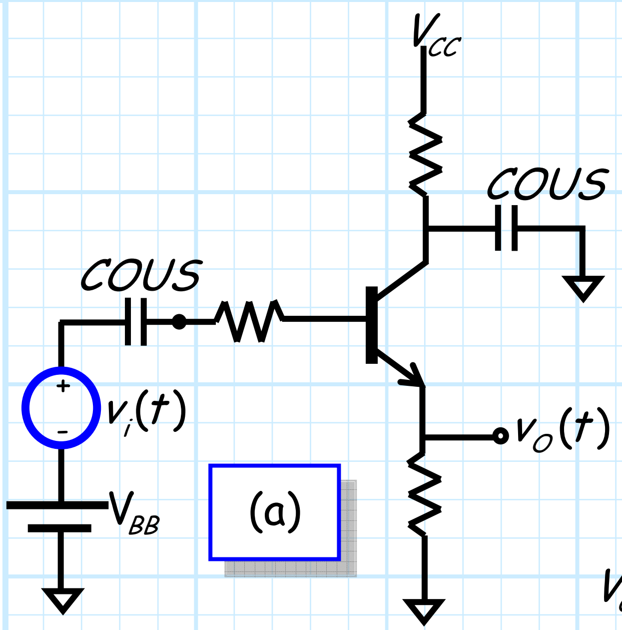
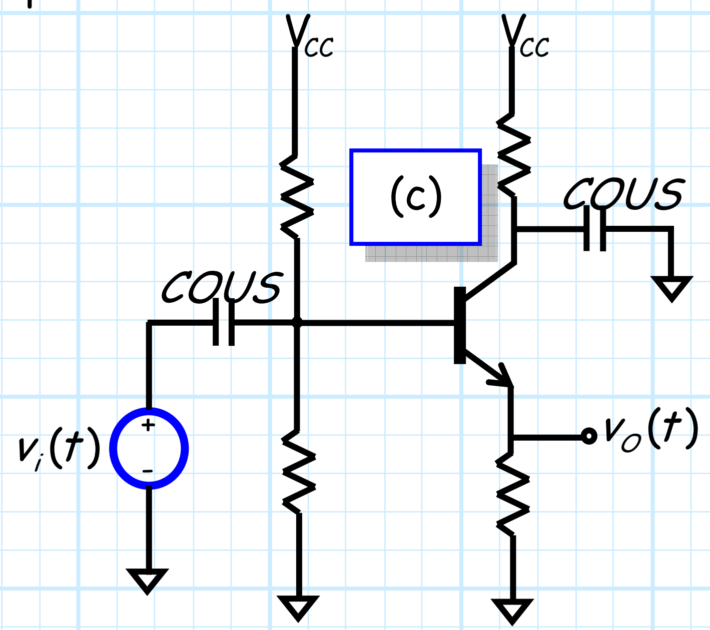
The Common-Collector Amplifier

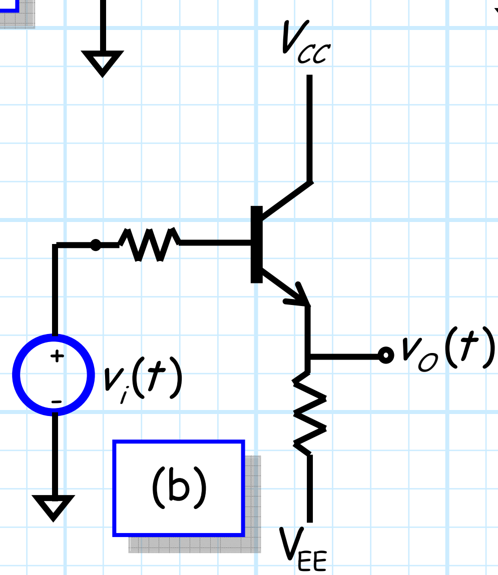
The **common-collector** amplifier: the BJT **collector** is at small-signal **ground**! Examples of this type of amplifier include:

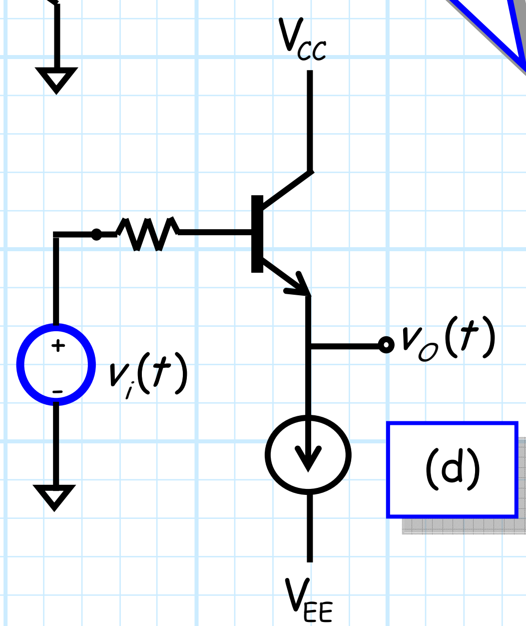




*Do **you** see **why** each of these four circuits is a gul-durn **common-collector** amplifier?*

*Make **dang** sure that you do!*



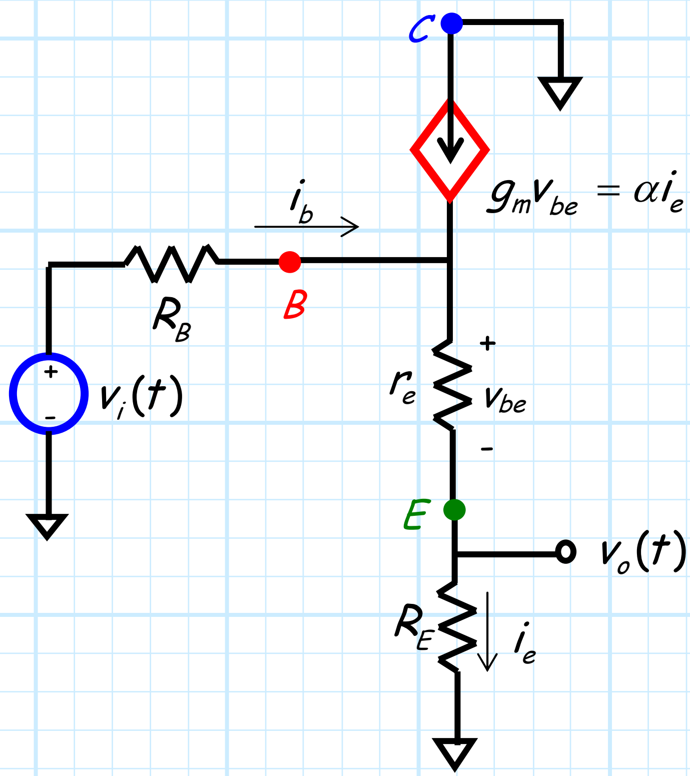


We'll use the T-model

Let's consider **circuit (a)**.

It turns out that for **common-collector** amplifiers, the **T-model** (as opposed to the hybrid-π) typically provides the **easiest** small-signal analysis.

Using the **T-model**, we find that the **small-signal circuit** for amplifier (a) is:



Let's analyze this amplifier!

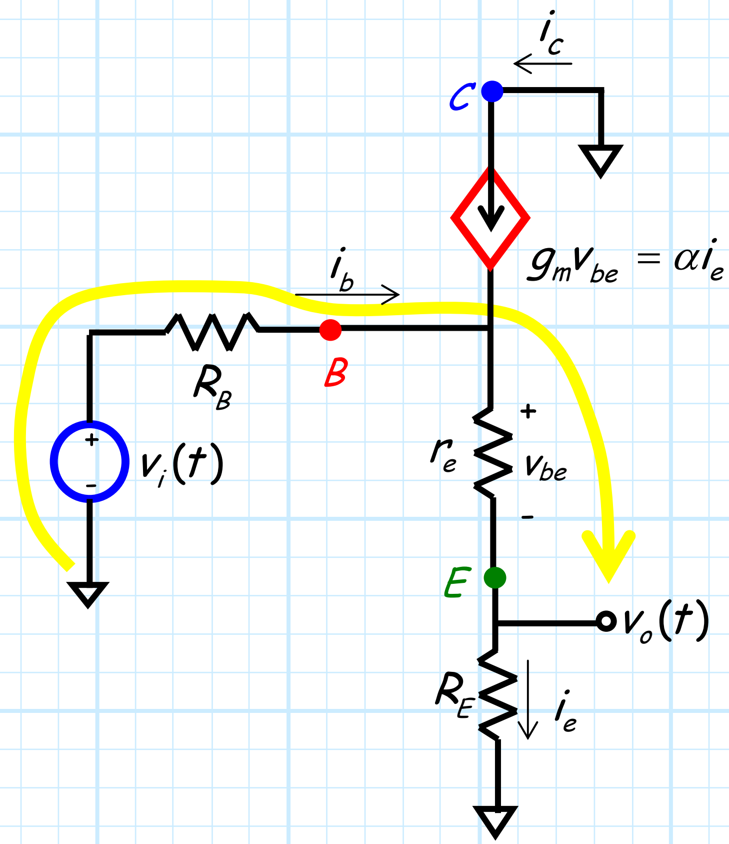
Let's determine the open-circuit voltage gain of this small-signal amplifier:

$$A_{vo} = \frac{v_o^{oc}}{v_i}$$

We therefore must determine the output voltage v_o in terms of input voltage v_i

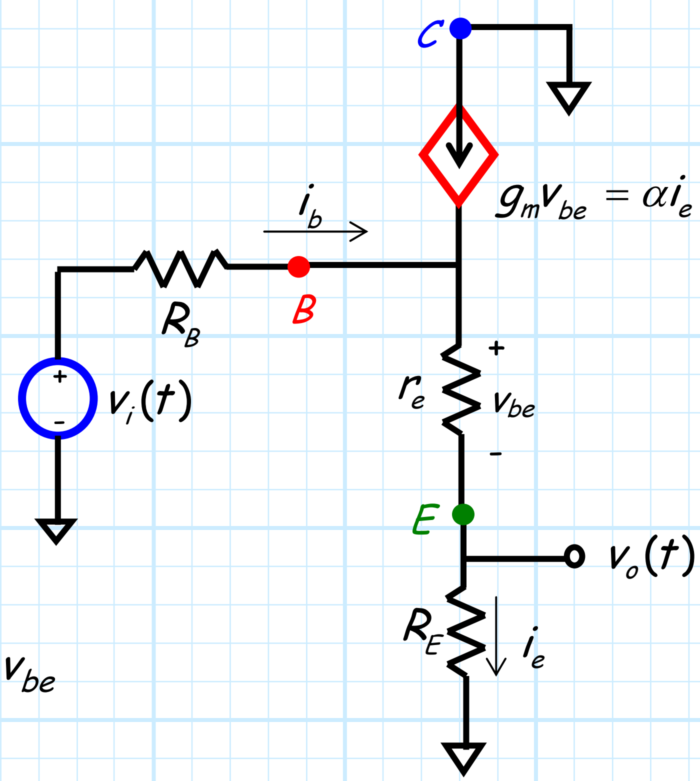
From **KVL**, we find that:

$$0 + v_i - R_B\, i_b - v_{be} = v_o$$



Let's apply KCL!

And from **KCL**, we find:



$$
\begin{aligned}
i_b &= i_e - i_c \\
&= i_e - g_m v_{be}
\end{aligned}
$$

Where from Ohm's Law:

$$i_e = \frac{v_o - 0}{R_E} = \frac{v_o}{R_E}$$

So:

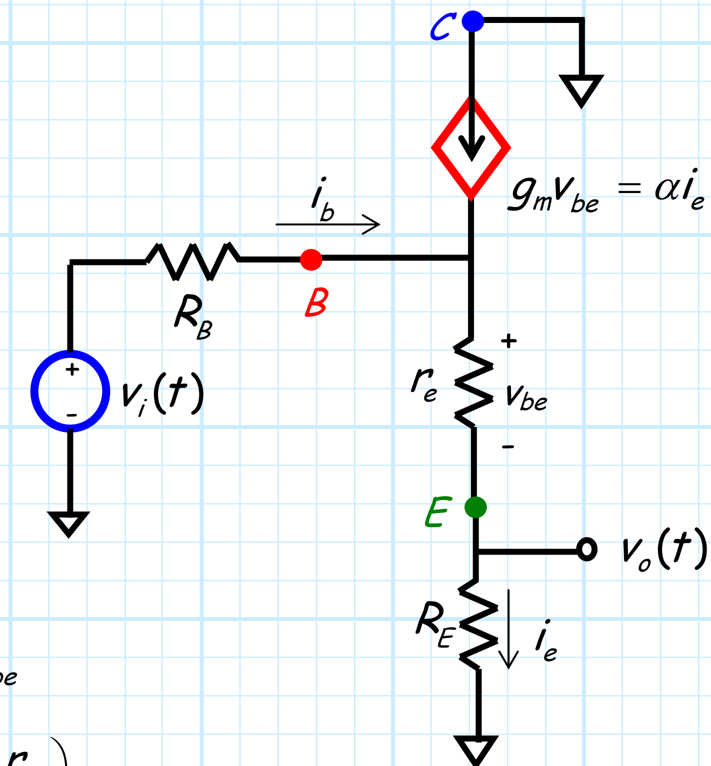
$$i_b = i_e - g_m v_{be} = \frac{v_o}{R_E} - g_m v_{be}$$

Inserting this into the **KVL** equation above:

$$
\begin{aligned}
v_o &= v_i - R_B\, i_b - v_{be} \\
&= v_i - R_B \left(\frac{v_o}{R_E} - g_m v_{be} \right) - v_{be} \\
&= v_i - \frac{R_B}{R_E} v_o + g_m R_B\, v_{be}
\end{aligned}
$$

Let's apply Ohm's Law!

Likewise using KCL and Ohm's Law:



$$i_e = \frac{v_{be}}{r_e} = \frac{v_o}{R_E}$$

Or rearranging:

$$v_{be} = \frac{r_e}{R_E} v_o$$

Inserting this result in the solution above:

$$\begin{aligned} v_o &= v_i - \left(\frac{R_B}{R_E}\right) v_o + g_m R_B \, v_{be} \\ &= v_i - \left(\frac{R_B}{R_E}\right) v_o + g_m R_B \left(\frac{r_e}{R_E}\right) v_o \\ &= v_i - \left(\frac{R_B}{R_E}\right) v_o + g_m r_e \left(\frac{R_B}{R_E}\right) v_o \\ &= v_i + \left(g_m r_e - 1\right)\left(\frac{R_B}{R_E}\right) v_o \end{aligned}$$

It's the gain—but look closer!

From this result we can determine the small-signal output voltage:

$$v_o = \left(1 + \left(1 - g_m r_e\right)\frac{R_B}{R_E}\right)^{-1} v_i$$

And so the open-circuit voltage gain is:

$$A_{vo} = \frac{v_o}{v_i} = \left(1 + \left(1 - g_m r_e\right)\frac{R_B}{R_E}\right)^{-1}$$

We now note that:

$$g_m\, r_e = \frac{V_T}{I_E}\frac{I_C}{V_T} = \frac{I_C}{I_E} = \alpha$$

Therefore:

$$1 - g_m\, r_e = 1 - \alpha = 1 - \frac{\beta}{\beta + 1} = \frac{1}{\beta + 1}$$

The output is no bigger than the input!

And so the gain becomes:

$$A_{vo} = \frac{v_o}{v_i} = \left(1 + \frac{1}{\beta+1}\frac{R_B}{R_E}\right)^{-1}$$

We note here that:

$$\frac{1}{\beta+1} \ll 1$$

We find therefore, that the **small-signal gain** of this common-collector amplifier is approximately:

$$\begin{aligned} A_{vo} &= \left(1 + \frac{1}{\beta+1}\frac{R_B}{R_E}\right)^{-1} \\ &\cong (1+0)^{-1} \\ &= 1.0 \end{aligned}$$

The gain is approximately **one**!

This doesn't seem to be useful

Q: *What!? The gain is equal to one? That's just **dog-gone** silly!*

*What good is an amplifier with a gain of **one**?*

A: Remember, the open-circuit voltage gain is just **one** of **three** fundamental amplifier parameters.

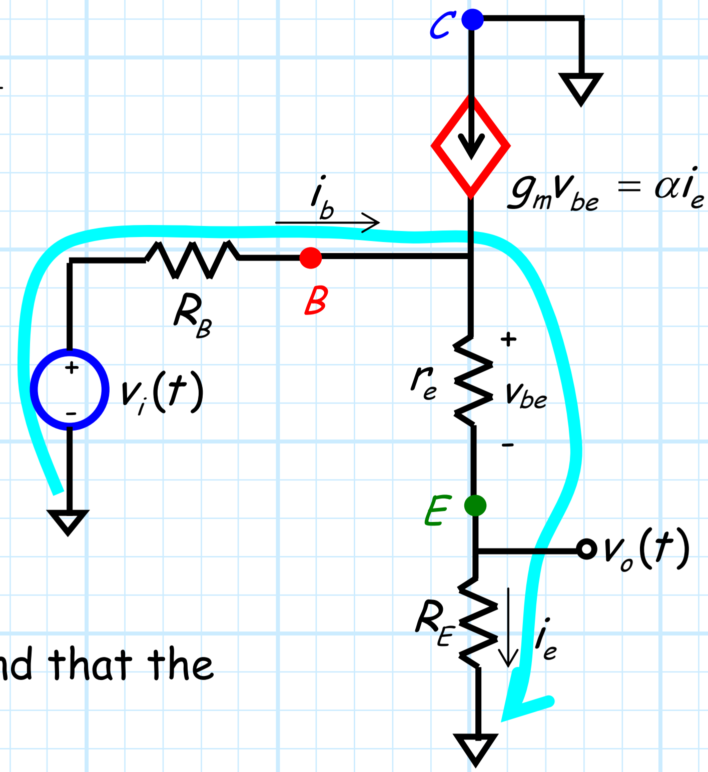
The other two are **input resistance** R_{in} and **output resistance** R_{out}.

First, let's examine the **input** resistance.

Let's determine the input resistance

Using the **small-signal circuit**, we find that:

$$R_{in} = \frac{v_i}{i_i} = \frac{v_i}{i_b}$$



Using **KVL**,

$$0 + v_i - R_B\, i_b - (r_e + R_E)\, i_e = 0$$

and adding the fact that $i_e = (\beta + 1)\, i_b$, we find that the small-signal **base** current is:

$$i_b = \frac{v_i}{R_B + (\beta + 1)(r_e + R_E)}$$

A large input resistance; it's a very good thing

Combining these equations, we find that the input resistance for **this** common-collector amplifier is:

$$R_{in} = \frac{v_i}{i_b} = R_B + (\beta + 1)(r_e + R_E)$$

Since beta is large, the input resistance is **typically large**—this is **good**!

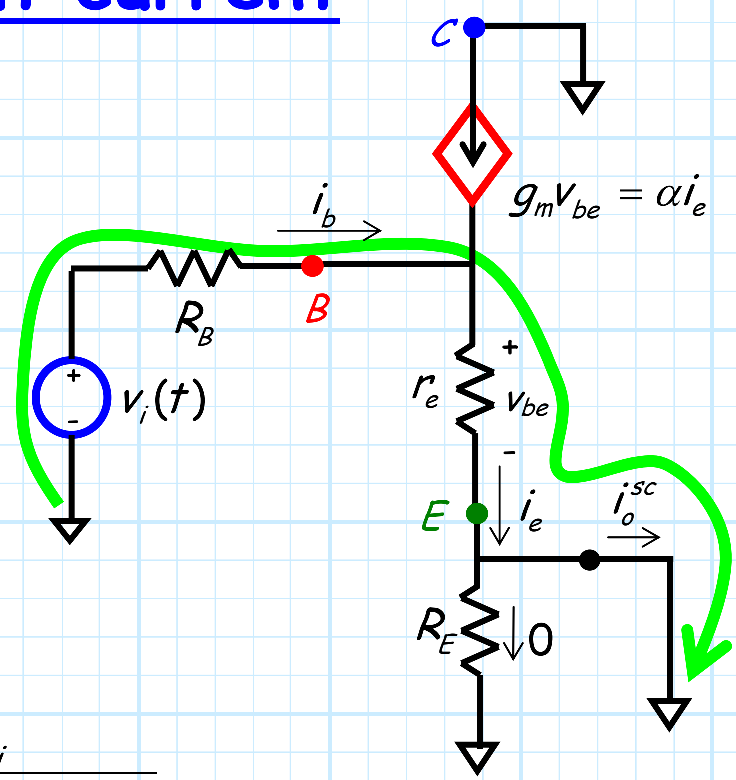
Now, let's consider the **output** resistance R_{out} of this particular common-collector amplifier.

Recall that the output resistance is defined as:

$$R_{out} = \frac{v_o^{oc}}{i_o^{sc}}$$

where v_o^{oc} is the **open-circuit output voltage** and i_o^{sc} is the **short-circuit output current**.

We must find the short circuit output current



Using **KVL**,

$$0 + v_i - R_B\, i_b - r_e\, i_e = 0$$

and adding the fact that $i_b = (\beta+1)^{-1}\, i_e$, we find that the small-signal **emitter** current is:

$$i_e = \frac{v_i}{R_B(\beta+1)^{-1} + r_e}$$

And from KCL, this emitter current is likewise the short circuit output current:

$$i_o^{sc} = i_e = \frac{v_i}{R_B(\beta+1)^{-1} + r_e}$$

A small output resistance; it's a very good thing as well

Of course, we already have determined that the open-circuit **output** voltage is approximately **equal** to the **input** voltage:

$$v_o^{oc} = v_i \qquad \text{(i.e., } A_{vo} \cong 1\text{)}$$

Therefore, we find that the **output** resistance will be:

$$R_{out} = \frac{v_o^{oc}}{i_o^{sc}} = R_B\left(\beta+1\right)^{-1} + r_e$$

Since the emitter resistance r_e is typically **small** (e.g., $r_e = 2.5\Omega$ if $I_E = 10.0mA$), and β is typically large, we find that the **output** resistance of this common-collector amplifier will typically be **small**!

The emitter follower is like a voltage follower—it's a buffer!

Let's **summarize** what we have learned about this **common-collector amplifier**:

1. The small-signal voltage **gain** is approximately equal to **one**.

2. The **input** resistance is typically very **large**.

3. The **output** resistance is typically very **small**.

*This is just like the op-amp **voltage follower** !*

The common-collector amplifier is alternatively referred to as an **emitter follower** (i.e., the output voltage follows the input voltage).

The emitter follower is a great output stage

The common-collector amplifier is typically used as an **output stage**, where it **isolates** a high gain **amplifier** with large output resistance (e.g. a **common emitter**) from an output **load** of small resistance (e.g. an audio speaker).