431/531 Class Notes 6

Following our discussion last time of the basic transistor switch and emitter follower, we will likewise introduce the basic relations for two other transistor circuit configurations: the current source and the common-emitter amplifier. We will then return to the issue of input and output impedance so that we can build realistic circuits using these configurations.

5.4 Transistor Current Source

Figure 20 illustrates the basic configuration for a single-transistor current source. $V_{\rm CC}$ is a constant positive voltage from a DC power supply. Hence, the base voltage V_B is also a constant, with $V_B = V_{\rm CC} R_2/(R_1 + R_2)$. R_L represents a load which we intend to power with a current which is approximately independent of the specific value of R_L.

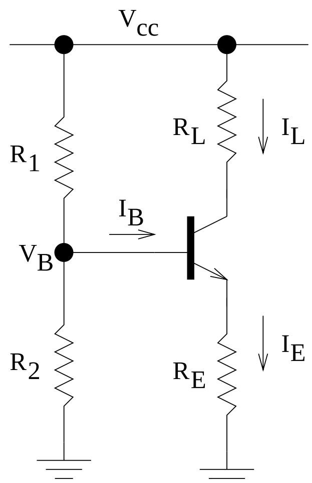

Figure 20: Basic transistor current source.

When the transistor is on, we have $I_E = (\beta+1)I_B$. In addition, we have $V_E = V_B - 0.6$; and $V_E = I_E R_E = (\beta + 1)I_B R_E$. Solving for I_B in this last equation gives $I_B = V_E/((\beta + 1)R_E)$. We can combine these to solve for the current which passes through R_L:

$$I_L = I_C = \beta I_B = \beta \frac{V_E}{(\beta + 1)R_E} = \frac{\beta}{\beta + 1} \frac{V_B - 0.6}{R_E} \approx \frac{V_B - 0.6}{R_E} \tag{25}$$

Hence, we see that indeed I_L is independent of R_L.

Of course, there are limitations to the range of R_L for which the current source behavior is reasonable. Recall that the transistor will shut down if $V_B \leq V_E$ or if $V_{\rm CE}$ is less than ≈ 0.2 V. These criteria determine the *compliance* of the current source, that is its useful operating range. So, for example, if we have $V_{\rm CC} = 15$ V and $V_B = 5$ V in our circuit above, then $V_E = 5 - 0.6 = 4.4$ V, and the range of compliance for the collector voltage V_C will be approximately 4.6 V to 15 V.

5.5 Common-emitter Amplifier

Figure 21 represents the basic configuration of the common-emitter amplifier. To determine the output for this circuit, we assume at this point that the input is a sum of a DC offset voltage V_0 and a time-varying signal $v_{\rm in}$, as discussed last time. (In the next section we will discuss how to achieve these.) V_0 provides the transistor "bias", so that $V_B > V_E$, and the signal of interest is $v_{\rm in}$.

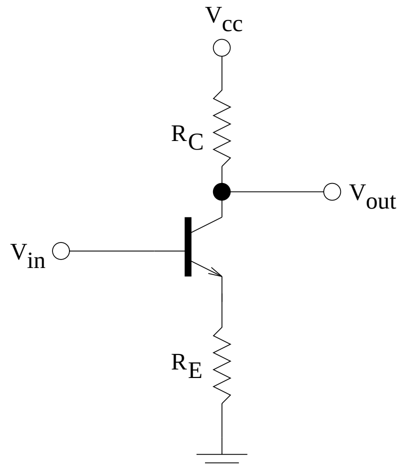

Figure 21: Basic common-emitter amplifier.

The incoming signal shows up on the emitter: $v_{\rm in} = \Delta(V_E + 0.6) = \Delta V_E \equiv v_E$. And by Ohm's Law, $i_E = v_E/R_E = v_B/R_E$. As we found previously, $i_E = i_C + i_B \approx i_C$. Now, the voltage at the output is $V_{\rm out} = V_C = V_{\rm CC} - I_C R_C$. And therefore, $\Delta V_{\rm out} \equiv v_{\rm out} = -i_C R_C$. Putting all of this together, $v_{\rm out} = -i_C R_C \approx -i_E R_C = -(v_B/R_E)\, R_C$, giving the voltage gain G:

$$G \equiv v_{\rm out}/v_{\rm in} = -R_C/R_E \tag{26}$$

5.6 Circuit Biasing and Input

Now we need to figure out how to provide inputs to our basic circuits. In Fig. 22 below we show the input network for a common-emitter amplifier. The same considerations we apply here apply equally to the input of an emitter follower. The idea is that the voltage divider R_1 and R_2 provide the DC bias voltage (V_0 in our discussion above), and the time varying signal is input through the capacitor (which blocks the DC). We need to figure out what design criteria should be applied to this design.

We need to make sure that our input circuit does not load the amplifier, C is chosen to give a reasonable RC cutoff, and that the gain of the amplifier is what we want. We will start by designing the DC component of the input network, that is choosing R_1 and R_2. It is helpful when designing the input network to consider the equivalent circuit shown in Fig. 23. The diode and resistor labelled $Z_{\rm in}$ represent the transistor input: the voltage drop across the base-emitter "diode" and the input impedance from Eqn. 23. $R_{\rm TH}$ is the Thenenin equivalent resistance for the DC input network.

So our design procedure can be as follows:

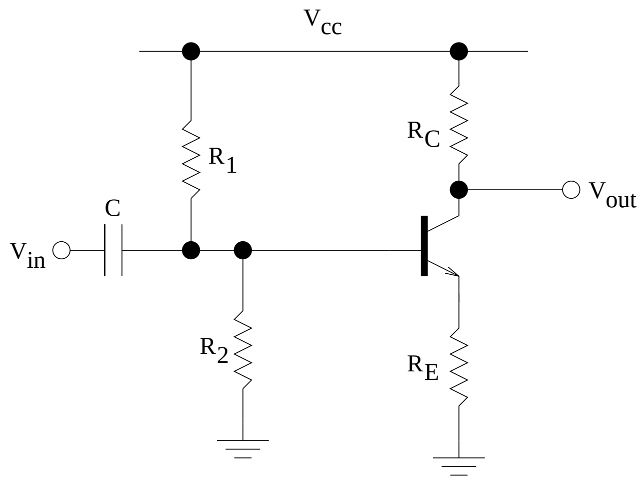

Figure 22: Common-emitter amplifier with input network.

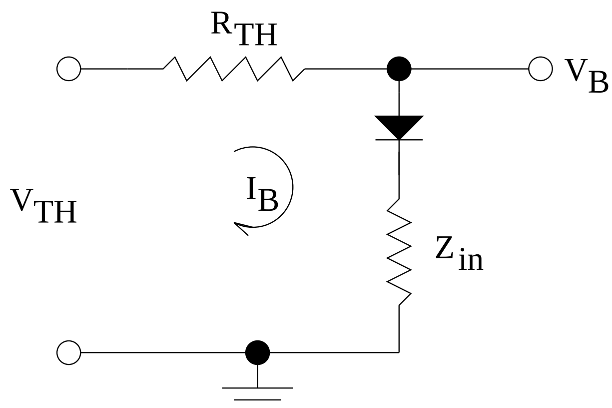

Figure 23: Equivalent circuit for design of DC input network.

1. Choose $R_{\text{TH}} \ll Z_{\text{in}} = R_E(\beta + 1)$.
2. Determine R_1 and R_2 based on the equivalent circuit.
3. Choose C to provide a proper high-pass cutoff frequency.
4. Choose the amplifier gain, if need be.