BJT Small-Signal Analysis Steps

Complete **each** of these steps if you choose to correctly complete a BJT Amplifier **small-signal** analysis.

Step 1: Complete a **D.C. Analysis**

Turn **off** all **small-signal** sources, and then complete a circuit analysis with the remaining **D.C. sources** only.

* Complete this DC analysis exactly, precisely, the same way you performed the DC analysis in section 5.4.

That is, you assume (the active mode), enforce, analyze, and **check (do not forget to check!)**.

* Note that you enforce and check exactly, precisely the same the same equalities and inequalities as discussed in section 5.4 (e.g., $V_{BE} = 0.7$ V , $V_{CB} > 0$).

You must remember this

* Remember, if we "turn off" a **voltage** source (e.g.,$v_i(t)=0$), it becomes a **short** circuit.

* However, if we "turn off" a **current** source (e.g., $i_i(t)=0$), it becomes an **open** circuit!

* Small-signal amplifiers frequently employ Capacitors of Unusual Sizes (**COUS**), we'll discuss why later.

Remember, the impedance of a capacitor at **DC** is infinity—a DC **open** circuit.

The goals of DC analysis—and don't forget to CHECK

The **goal** of this DC analysis is to determine:

1) **One** of the DC BJT currents (I_B, I_C, I_E) for **each** BJT.

2) Either the voltage V_{CB} or V_{CE} for **each** BJT.

You do not **necessarily** need to determine any other DC currents or voltages within the amplifier circuit!

Once you have found these values, you can **CHECK** your active assumption, and then move on to **step 2**.

The DC bias terms are required to determine our small-signal parameters

Q: *I'm **perplexed**. I was eagerly anticipating the steps for **small-signal** analysis, yet you're saying we should complete a **DC analysis**.*

***Why** are we doing this—**why** do we care what any of the **DC** voltages and currents are?*

A: Remember, all of the **small-signal** BJT parameters (e.g., g_m, r_π, r_e, r_o) are dependent on **D.C.** values (e.g., I_C, I_B, I_E).

In other words, we must **first** determine the operating (i.e., **bias**) point of the transistor in order to determine its **small-signal** performance!

Now for step 2

Step 2: Calculate the **small-signal circuit parameters** for each BJT.

Recall that we now understand **4** small-signal parameters:

$$g_m = \frac{I_C}{V_T} \qquad r_\pi = \frac{V_T}{I_B} \qquad r_e = \frac{V_T}{I_E} \qquad r_o = \frac{V_A}{I_C}$$

Q: *Yikes! Do we need to calculate **all** four?*

A: Typically no. You need to calculate **only** the small signal parameters required by the small-signal circuit **model** that you plan to implement.

For example, if you plan to:

a) use the **Hybrid-**Π model, you must determine g_m and r_π.

b) use the **T-model**, you must determine g_m and r_e.

c) account for the **Early effect** (in either model) you must determine r_o.

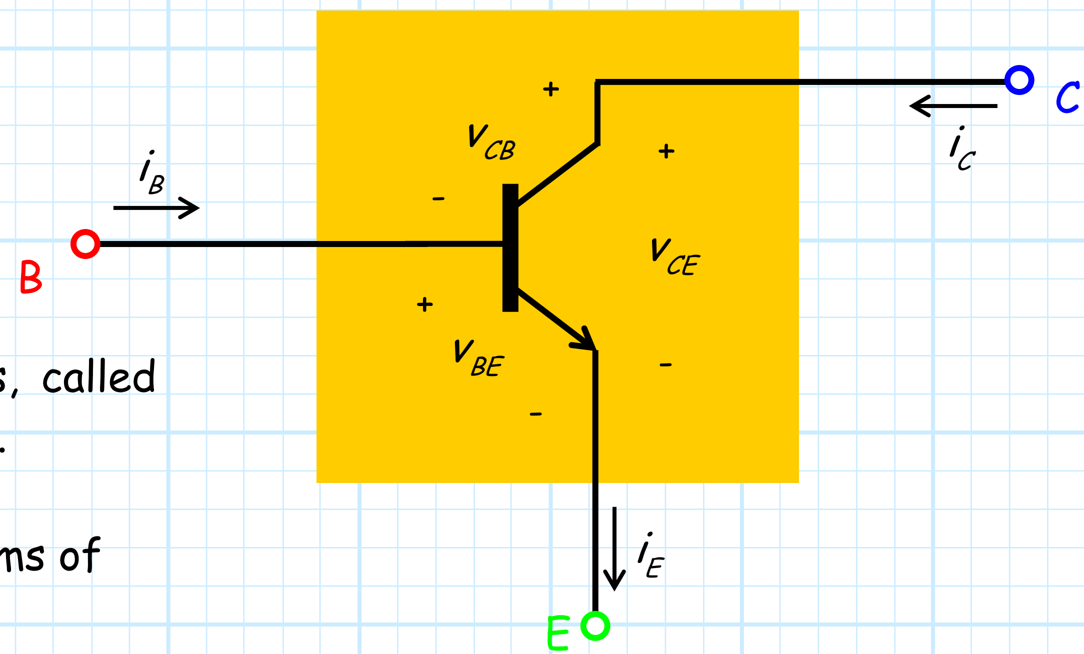
The four "Pees"

Step 3: Carefully replace all BJTs with their **small-signal circuit model.**

This step often gives students **fits**!

However, it is actually a **very simple** and straight-forward step.

It does require four important things from the student—**patience**, **precision**, **persistence** and **professionalism**!



First, note that a **BJT** is:

A device with **three** terminals, called the base, collector, and emitter.

Its behavior is described in terms of currents i_B, i_C, i_E and voltages v_{BE}, v_{CB}, v_{CE}.

They're both so different—not!

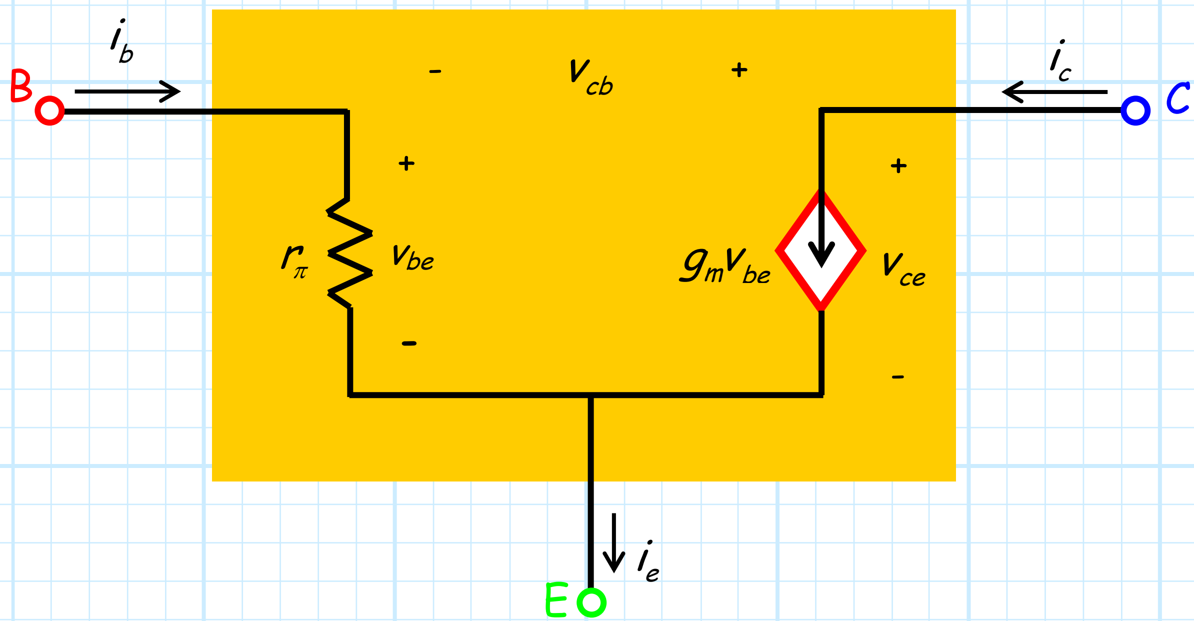
Now, **contrast** the BJT with its small-signal circuit model.

A BJT small-signal circuit model is:

A device with **three** terminals, called the base, collector, and emitter.

Its behavior is described in terms of currents i_b, i_c, i_e and voltages v_{be}, v_{cb}, v_{ce} .

Exactly the **same**—what a coincidence!



Am I making this clear?

Therefore, replacing a BJT with its small-signal circuit model is very simple—you simply change the stuff **within** the orange box!

Note the parts of the circuit **external** to the orange box do not change! In other words:

1) **every** device attached to the BJT **base** is attached in **precisely** the same way to the base terminal of the **circuit model**.

2) **every** device attached to the BJT **collector** is attached in **precisely** the same way to the collector terminal of the **circuit mode**

3) **every** device attached to the BJT **emitter** is attached in **precisely** the same way to the emitter terminal of the **circuit model**.

4) **every** external voltage or current (e.g., v_i, v_o, i_R) is defined in **precisely** the same way both before and after the BJT is replaced with its circuit model is (e.g., if the output voltage is the collector voltage in the BJT circuit, then the output voltage is **still** the collector voltage in the small-signal circuit!).

It's just like working in the lab

You can think of replacing a BJT with its small-signal circuit model as a **laboratory** operation:

1) Disconnect the red wire (base) of the BJT from the circuit and then "solder" the red wire (base) of the circuit model to the same point in the circuit.

2) Disconnect the blue wire (collector) of the BJT from the circuit and then "solder" the blue wire (collector) of the circuit model to the same point in the circuit.

3) Disconnect the green wire (emitter) of the BJT from the circuit and then "solder" the green wire (emitter) of the circuit model to the same point in the circuit.

This is superposition—turn off the DC sources!

Step 4: Set all **D.C. sources** to zero.

Remember:

A zero-**voltage** DC source is a **short circuit**.

A zero-**current** DC source is an **open circuit**.

The schematic in now in front of you is called the **small-signal circuit**. Note that it is **missing** two things—**DC sources** and bipolar junction **transistors**!

* Note that steps three and four are **reversible**.

You could turn off the DC sources **first**, and then replace all BJTs with their small-signal models—the resulting small-signal circuit will be the **same**!

* You will find that the small-signal circuit schematic can often be greatly **simplified**.

Many things will be connected to ground!

Once the DC voltage sources are turned **off**, you will find that the terminals of many devices are **connected to ground**.

* Remember, all terminals connected to ground are **also** connected to each other!

For **example**, if the emitter terminal is connected to ground, and one terminal of a resistor is connected to ground, then that resistor terminal is connected to the emitter!

* As a result, you often find that resistors in different parts of the circuit are actually connected in **parallel**, and thus can be **combined** to simplify the circuit schematic!

* Finally, note that the AC impedance of a **COUS** (i.e., $|Z_c| = 1/\omega C$) is small for all but the lowest frequencies ω.

If this impedance is smaller than the other circuit elements (e.g., < 10Ω), we can view the impedance as **approximately zero**, and thus replace the **large** capacitor with a (AC) **short**!

Organize and simplify or perish!

Organizing and **simplifying** the small-signal circuit will pay **big** rewards in the next step, when we **analyze** the small-signal circuit.

However, correctly organizing and simplifying the small-signal circuit requires **patience**, **precision**, **persistence** and **professionalism**.

Students frequently run into problems when they try to accomplish **all** the goals (i.e., replace the BJT with its small-signal model, turn off DC sources, simplify, organize) in **one** big step!

*Steps 3 and 4 are **not** rocket science!*

*Failure to correctly determine the simplified small-signal circuit is **almost always** attributable to an engineer's patience, precision and/or persistence (or, more specifically, the lack of same).*

This is a EECS 211 problem, and *only* a 211 problem

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

We now can **analyze** the small-signal **circuit** to find all small-signal **voltages** and **currents**.

* For small-signal **amplifiers**, we typically attempt to find the small-signal output voltage v_o in terms of the small-signal input voltage v_i.

From this result, we can find the **voltage gain** of the amplifier.

* Note that this analysis requires **only** the knowledge you acquired in **EECS 211**!

The small-signal circuit will consist **entirely** of resistors and (small-signal) voltage/current sources.

These are **precisely** the same resistors and sources that you learned about in EECS 211. You analyze them in **precisely** the same way.

Trust me, this works!

* Do **not** attempt to insert any BJT knowledge into your small-signal circuit analysis—there are **no** BJTs in a small-signal circuit!!!!!

* Remember, the BJT circuit model contains **all** of our BJT small-signal knowledge, we **do** not—indeed **must** not—add any more information to the analysis.

You must **trust** completely the BJT small-circuit model. It **will** give you the correct answer!