

ECE 139 Spring 2009

Homework Set #5

Handed out: May 26

Due: June 4

Objective: This homework deals with the Gummel-Poon model of bipolar transistors for SPICE simulation, and bipolar device simulation using Atlas.

The following is a Gummel Poon SPICE model for npn bipolar transistor:

* Si bipolar standard npn transistor with emitter area=2x2um²

```
.model n1 npn (bf=100 br=10 is=2e-17A nf=1.0 vaf=40V
```

```
+ise=4e-13A ne=2.0 ikf=0.002A isc=2e-13A nc=2.0
```

```
+re=10 rb=450 rc=50 tf=10ps tr=10ns
```

```
+cje=10ff vje=0.8V mje=0.33 cjc=10ff vjc=0.8V mjc=0.2 cjs=30ff vjs=0.8V)
```

Problem 1

Using SPICE, determine the characteristics of a nominal BJT whose model is given above, as follows:

a) Plot the common-emitter characteristics of the transistor, that is, plot I_c vs V_{ce} at different values of I_b . Pick I_b steps so that the maximum I_c is about 4 to 5 mA. This corresponds to about 1mA/um² or 10⁵ A/cm², which is a reasonable limit for traditional BJTs (the most recent SiGe HBTs can go to 10⁶ A/cm²).

b) Plot $\log_{10}(I_c)$ vs V_{be} and $\log_{10}(I_b)$ vs V_{be} . You may take $V_{ce}=2V$. Choose the V_{be} range to cover I_c from about 0.1nA to 10mA. This is a "Gummel plot". What is the "ideality factor" for I_c and for I_b ?

b) Determine the transconductance (g_m) as a function of V_{be} . Also plot g_m vs I_c .

c) Increase the value of parasitic emitter resistance by a factor of 2. Show the changes that are produced in the Gummel plot and in g_m .

d) Use SPICE to determine the value of $|h_{21}|$ vs frequency. For this, you need to use ac analysis, and plot $\text{mag}(i_{out}/i_{in})$. Choose dc bias conditions corresponding approximately to $V_{ce}=2V$ and $J_c=I_c/(\text{emitter area})=20,000$ A/cm².

Problem 2

Imagine that you are in a research laboratory, making measurements of the high frequency characteristics of a bipolar transistor just fabricated in your lab. The collector current is 5mA. You assess the f_t of the transistor to be 40GHz.

The structure of the transistor has the following features:

Base thickness 500Å

Collector thickness 2000Å

Base-emitter capacitance (at bias) 250fF

Base-collector capacitance (at bias) 100fF

The dc current gain of the transistor is found to be 80.

a) Plot $|h_{21}|$ (in dB) vs logarithm of the frequency for this device.

b) What is the total emitter-to-collector delay?

c) Estimate how much f_t will rise if the collector current is raised to 20mA. (assume that the resultant value is still below the Kirk effect current).

d) Estimate how much the f_t will change if the base thickness is increased by a factor of two. You will have to use a "reasonable value" for electron mobility as a minority carrier in the base (and apply Einstein's relation to get the diffusivity). Pick electron mobility to be $800 \text{ cm}^2/\text{Vsec}$.

Problem 3:

Simulate the behavior of an idealized SiGe heterojunction bipolar transistor using Silvaco's Atlas program, based on the file hbtex01.in. This file is available within the ee139s public directory. It must be copied to your home directory before running it.

a) Examine the structure of the HBT; what is the emitter width of the actual device? How does the germanium content of the base vary across the base layer? Compare the donor doping density with the acceptor doping density, and show where the junctions reside, and what is the net base doping.

b) Determine the Gummel plot for this transistor - that is- plot the log of I_c and I_b vs V_{be} , at fixed V_{ce} (which you may choose to be $V_{ce}=+2.0\text{V}$, as per the program as it is written). What is the maximum collector current density reached? (Actually, use the emitter area to calculate this; the active area of the collector is about the same as the emitter area. Silvaco assumes a device dimension of $1\mu\text{m}$ in the direction not plotted).

c) For the case of $V_{ce}=2\text{V}$ and $V_{be}=0.8\text{V}$, plot the band diagram of the transistor from emitter through base, collector and subcollector, along a vertical cutline near the center of the emitter. Show on the plot where the BE and BC depletion regions are. What is the electric field in the middle of the base? (Why is it not zero?).

Plot also the electron and hole concentrations vs position along this cutline.

Can you determine what controls the number of electrons in the base-collector "space-charge region"?

Is the number of electrons injected into the base in agreement with simple theory?

How many holes are in the emitter of the transistor under the forward bias? Does the number agree with expectations?

What is the IR drop (difference in potential) between positions within the base layer under the emitter and under the base contact?