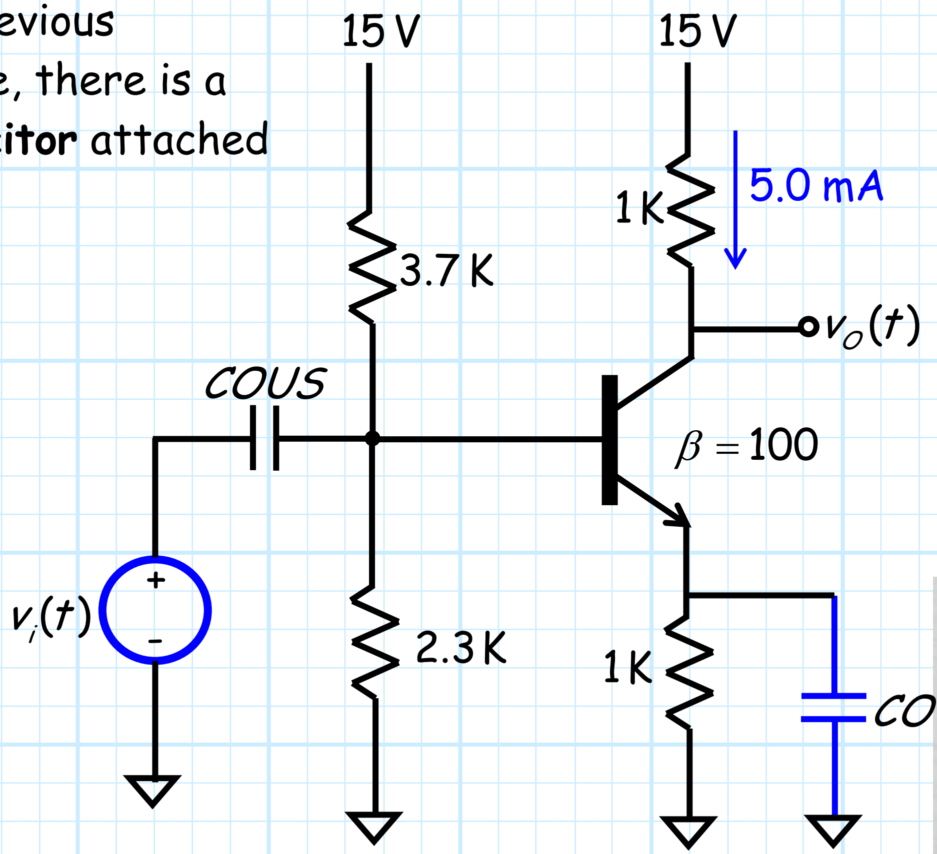
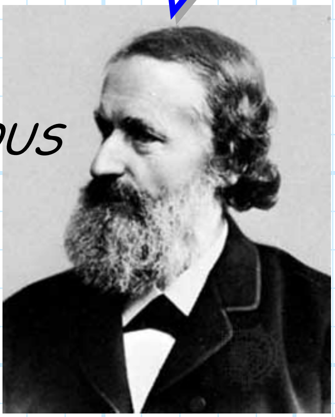
The Emitter Capacitor: What's up with that?

Note that in a previous amplifier example, there is a **mysterious capacitor** attached to the emitter:





Q: ***Why*** *is this big capacitor here? Is it really required?*

A: Let's do a **small-signal** analysis and see **why** we place this large capacitor at the emitter.

Let's analyze this amplifier!

Step 1 - *DC Analysis*

This is **already** completed! Recall that we **designed** the single supply DC bias circuit such that:

$$I_C = 5 \text{ mA}$$

and

$$V_{CE} = 5.0 > 0.7 \quad ✓$$

Step 2 - *Calculate the BJT small-signal parameters*

If we apply the **hybrid-**π model, we will require the small signal parameters:

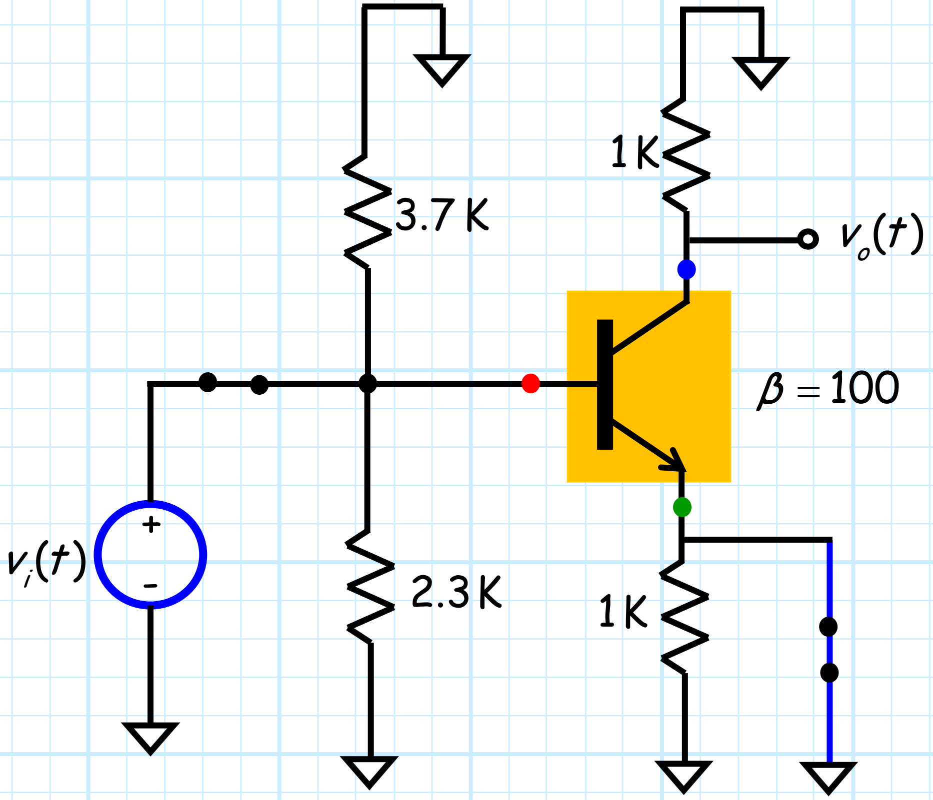
$$g_m = \frac{I_C}{V_T} = \frac{5 \text{ mA}}{0.025\text{V}} = 200 \text{ mA/V}$$

$$r_\pi = \frac{V_T}{I_B} = \frac{\beta V_T}{I_C} = \frac{100(0.025)}{5.0} = 0.5 \text{ K}$$

This is step 3…

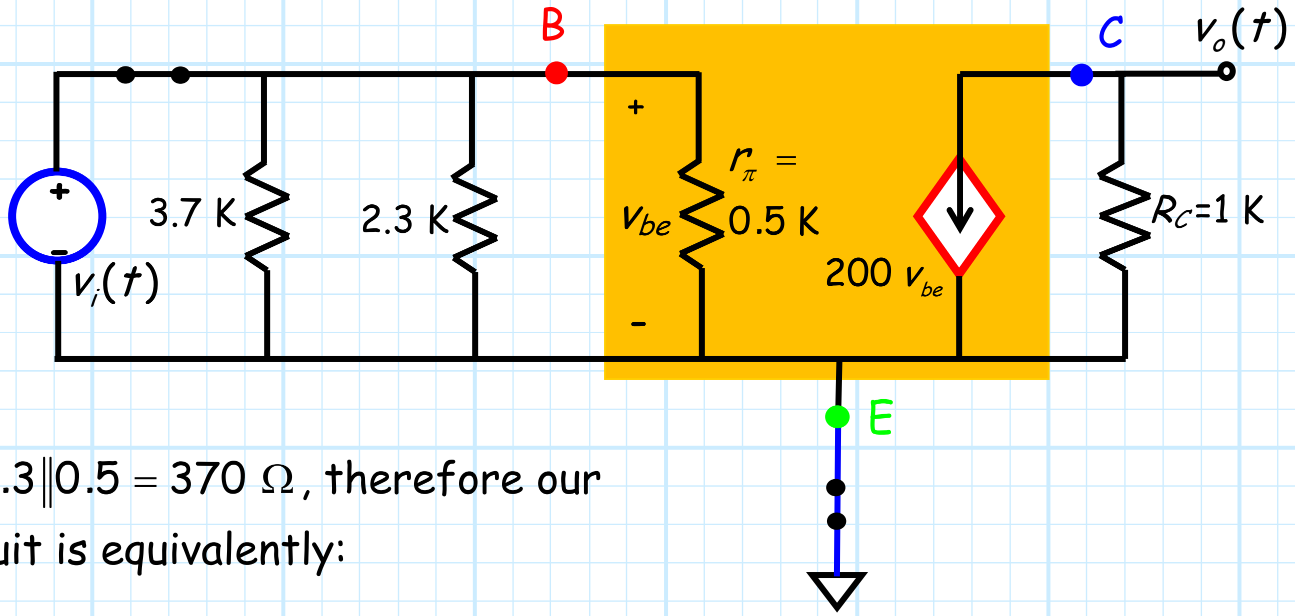
Steps 3 and 4 – *Replace the BJT with its small-signal equivalent circuit , and turn off all DC sources.*

Tuning off the DC sources, and replacing the **C**apacitors **O**f **U**nusual **S**ize with **short** circuits, we find that the circuit becomes:

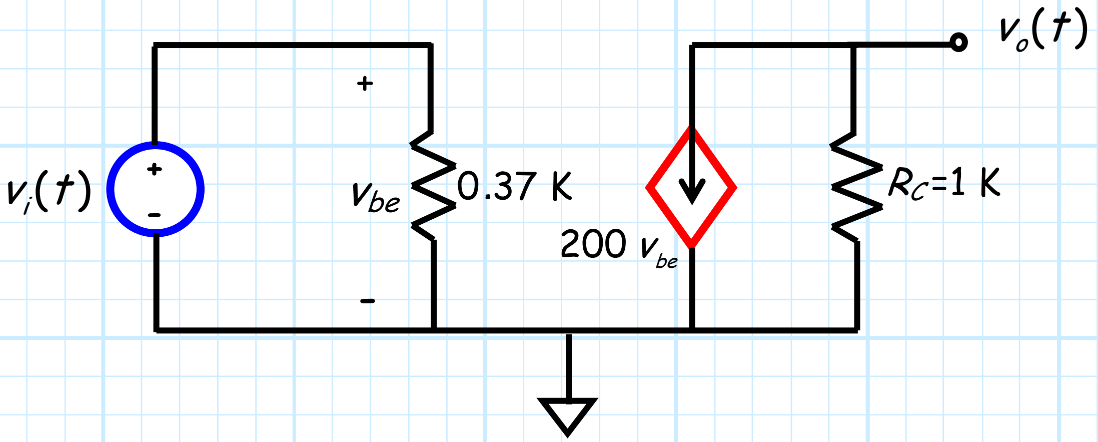


…and this is step 4

Now carefully replace the BJT with its small-signal model:



Note that $3.7 \| 2.3 \| 0.5 = 370\ \Omega$, therefore our small-signal circuit is equivalently:



A hefty gain

Step 5 - *Analyze the small-signal circuit.*

Since for **this** circuit $v_{be} = v_i$ and $v_o = -(1)200 v_{be}$, the open-circuit, small-signal **voltage gain** of this amplifier is:

$$A_{vo} = \frac{v_o}{v_i} = \frac{-200 v_{be}}{v_{be}} = -200$$

Likewise, we can find that the small-signal **input** and **output resistances** are:

$$R_{in} = 370\Omega$$

and

$$R_{out} = 1.0 \text{ K}$$

Note that the gain in this case is fairly **large**—46 dB.

Still, what's up with the capacitor?

Q: *I still don't understand why the* ***emitter capacitor*** *is required.*

Sure, our amplifier has large voltage ***gain****, but I don't see how a* ***capacitor*** *could be responsible for* ***that****.*

A: To see why the emitter capacitor is important, we need to compare these results to those obtained if the **emitter capacitor is removed**.

Note that if we **remove** the emitter capacitor, the first **two** steps of the small-signal analysis remains the **same**—the DC **operating point** is the same, and thus the small-signal **parameters** remain unchanged.

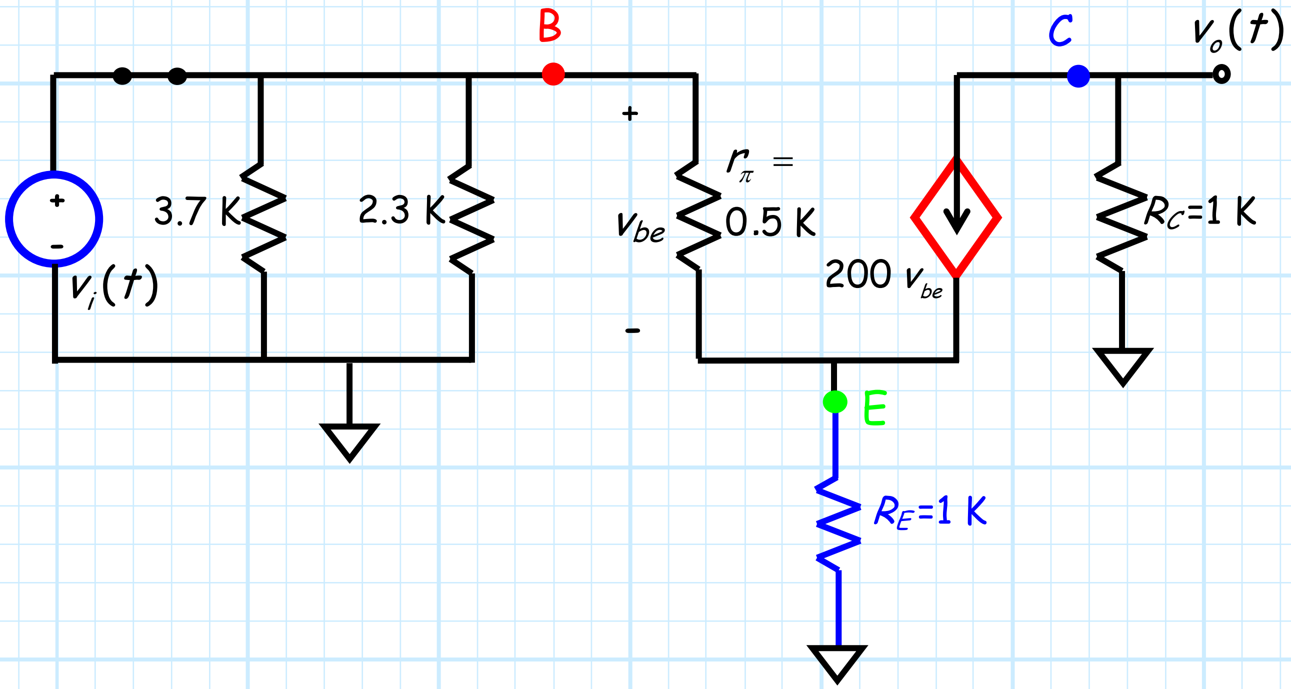
However, this does **not** mean that our resulting small signal **circuit** is left unchanged!

The emitter resistor is not "shorted out"!

- Recall that **large** capacitors (COUS) are approximated as *AC* **shorts** in the small-signal circuit.
- The emitter capacitor thus "shorts out" the emitter resistor in the small-signal circuit—the BJT **emitter** is connected to small-signal **ground**.
- If we remove the emitter capacitor, the emitter resistor is **no longer** shorted, and thus the BJT emitter is **no longer** connected to ground!

A horse of an entirely different color

The small-signal circuit in this case is:

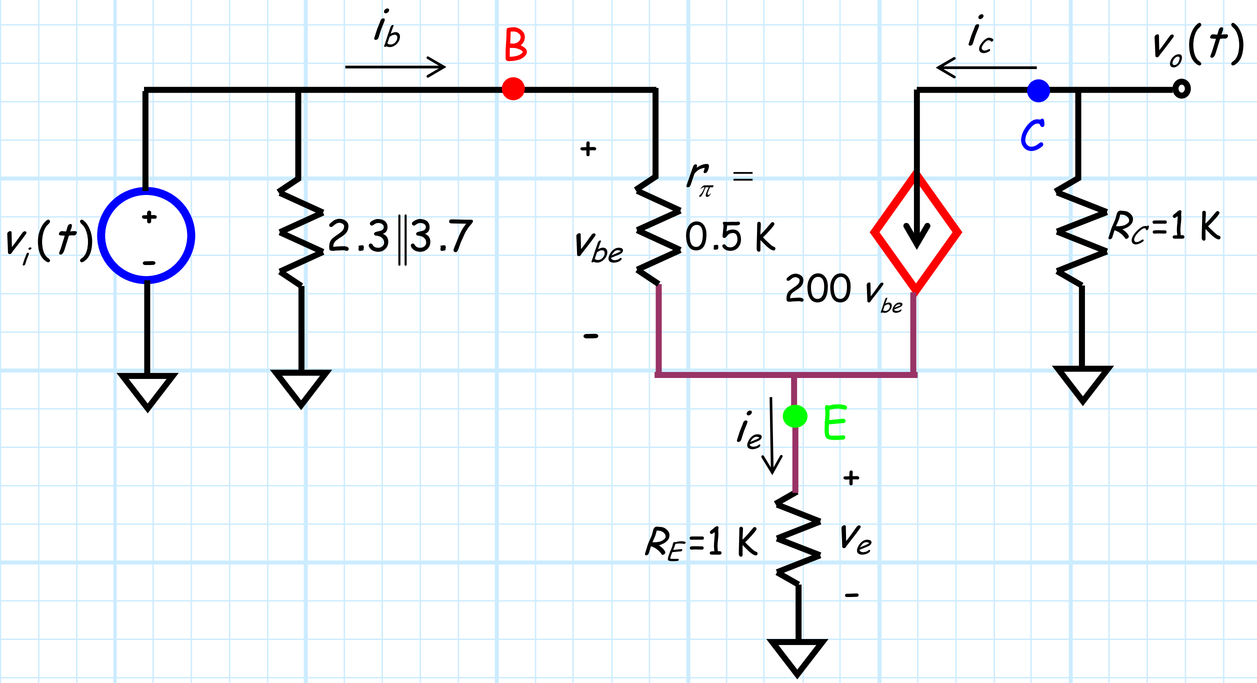


Note that the resistors $R_1 = 3.7$ K and $R_2 = 2.3$ K are **no longer** in parallel with base resistance $r_\pi = 0.5$ K!

As are result, we find that small signal voltage v_{be} is **not** equal to small signal input voltage v_i.

This circuit—it's harder

Note also that the collector resistor is **not** connected in parallel with the dependent current source!



Analyzing **this** small-signal circuit is not so easy!

We first need to determine the small signal **base-emitter** voltage v_{be} in terms of **input** voltage v_i.

Start with KCL

From **KCL**, we know that:

$$i_e = i_b + i_c$$

Where:

$$i_e = \frac{v_e}{R_E} = \frac{v_e}{1} = v_e$$

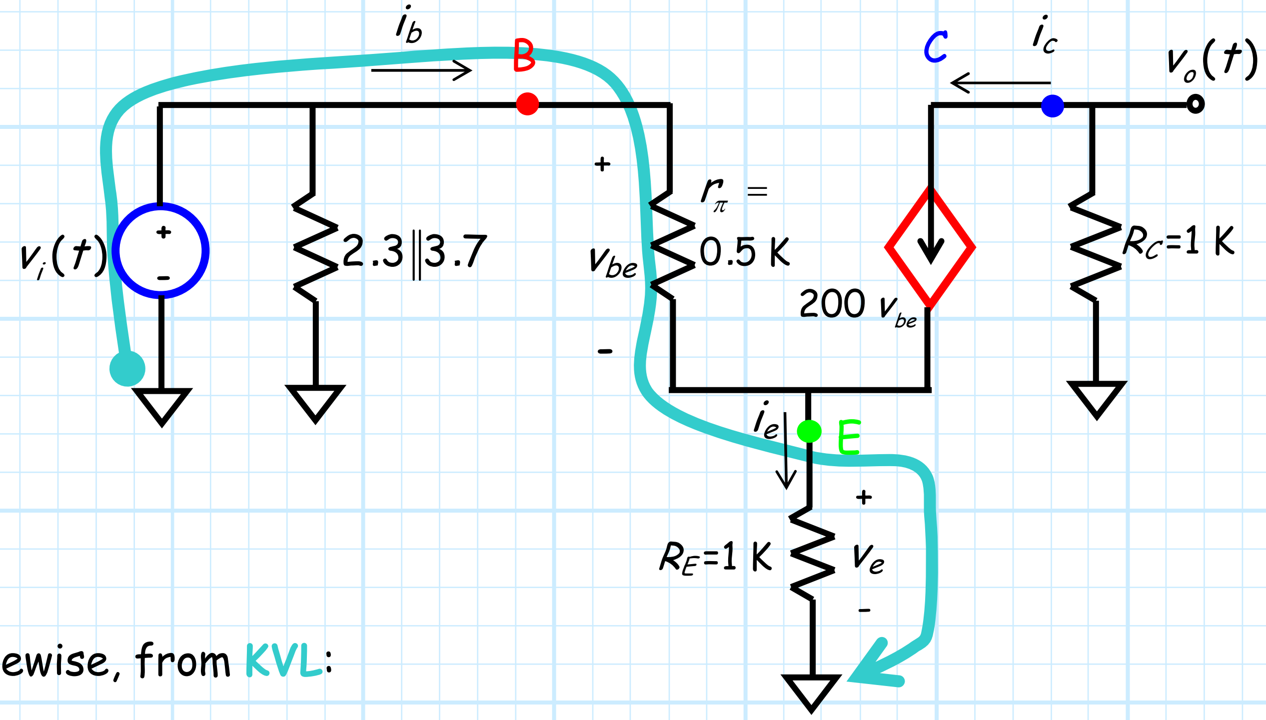
$$i_b = \frac{v_{be}}{r_\pi} = \frac{v_{be}}{0.5} = 2.0\, v_{be}$$

$$i_c = 200\, v_{be}$$

Therefore:

$$v_e = 2.0\, v_{be} + 200\, v_{be} = 202\, v_{be}$$

And now for KVL



Likewise, from **KVL**:

$$0 + v_i - v_{be} - v_e = 0$$

$$\Rightarrow \quad v_{be} = v_i - v_e$$

This is NOT voltage division!

Inserting this into the first **KCL** result:

$$\begin{aligned} v_e &= 202\, v_{be} \\ &= 202\, v_i - 202\, v_e \end{aligned}$$

And now solving for small-signal emitter voltage:

$$v_e = \frac{202}{203} v_i$$

Note that the small-signal base voltage is **not** related to the small signal input voltage by **voltage division**, i.e.:

$$v_e \neq \frac{R_E}{r_\pi + R_E} v_i = \frac{1}{1.5} v_i \quad !!!$$

v_{be} is really small!

Therefore, we can **finally** determine v_{be} in terms of input voltage v_i:

$$v_{be} = v_i - v_e = v_i - \frac{202}{203} v_i = \left(1 - \frac{202}{203}\right) v_i = \frac{v_i}{203}$$

Note then that not only is $v_{BE} \neq v_i$, the small-signal base-emitter voltage is **much smaller** than input voltage v_i!

This of course is evident from the relationship:

$$v_e = \frac{202}{203} v_b = \frac{202}{203} v_i$$

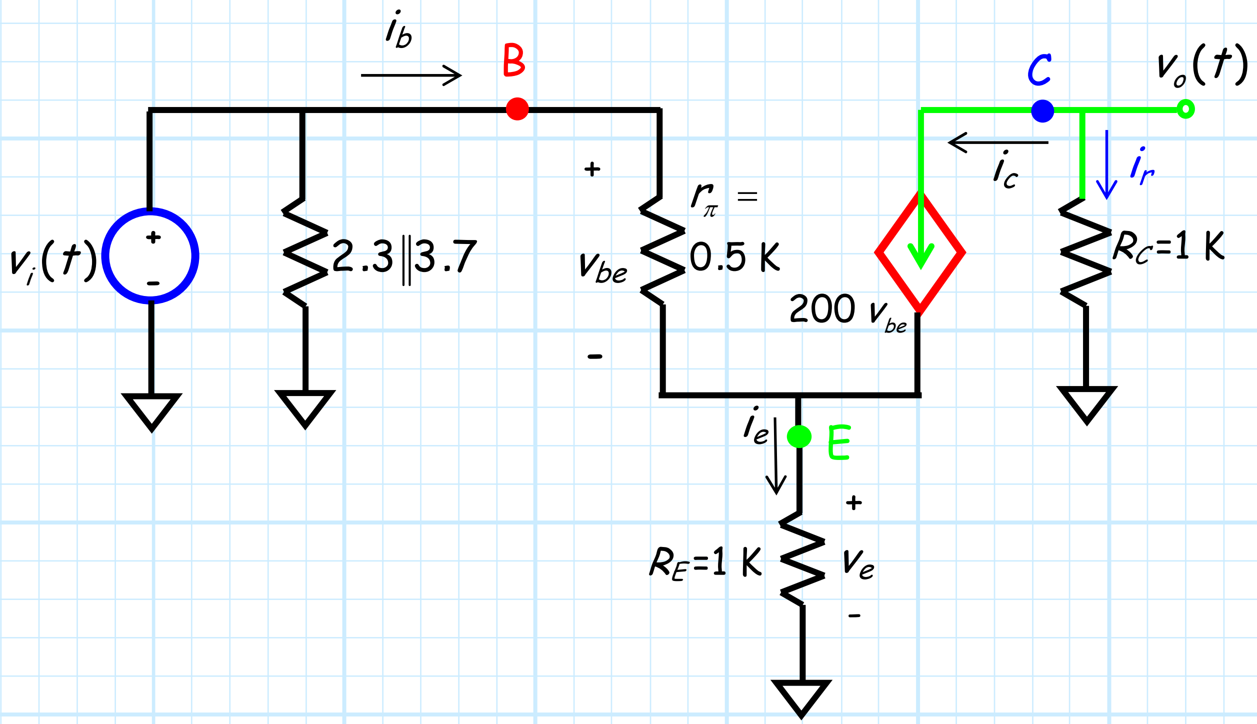
which states that the emitter voltage is **approximately equal** to the base (input) voltage v_b (v_i).

Now for the output voltage

This result will have a **profound** impact on amplifier performance!

To determine the output voltage, we begin with **KCL**:

$$i_r = -i_c = -200\, v_{be}$$



What a wimpy gain

Now applying Ohm's Law to R_C:

$$\frac{v_o - 0}{R_C} = \frac{v_o}{1} = i_r = -200\, v_{be} \qquad \Rightarrow \qquad v_o = -200\, v_{be}$$

But recall that:

$$v_{be} = \frac{v_i}{203}$$

so we find that the small-signal **output voltage** is:

$$v_o = -200\, v_{be} = -\frac{200}{203}\, v_i$$

And thus the open-circuit **voltage gain** of this amplifier is:

$$A_{vo} = \frac{v_o}{v_i} = -\frac{200}{203} \approx -1.0$$

See, the emitter capacitor is important

Yikes! Removing the emitter capacitor cause the voltage gain to change from –200 (i.e., 46 dB) to approximately –1.0 (i.e., 0dB)—a ***46 dB reduction!***

That emitter capacitor makes a **big** difference!

We can likewise finish the analysis and find that the small-signal input and output **resistances** are:

$$R_{in} \approx R_1 \| R_2 = 3.7 \| 2.3 = 1.42 \text{ K}$$

$$R_{out} = 1.0\text{K}$$

Note that **input** resistance actually **improved** in this case, increasing in value from 370 Ω to 1.42 KΩ.

However, the decrease in voltage gain makes this amplifier (without a emitter capacitor) almost completely **useless**.

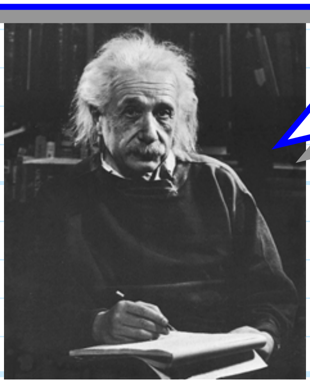
He only knows this because your TA explained it to him

The amplifier in this case (with the emitter capacitor) is an example of a design known as a ***common-emitter*** *amplifier.*

There are an infinite number of common-emitter designs, but they all share one thing in common—the ***emitter*** *of the BJT is* ***always*** *connected directly to* ***small-signal ground****.*

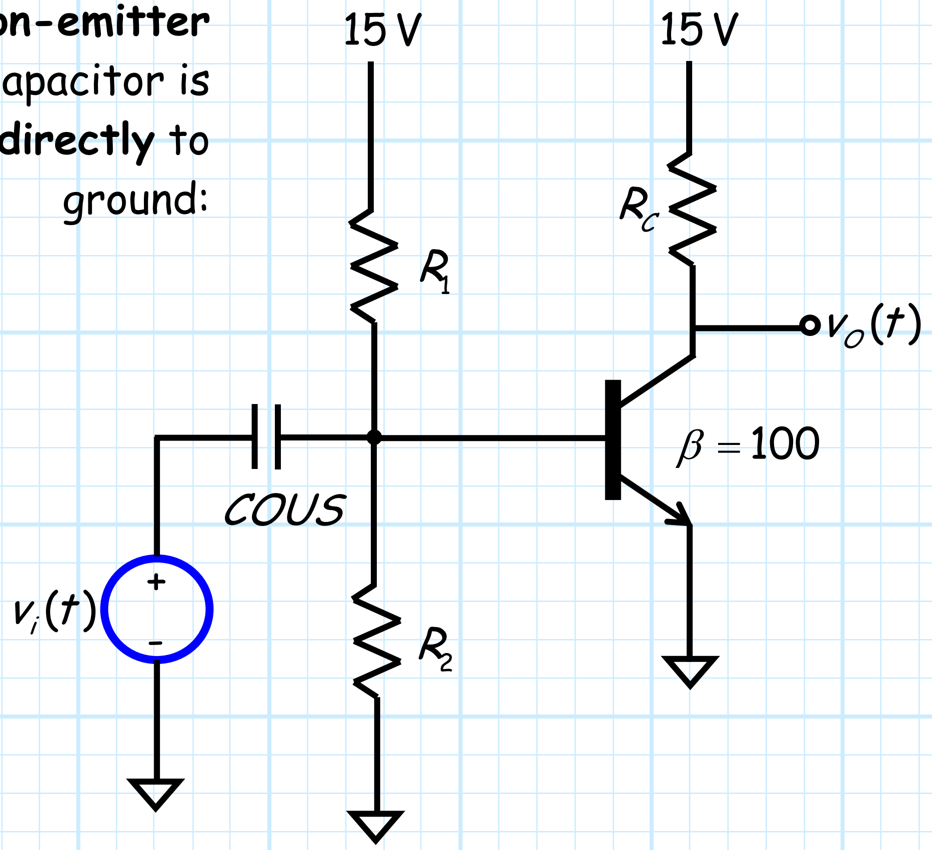
Common-emitter amplifier, such as the one examined here, typically result in ***large*** *small-signal* ***voltage gain*** *(this is* ***good****!).*

However, ***another*** *characteristic of common emitter amplifiers is a typically* ***low*** *small-signal* ***input*** *resistance and high small-signal output resistance(this is* ***bad****!).*



Make sure you can answer this question

One way to construct a **common-emitter** amplifier **without** using an emitter capacitor is simply to connect the BJT emitter **directly** to ground:



In this case, the emitter is at **both** *AC* (small-signal) ground and DC ground!

Q: *Why is this common-emitter design* ***seldom*** *used??*

A: