Review of Chapter 2

An A-to-W review of Chapter 2. This review doesn't follow the exact topic order in the chapter: here we first cover transistor theory, then circle back to discuss some applications. In the chapter circuits have been interspersed with theory to provide motivation and illustrate how to use the theory.

¶A. Pin-Labeling Conventions.
The introduction (§2.1) describes some transistor and circuit-labeling conventions. For example, V_B (with a single subscript) indicates the voltage at the base terminal, and similarly I_B indicates current flowing into the base terminal. V_{BE} (two subscripts) indicates base-to-emitter voltage. Symbols like V_{CC} and V_{EE} (repeated subscripts) indicate the positive and negative supply voltages.

¶B. Transistor Types and Polarities.
Transistors are three-terminal devices capable of amplifying signals. They come in two broad classes, *bipolar junction transistors* (BJTs, the subject of this chapter), and *field-effect transistors* (FETs, the subject of Chapter 3). BJTs have a control terminal called the *base*, and a pair of output terminals, called the *collector* and the *emitter* (the corresponding terminals in a FET are *gate*, *drain*, and *source*). A signal applied to the base controls the current flowing from collector to emitter. There are two BJT polarities available, *npn* and *pnp*; for *npn* devices the collector is more positive than the emitter, and the opposite is true for *pnp*. Figure 2.2 illustrates this and identifies intrinsic diodes that are part of the transistor structure, see ¶D and ¶ below. The figure also illustrates that the collector current and the (much smaller) base current combine to form the emitter current.

Operating modes Transistors can operate as *switches* – turned ON or OFF – or they can be used as *linear* devices, for example as amplifiers, with an output current proportional to an input signal. Put another way, a transistor can be in one of three states: *cutoff* (non-zero V_{CE} but zero I_C), *saturated* (non-zero I_C but near-zero V_{CE}), or in the *linear region* (non-zero V_{CE} and I_C). If you prefer prose (and using "voltage" as shorthand for collector-to-emitter voltage V_{CE}, and "current" as shorthand for collector current I_C), the cutoff state has voltage but no current, the saturated state has current but near-zero voltage, and the linear region has both voltage and current.

¶C. Transistor Man and Current Gain.
In the simplest analysis, §2.1.1, the transistor is simply a current amplifier, with a *current gain* called *beta* (symbol β, or sometimes h_{FE}). A current into the base causes a current β times larger to flow from collector to emitter, $I_C=\beta I_B$, if the external circuit allows it. When currents are flowing, the base-emitter diode is conducting, so the base is ~0.65 V more positive (for *npn*) than the emitter. The transistor doesn't *create* the collector current out of thin air; it simply throttles current from an available supply voltage. This important point is emphasized by our "transistor man" creation (Figure 2.7), a little homunculus whose job is to continuously examine the base current and attempt to adjust the collector's current to be a factor of β (or h_{FE}) times larger. For a typical BJT the beta might be around 150, but beta is only loosely specified, and a particular transistor type may have a 3:1 spread (or more) in specified beta at some collector current (and further 3:1 spreads of β versus I_C and β versus temperature, see for example Figure 2.76).

¶D. Switches and Saturation.
When operated as a switch, §2.2.1, a current must be injected into the base to keep the transistor "ON." This current must be substantially more than $I_B=I_C/\beta$. In practice a value of 1/10th of the maximum expected collector current is common, but you could use less, depending on the manufacturer's recommendations. Under this condition the transistor is in *saturation*, with 25–200 mV across the terminals. At such low collector-to-emitter voltages the base-to-collector diode in Figure 2.2 is conducting, and it robs some of the base-current drive. This creates an equilibrium at the saturation voltage. We'll return in ¶K to look at some circuit examples. See also the discussion of transistor saturation in Chapter *2x*.

¶E. The BJT is a Transconductance Device.
As we point out in §2.1.1, "A circuit that depends on a particular value for beta is a bad circuit." That's because β can vary by factors of 2 to 3 from the manufacturer's nominal datasheet value. A more reliable design approach is to use other highly-predictable BJT parameters that take into account that it is a *transconductance* device. In keeping with the definition of transconductance (an output current proportional to an input voltage), a BJT's collector current, I_C, is controlled by its base-to-emitter voltage, V_{BE}, see §2.3. (We can then rely on $I_B=I_C/\beta$ to estimate the base current, the other way around from the simple approach in ¶C.) The transconductance view of BJTs is helpful in many circumstances (estimating gain, distortion, tempco), and it is essential in understanding and designing circuits such as differential amplifiers and current mirrors. However, in many situations you can circumvent the beta-uncertainty problem with circuit design tricks such as dc feedback or emitter degeneration, without explicitly invoking Ebers–Moll