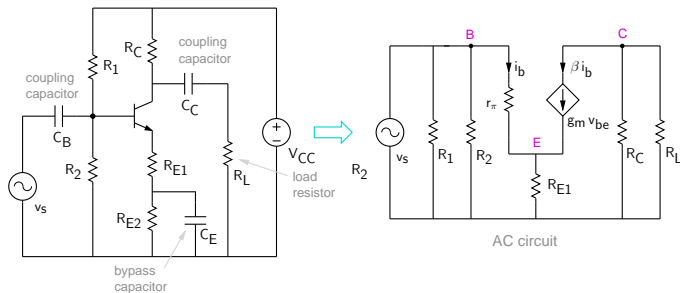


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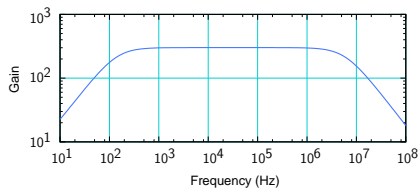
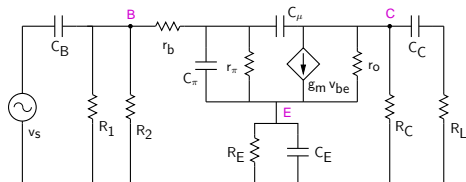
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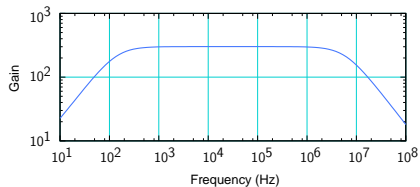
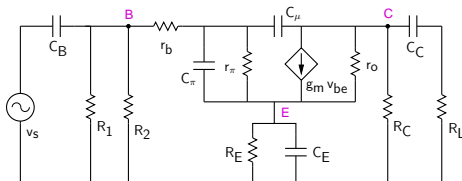
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Note: R_E gets multiplied by $(\beta + 1)$.

Frequency response of common-emitter amplifier

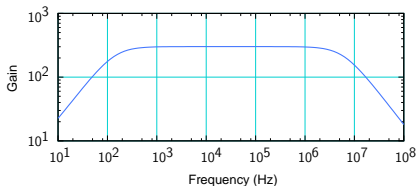
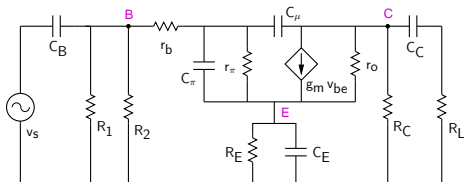


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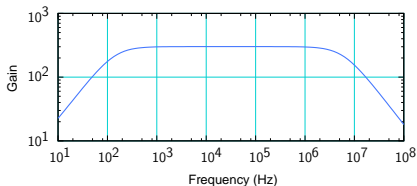
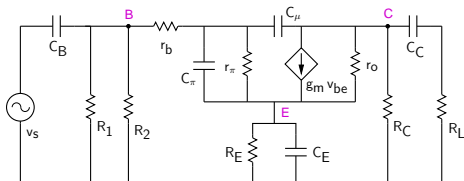
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Frequency response of common-emitter amplifier



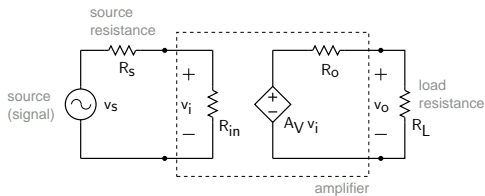
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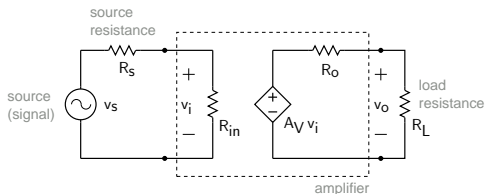
- * C_B , C_E , C_C are large capacitances $\rightarrow 1/\omega C$ is perceptibly large only at low frequencies.
- * C_π , C_μ are small capacitances $\rightarrow 1/\omega C$ is perceptibly small only at high frequencies.
- * In the intermediate range (called “mid-band”), the large capacitances behave 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



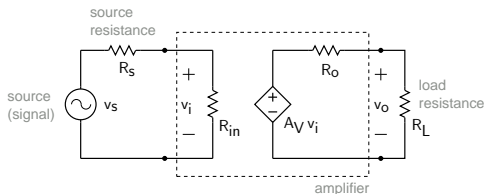
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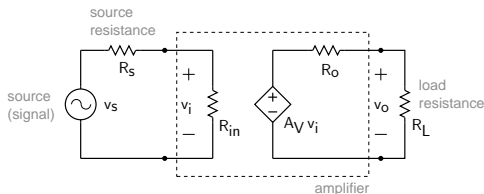
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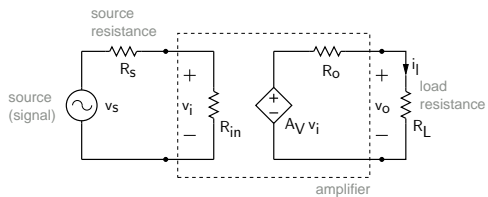
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- * The DC bias of the circuit can affect parameter values in the AC equivalent circuit (A_V , R_{in} , R_o). For example, for the common-emitter amplifier, $A_V \propto g_m = I_C/V_T$, I_C being the DC (bias) value of the collector current.

General representation of an amplifier



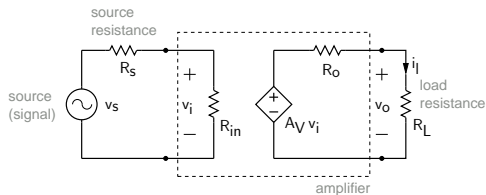
- * An amplifier is represented by a voltage gain, an input resistance, and an output resistance.
- * The above representation involves AC quantities *only*, i.e., it describes the AC equivalent circuit of the amplifier.
- * The DC bias of the circuit can affect parameter values in the AC equivalent 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 $v_o \rightarrow A_V v_i$.

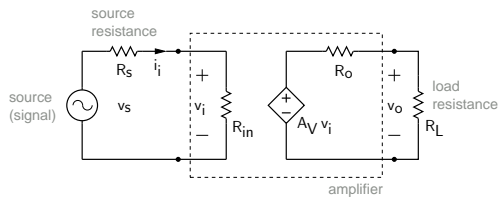
Voltage gain A_V



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

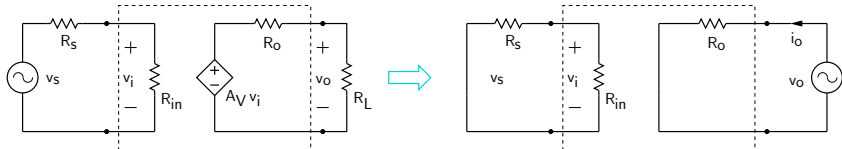
We can remove R_L (i.e., replace it with an open circuit), measure v_i and v_o , then use $A_V = v_o/v_i$.

Input resistance R_{in}



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

Output resistance R_o



Method 1:

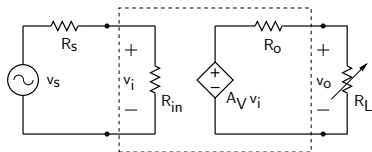
If $v_s \rightarrow 0$, $A_V v_i \rightarrow 0$.

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

Clearly, $R_o = v_o / i_o$.

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

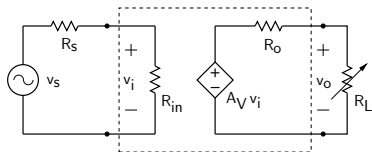
Output resistance R_o



Method 2:

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

Output resistance R_o

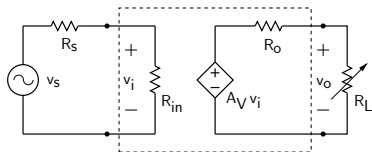


Method 2:

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

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

Output resistance R_o



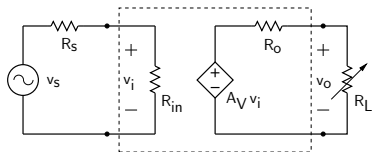
Method 2:

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

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

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

Output resistance R_o



Method 2:

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

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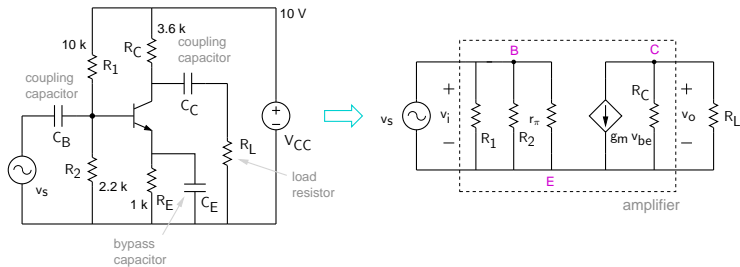
Procedure:

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

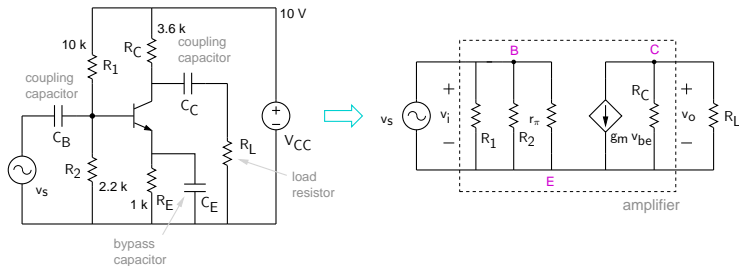
Vary R_L to obtain $v_o = v_{o1}/2$.

The corresponding R_L is the same as R_o .

Common-emitter amplifier



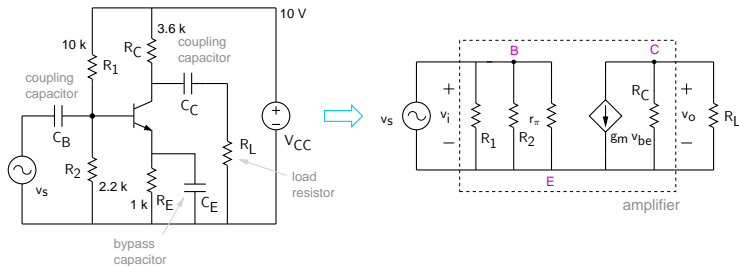
Common-emitter amplifier



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

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

Common-emitter amplifier



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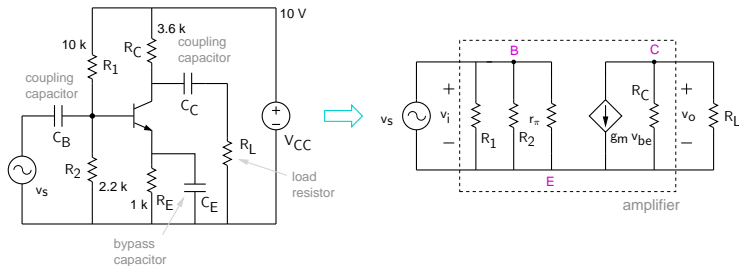
$$A_V = \frac{-g_m v_{be} R_C}{v_i} = -g_m R_C = -42.5 \text{ m}\mathcal{U} \times 3.6 \text{ k} = 153.$$

The input resistance of the amplifier is, by inspection,

$$R_{in} = (R_1 \parallel R_2) \parallel r_\pi.$$

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

Common-emitter amplifier



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