ECE 340 # Homework Assignment #11 **Fall 2015**

DUE: FRIDAY, DECEMBER 4, 2015

Print your **name** and **NetID** legibly. Follow the guidelines and format given in the syllabus. Staple multiple pages. Show all units. Homework must be turned in at the **beginning** of class and any late homework assignments will not be accepted. Please contact the course director, Professor Dallesasse, should any issues with late homework arise.

1. BIPOLAR JUNCTION TRANSISTOR (BJT) FUNDAMENTALS

(A). Sketch the energy band diagram for n-p-n BJT in equilibrium.

(B). Sketch the energy band diagram for n-p-n BJT in forward active mode.In forward active mode, state the bias condition (forward or reverse) of B-E junction and B-C junction. Also state the signs of V_{BE} and V_{CE} if the emitter is grounded (common-emitter setup).

(C). Replicate Fig. 7-3 from the Streetman textbook for the case of a n-p-n transistor. Clearly label each type of carrier flow and describe its role in BJT functionality. Clearly state the direction of the currents resulting from the different carrier flows.

(D). The current gain in a BJT, β, is defined as the ratio between the collector current and the base current in Eq. 7-7 in the Streetman textbook. Is it possible to get infinitely large β in a BJT by eliminating the base current ($I_B = 0$)? Why or why not?

(E). State the advantage of n-p-n BJT compared with p-n-p BJT.

2. BJT IN EQUILIBRIUM

A Si n-p-n transistor has emitter, base, collector doping as specified below: $N_E = 1E18\,cm^{-3}$, $N_B = 5E16\,cm^{-3}$, $N_C = 6E15\,cm^{-3}$. The transistor has cross-sectional area $A = 10^{-5}\,cm^2$ and base width of $4\,\mu m$. For electrons and holes in the transistor, assume $\tau_p = \tau_n = 1\,\mu s$ and $D_n = D_p = 10\,cm^2 \cdot s$.

(A). Sketch the energy band diagram for the device. Clearly label the Fermi level, valence band, and conduction band.

(B). Calculate the width of the quasi-neutral base (un-depleted base, i.e. base width minus depletion width).

(C). Sketch the electrostatic potential, electric field, and charge density as a function of position for the device. Clearly mark the different regions of the device.

3. BJT IN FORWARD ACTIVE MODE

The same transistor from problem 2 is now biased in the forward active regime with $V_{BE} = 0.3\,V$ and $V_{BC} = -0.2\,V$.

(A). Sketch the energy band diagram for the device. Clearly label the quasi-Fermi levels at each region, valence band, and conduction band.

(B). Calculate the width of the quasi-neutral base.

(C). Sketch the electrostatic potential, electric field, and charge density as a function of position for the device. Clearly mark the different regions of the device.

(D). Calculate α, β, I_E, I_B, I_C for the device.

4. Short base transistor

BJT is mostly used as an amplifying device. The current gain β characterizes the amplification ratio between output and input signals. Ideally β is a constant, i.e. the amplifier has a linear gain. In most cases we would like to maximize β .

(A). In order to maximize β , is it better to use short base or long base? Please explain in terms of the properties of the base (think about the origin of base current and the validity of straight-line approximation and what it entails. You can also refer to HW 6 Problem 3 (c)).

(B). Given a n-p-n BJT with both B-E junction and B-C junction forward biased at the same level ($V_{BE} = V_{BC}$, same doping in emitter and collector), and $\tau_n = \tau_p$ in the base. Find the ratio of recombination currents between (A) base width $W_B = 10L_n$ and (B) $W_B = \frac{1}{10}L_n$.

(C). Draw the minority carrier distribution in the base region for (A) and (B).

(D). In Problem 2 the base doping is very low (5E16). What is the advantage of using low base doping? What is the disadvantage of low base doping, say if we would like to modulate B-E junction at a very high frequency?