Bipolar Junction Transistor Basics

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Introduction

A bipolar junction transistor (BJT) is a three layer semiconductor device with either NPN or PNP construction. Both constructions have the identical mathematical model but differ in that the terminal currents are inverted from each other. There are three terminals described as follows:

Base	the control terminal
Emitter	the source of majority carriers
Collector	the collector of majority carriers

The basic mathematical model of the BJT is a current controlled current source. A current between the base and emitter terminals controls a current between the collector and emitter terminals. The name for the control factor is beta. The symbol for beta is β although B is often used too. The collector current is the base current multiplied by beta. The beta for typical small signal BJTs ranges from about 50 to 300.

For linear amplifiers the base-emitter junction is always forward biased and the base-collector junction is always reversed biased. All of the math we use is based on this and will produce incorrect results if either condition is not true. An amplifier is based on a small base-emitter current controlling a much larger collector-emitter current.

Although we treat beta as if it were a constant, we must keep in mind that beta is a complex function of temperature, collector current, and collector to emitter voltage. At first it would seem that it would be difficult to design a BJT circuit since the exact value of beta is not known for a particular transistor other than roughly the broad range described above. But, with proper design techniques, the bias design for a BJT circuit can be made to be very independent of beta.

Figure 1 shows the construction and schematic symbols of NPN and PNP structures. The plots at the bottom show a family of characteristic curves. Linear operation is in the current saturation region as shown on the plots. In this region the collector current is very independent of the voltage across the transistor – thus the name, current saturation. At very low voltages across the transistor the collector current has a strong dependency on voltage – thus the name, ohmic region.

Figure 2 shows how beta varies with temperature, voltage, and current through the transistor. Note that there is a DC beta (I_C / I_B) term and an AC beta (ΔI_C / ΔI_B) term. For most normal cases these two values are practically identical and for this course we will not make a distinction.

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TRANSISTORS

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- A THREE LAYER SEMICONDUCTOR DEVICE WITH EITHER NPN OR PNP CONSTRUCTION
- THE THREE TERMINALS ARE:

  BASE   COLLECTOR   EMITTER
- THE BASE-EMITTER JUNCTION IS FOWARD BIASED. THE BASE-COLLECTOR JUNCTION IS REVERSE BIASED.
- A SMALL BASE-EMITTER CURRENT CONTROLS A MUCH LARGER COLLECTOR-EMITTER CURRENT.

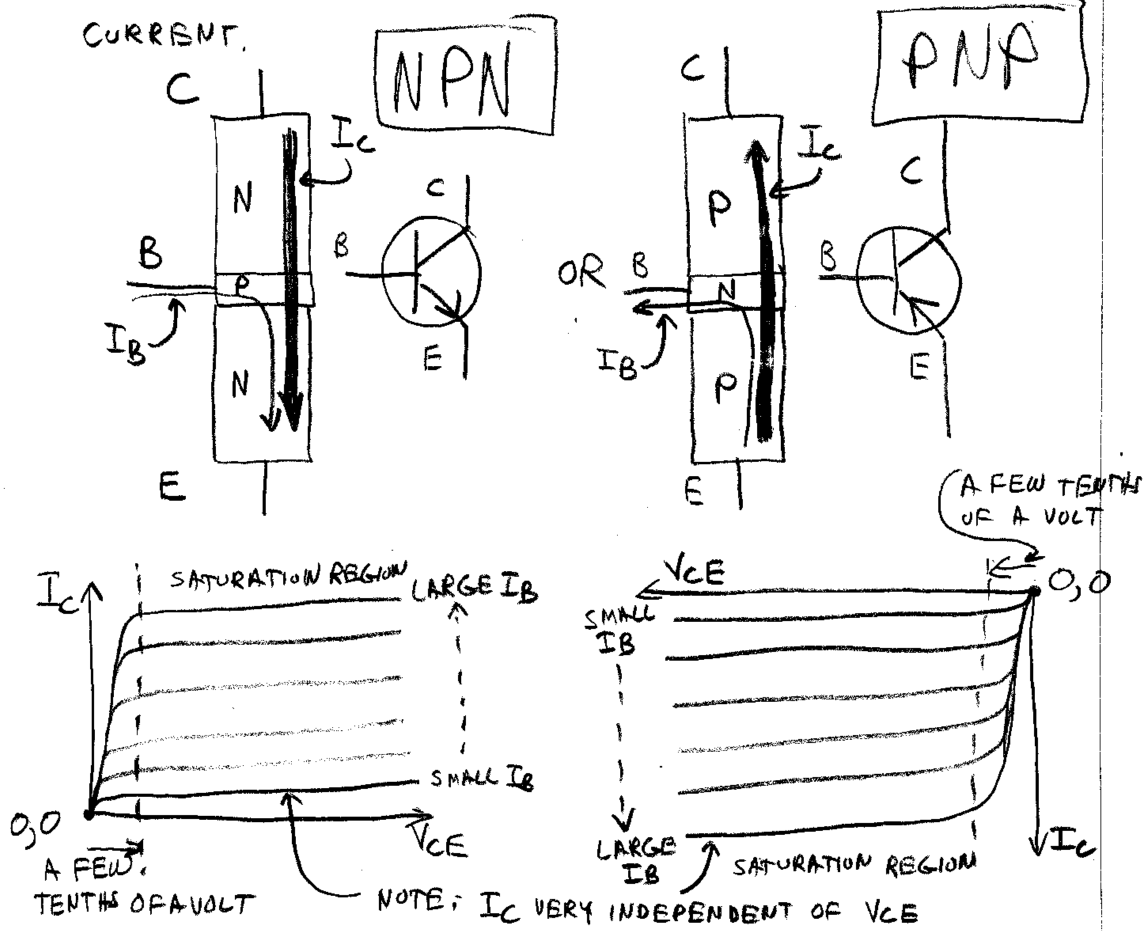

Figure 1: Basic transistor characteristics

- THE COLLECTOR CURRENT IS RELATED TO THE BASE CURRENT BY A FACTOR KNOWN AS BETA (β). β IS TYPICALLY BETWEEN 30 AND 300 WITH A NOMINAL VALUE OF 100.
- β IS A FUNCTION OF:
  - TEMPERATURE — INCREASES WITH TEMP.
  - V_{CE} — INCREASES WITH V_{CE}
  - I_C — NON LINEAR AS SHOWN BELOW
- THERE IS A DC β WHICH IS I_C/I_B AND AN AC β WHICH IS i_c/i_b OR $\Delta I_C/\Delta I_B$. OVER THE NORMAL OPERATING RANGE (FOR SMALL SIGNAL AMPLIFIERS) BOTH VALUES ARE ABOUT THE SAME SO WE USE JUST ONE VALUE OF β.

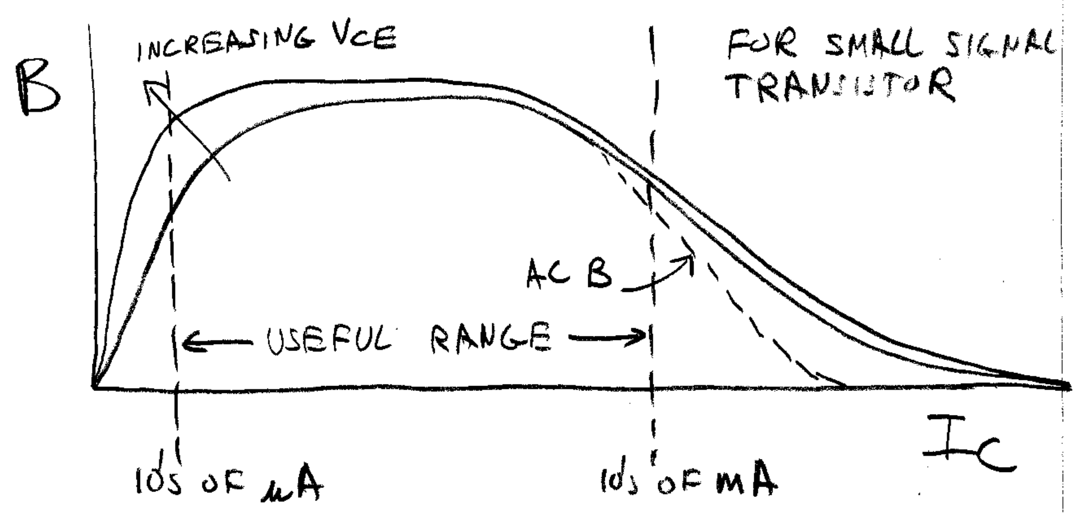

Figure 2: Beta variations

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Transistor Nomenclature

Figure 3 illustrates standard transistor nomenclature. Note that DC values are in upper case and AC or signal values are in lower case. This is done because there is a significant difference between the DC and AC solution. We always calculate the DC or bias solution first and then that result is used to calculate the AC or signal characteristics. It is very important to note that the signal is generally a small value compared to the corresponding bias value

Transistor Equations

Here are the two fundamental bipolar transistor equations for linear circuit analysis. Everything we do with bipolar transistors is based on these two equations.

$I_C = B * I_B$ The collector current is controlled by the base current

$I_E = I_B + I_C$ The emitter current is the sum of the base and collector currents

The following equations are derived from the first two (The student should become proficient at deriving these).

$I_B = I_C / B$

$I_E = (B + 1) * I_B$

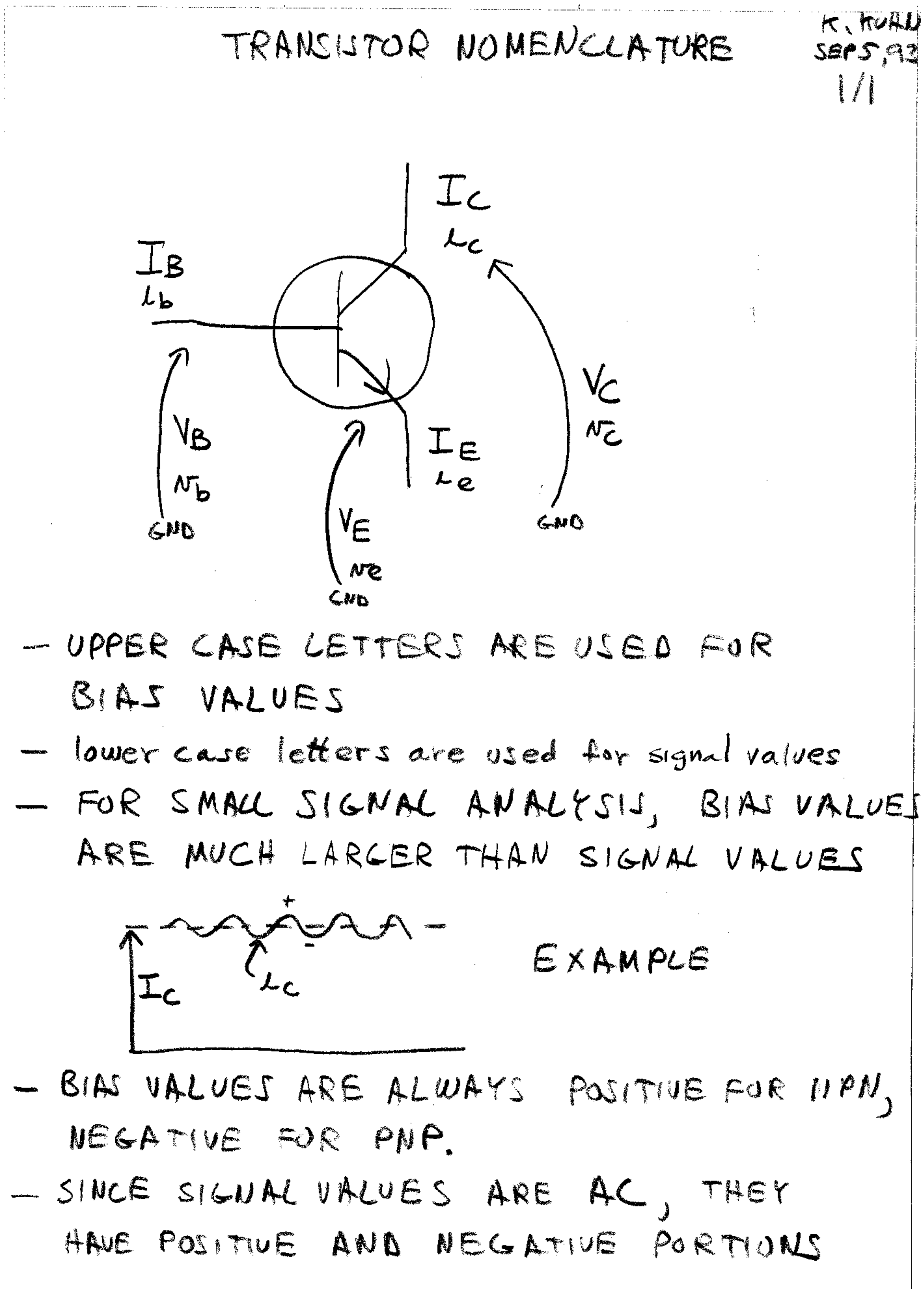
$I_B = I_E / (B + 1)$

$I_C = (B / (B + 1)) * I_E$ Note that B/(B+1) is always slightly less than 1

$I_E = ((B + 1) / B) * I_C$ Note that (B+1)/B is always slightly greater than 1

The following is a summary of all the possible permutations of the above equations. The student should develop the ability to quickly derive all of them. It is very important to note that these equations only apply if the transistor is being operated in the current saturation region (i.e. linear region for building amplifiers). These equations do not apply in the ohmic region.

	Known		
Unknown	$\mathbf{I_C}$	$\mathbf{I_B}$	$\mathbf{I_E}$
$\mathbf{I_C}$ =	*	$B * I_B$	$(B / (B + 1)) * I_E$
$\mathbf{I_B}$ =	I_C/B	*	$I_E / (B + 1)$
$\mathbf{I_E}$ =	$((B + 1) / B) * I_C$	$(B + 1) * I_B$	*



TRANSISTOR NOMENCLATURE

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- UPPER CASE LETTERS ARE USED FOR BIAS VALUES
- lower case letters are used for signal values
- FOR SMALL SIGNAL ANALYSIS, BIAS VALUES ARE MUCH LARGER THAN SIGNAL VALUES

EXAMPLE

- BIAS VALUES ARE ALWAYS POSITIVE FOR NPN, NEGATIVE FOR PNP.
- SINCE SIGNAL VALUES ARE AC, THEY HAVE POSITIVE AND NEGATIVE PORTIONS

Figure 3: Transistor nomenclature