6.301 Solid State Circuits

Recitation 1: Transistor Biasing and Thoughts on Design
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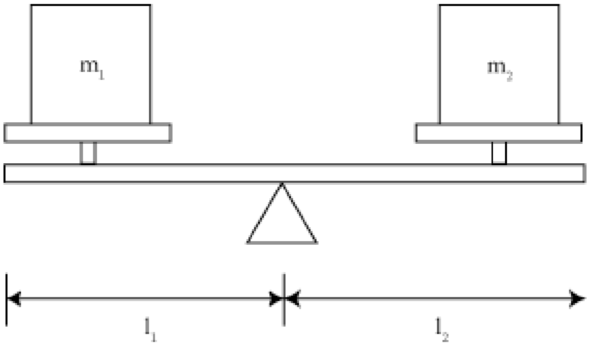
This course is about circuit design. Before we plunge in, let's take a conceptual step back and think about what we mean by "design" in an engineering sense.

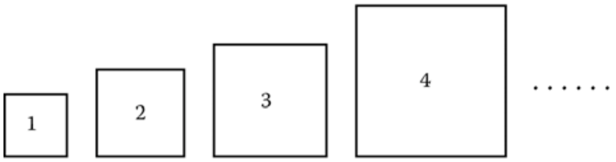
Broadly speaking, science gives us the laws of nature, and detailed descriptions of physical structures. Whenever possible, these laws and descriptions are specified mathematically.

In engineering design, we make use of our knowledge of nature's laws to build useful machines.

A simple balance provides a mechanical example of what we do when we design a machine. Suppose you were given a balance:



And a collection of weights:



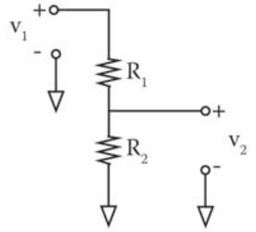
CLASS EXERCISE:

1) Using the balance and weights, come up with a mechanical adder.
2) Design a mechanical multiplier.

(Workspace)

With electronic circuits, of course, the particular laws we employ are different. But the principle is the same:

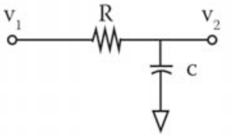
Ohm's Law ⇒



Resistive Voltage Divider

$$V_2 = \frac{R_2}{R_1 + R_2} V_1$$

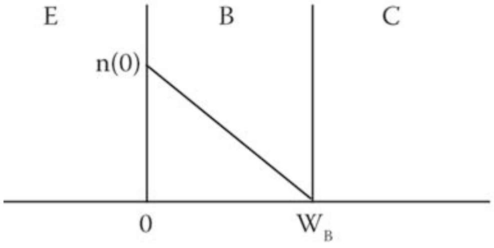
IV Relationships for
resistors and capacitors ⇒



Low-Pass Filter

$$\frac{V_2(s)}{V_1(s)} = \frac{1}{RCs + 1}$$

Statistical Mechanics ⇒



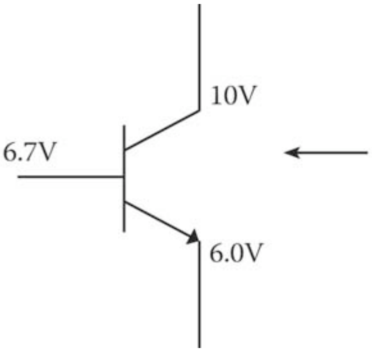
Bipolar Transistor

The list of examples is endless. Look for them!

Now let's move on to the matter of biasing a transistor circuit. What does this mean, and what constitutes a good biasing solution?

(1) What does it mean to bias a bipolar transistor?

- Establish the collector current at a desirable level. I_C determines so many of the characteristics that concern us: g_m, r_π, r_0, c_b.
- Establish terminal voltages that put the transistor in a "good" region of operation



Collector can swing down by ~ 4V before BC junction is forward biased.

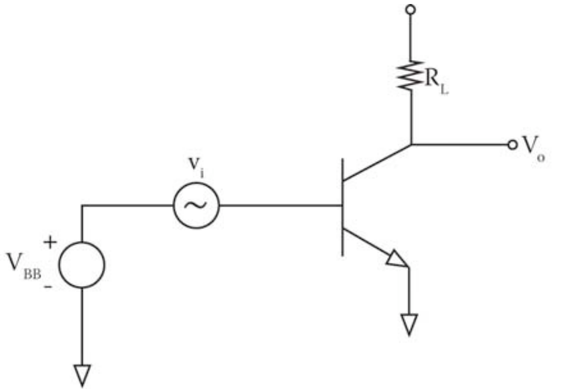
(2) What is a "good" bias solution?

- Does not rely on characteristics of the transistor to establish I_C. Transistor characteristics vary a great deal from device to device.

↳ Do not count on β; do not count on I_S.

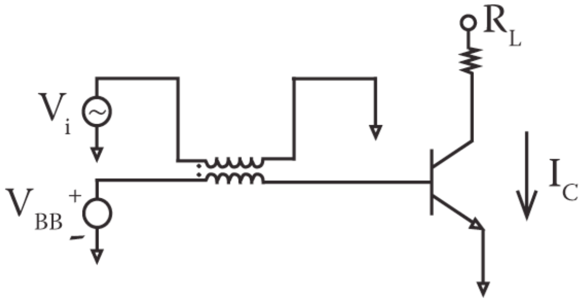
Let's look at some examples.

<u>Base Voltage-Source Biasing</u>



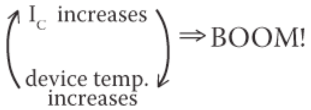
$$I_C = I_S \exp\left[\frac{V_{BB}}{V_T}\right]$$

Don't do this. The floating input source is annoying, but not, by itself, a reason to doom this technique. You could use a transformer, for example:

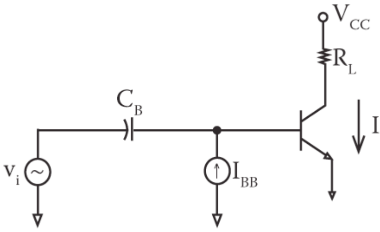


But still, I_C in this case depends linearly on I_S, which routinely varies over a wide range. The bias current is extremely sensitive to changes in V_{BB}. Worst of all, thermal runaway:

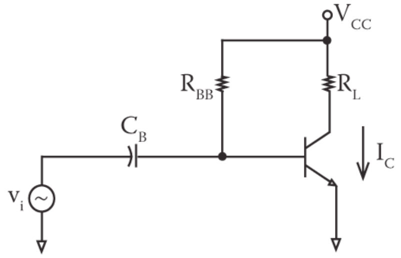
$$\left.\frac{\partial V_{BE}}{\partial T}\right|_{I_C} = -2mV/°C \Rightarrow$$



Base Current Biasing



OR

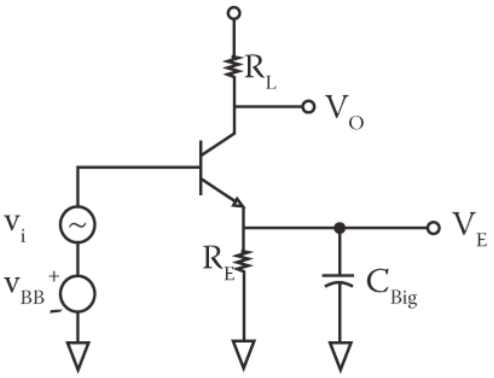


$$I_C = \beta_F I_{BB}$$

$$I_C = \beta_F \left(\frac{V_{CC} - V_{BE}}{R_{BB}} \right)$$

Problem: β_F can vary a lot (100-400 common)

Base Voltage Biasing



$$I_C = \frac{V_{BB} - V_{BE}}{R_E} = \frac{V_E}{R_E}$$

Okay! Still have that floating input voltage, but at least there's no β dependence. Let's examine further:

$$I_C = \frac{1}{R_E} V_E$$

$$\Delta I_C = \frac{1}{R_E} \Delta V_E$$

$$\frac{\Delta I_C}{I_C} = \frac{\cancel{R_E}}{V_E} \cdot \frac{\Delta V_E}{R_E} = \frac{\Delta V_E}{V_E}$$

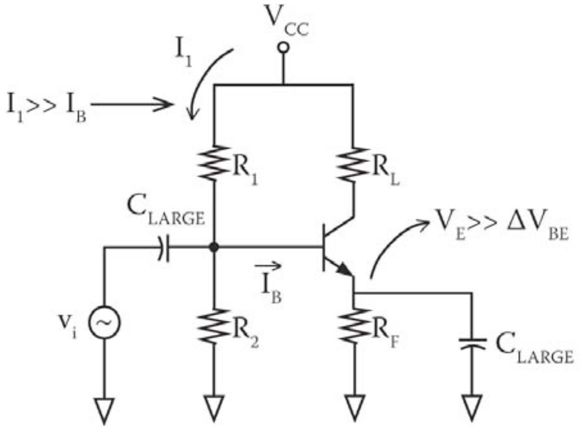
But with V_{BB} fixed, ΔV_E is due entirely to process variation in V_{BE}:

$$\frac{\Delta I_C}{I_C} = \frac{\Delta V_{BE}}{V_E}$$

→ We can limit $\frac{\Delta I_C}{I_C}$ by making V_E large compared to ΔV_{BE}. Typical ΔV_{BE}'s are $\pm 100 mV$.

<u>Remember this result.</u>

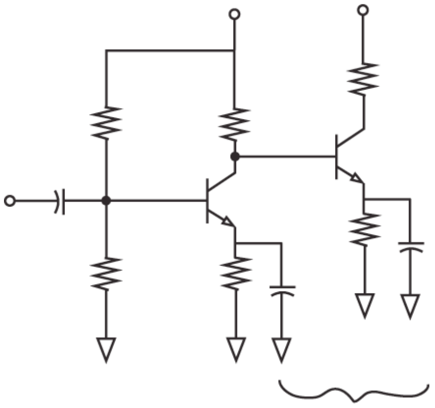
<u>Three-resistor biasing</u>



The way we often do things. See text for analysis, but note that $V_E >> \Delta V_{BB}$ and $I_1 >> I_B$ make for a robust biasing scheme.

Direct-Coupled Stages

Can save you some resistors and capacitors. Consider:



Biasing easy for second stage.

Finally, some results that you will need for the lab. Datasheets do not give hybrid-π model parameters directly. Sometimes they use something called h-parameters. Here's a guide to translation:

Output Capacitance: $C_{0b0} = C_{\mu}$

Input Capacitance: $C_{ib0} = C_{je}$

Input Impedance: $h_{ie} = \frac{v_i}{i_i} = r_{\pi}$

Reverse Voltage Gain: $h_{re} = \frac{v_i}{v_0} = \frac{r_{\pi}}{r_{\mu}}$

Forward Current Gain: $h_{fe} = \frac{i_0}{i_i} = \beta_0$

Output Admittance: $h_{0e} = \frac{i_0}{v_0} = \frac{2}{r_0}$

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