

Monday, May 2, 2005
EE 105 Discussion Section 101

Announcements

The Importance of BJTs

There are two major types of transistors: (i) MOSFETs, and (ii) BJTs. While MOSFETs are currently the prevalent technology due to their superior digital performance, BJTs play important roles in certain analog applications. To name a few examples, BJTs are preferred choice for power amplifiers (i.e. amplifiers that are designed to deliver a large amount of power to a load). Also, BJTs provide more g_m as compared to their MOSFET counterparts for the same bias current. Hence, one can obtain larger gain for less power using BJT transistors. Lastly, the transit frequency (i.e. ω_T) of BJTs has historically been larger than MOSFETs for any given technology node. This translates into better frequency response for the BJT transistor. It should be noted, however, that recent lithographic and manufacturing advancements have narrowed the gap between the ω_T of the BJT and MOSFET transistor.

The focus in EE105 is to have enough understanding of BJT operation such that one can analyze and design BJT amplifier circuits. To this end, we will follow the same outline as that for the MOSFET. More specifically,

1. Develop a model based upon device physics that relates the DC currents set up in response to DC voltages applied at the terminals of the device. This essentially encapsulates the development of the BJT large signal equations, thereby allowing one to analyze biasing issues in BJT circuits.
2. Construct the equivalent small-signal model for the BJT based upon the derived large signal equations.
3. Use the small-signal model to analyze and design circuits that process small changes in current and/or voltage (i.e. small signals).

BJT Structure and Regions of Operation

The bipolar junction transistor is nothing more than two pn junctions in series to one another, back to back. This is pictorially depicted in Figure 1. As was the case for MOSFETs, BJTs come in two different flavors. While the transistor structure appears to be symmetrical based upon Figure 1, it is not in practice. More specifically, the doping in the emitter and collector regions are quite different from one another.

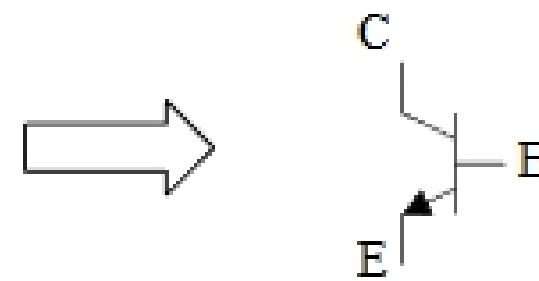
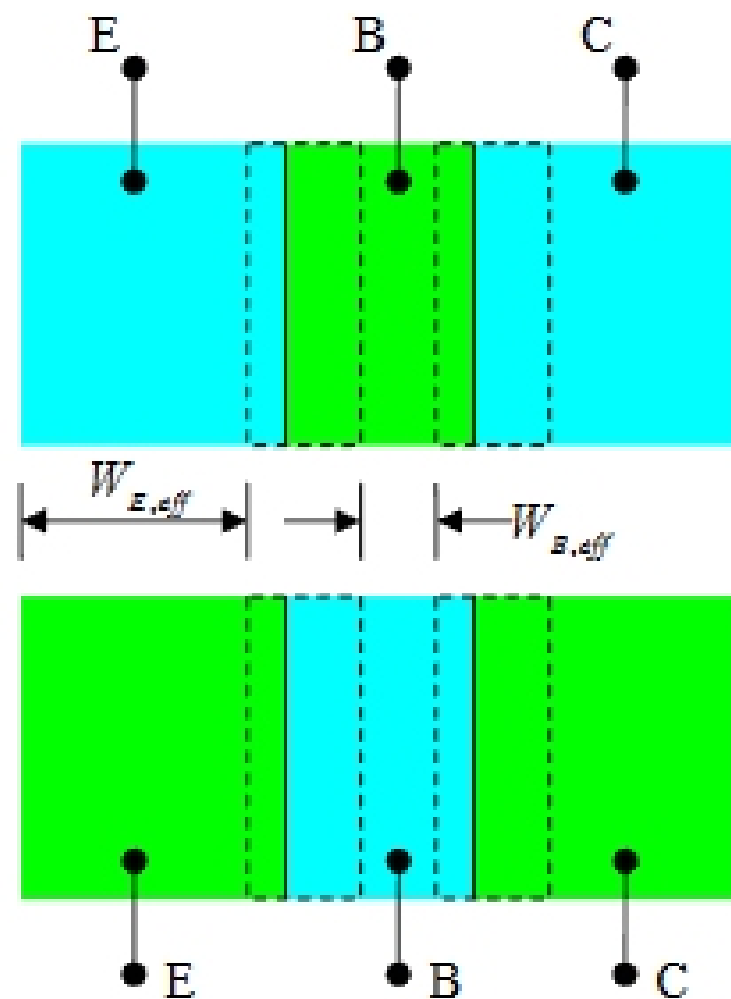


Figure 1a. NPN BJT

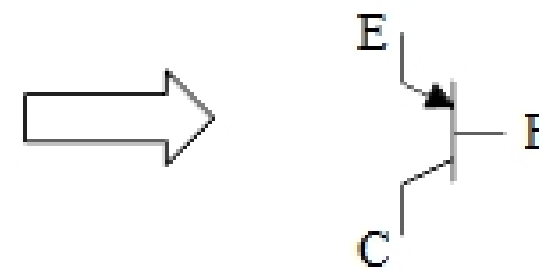


Figure 1b. PNP BJT

Legend



n-type Si



p-type Si

The effective base width (see Figure 1), $W_{B,eff}$, is an important device parameter for the BJT. Analogous to the length of a MOSFET, one strives to have as small of a $W_{B,eff}$ as possible for performance. Also, the dashed regions in Figure 1 are indicating the depletion regions present in the BJT structure.

Considering that the BJT consists of two diodes, it takes on 3 regions of operation:

1. **Cutoff:** Both pn junctions are reverse-biased, with very little current (ideally zero) flowing through the resultant device,
2. **Saturation:** Both pn junctions are forward-biased, and
3. **Active:** One pn junction is forward-biased, while the other is reverse-biased.

Note: The saturation region of operation should be avoided for amplifier design, as was the case for the triode region for MOSFETs. The region resembling the MOSFET saturation region in BJTs is the active region of operation.

Note: Here, the forward active region of operation shall be the focus. This region of operation is marked by the BE junction being forward-biased and the CB junction reverse-biased. The reverse active region of operation is when the BE junction is

reverse-biased and the CB junction forward-biased. These two regions are different from one another because the emitter and collector dopings of the device are different from one another in practice.

Large Signal Model for the PNP Transistor in Forward Active

In order to derive equations for the DC currents set up in a BJT in response to DC voltages applied at the terminals, one needs to focus on the minority carrier concentrations within the device. The reason for this is discussed in EE130. As such, let's first focus on the minority carrier concentrations present within the PNP structure at thermal equilibrium. Using relationships discussed in the early part of the semester, the minority carrier concentrations are as follows:

$$n_{emitter} = \frac{n_i^2}{N_{A,emitter}} \quad (1)$$

$$p_{base} = \frac{n_i^2}{N_{D,base}} \quad (2)$$

$$n_{collector} = \frac{n_i^2}{N_{A,collector}} \quad (3)$$

Note: In practice, $N_{A,emitter} \gg N_{D,base} \gg N_{A,collector}$.

Figure 2 depicts a PNP transistor biased in the forward active region of operation through the application of a couple of DC bias voltage sources. As will be discussed in EE130,

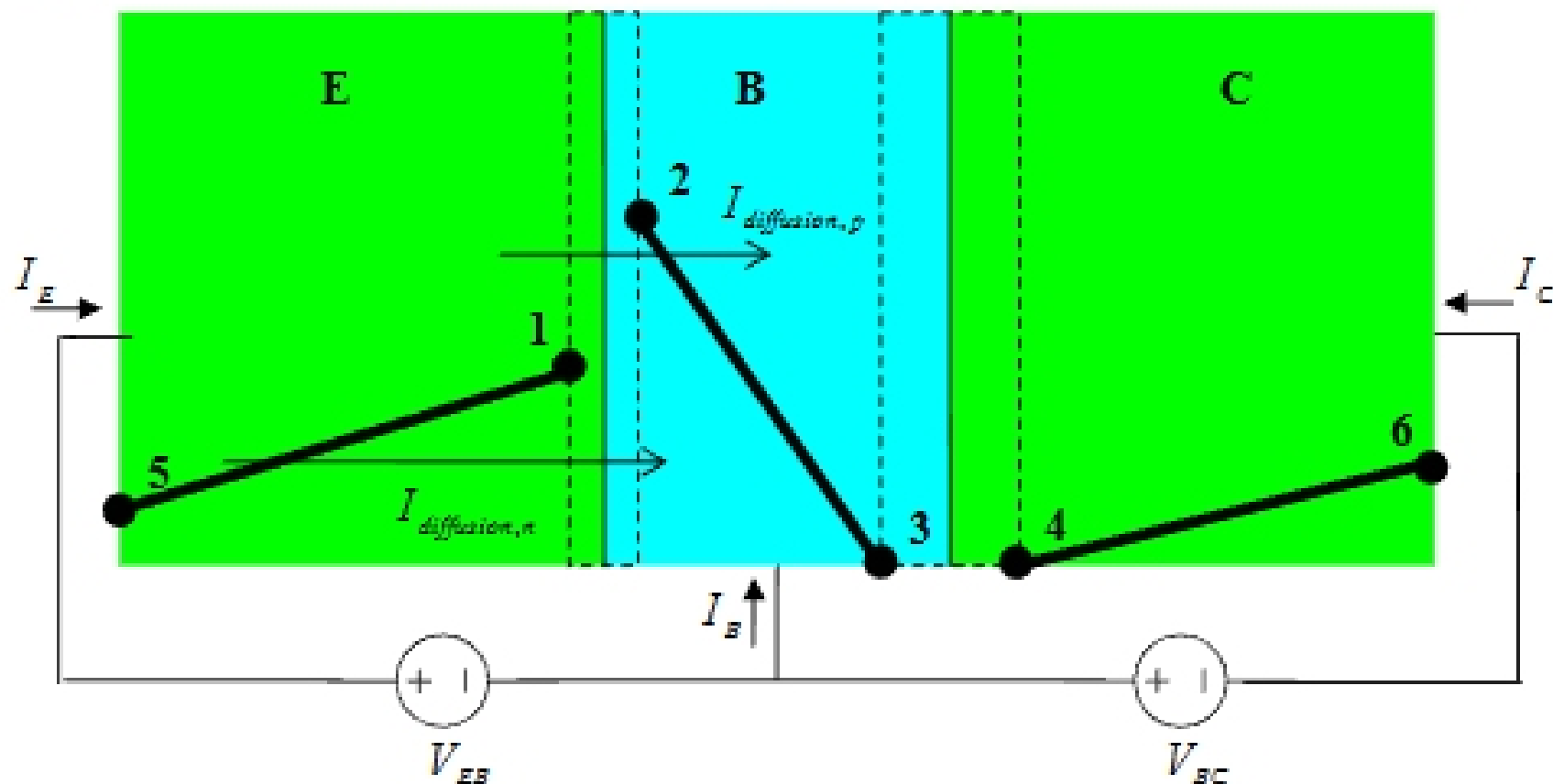


Figure 2. PNP in Forward Active Region