UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE 130/230A — Prof. Liu
Fall 2013

Homework Assignment #15
Due at the beginning of class on Thursday, 12/12/13
(Note: This assignment is optional, *i.e.* for extra credit.)

Problem 1: BJT – Deviations from the Ideal
Consider the Si NPN BJT in Problem 1 of HW#14, with the emitter junction forward biased such that $exp(qV_{BE}/kT) = 10^{10}$.

Emitter area $A = 10^{-7}$ cm^2, operating at room temperature (T = 300K)

Parameter	**Emitter**	**Base**	**Collector**
Dopant concentration (cm^{-3})	10^{18} (n-type)	10^{17} (p-type)	10^{15} (n-type)
Width (μm)	0.5	0.5	2.0
Minority-carrier lifetime (s)	10^{-7}	10^{-6}	10^{-6}

(a) What is the value of the Early voltage, V_A?
Note: You should use the value of C_{JC} (units F/cm^2) for V_{BC} = 0V.
(b) What is the punchthrough voltage ($V_{CE} = V_{CB} + V_{BE}$ for which the quasi-neutral base width $W = 0$)?
(c) Estimate the breakdown voltage V_{CEO} using the formula

$$V_{CEO} = \frac{V_{CBO}}{\sqrt{\beta_{dc} + 1}}$$

where V_{CBO} is the reverse breakdown voltage of the base-collector pn junction. Assume that the critical electric field for avalanche breakdown of the base-collector junction is 5×10^5 V/cm.
(d) Based of your answers in parts (b) and (c), will punchthrough be observed in the common-emitter output characteristics (I_C *vs.* V_{CE} plot) before breakdown?

Problem 2: Gummel Plot
Generate a standard Gummel plot (log(I_C) and log(I_B) *vs.* V_{BE}) showing non-ideal effects at very low current and very high current. Indicate qualitatively how this plot would change for the cases below. (Assume the common emitter d.c. current gain β_{dc} is 100 for moderate current, recombination in the base is negligible, and that current due to holes collected into the base from the collector are negligible.)
a) base doping increases by 10×
b) emitter doping increases by 10×
c) base width decreases by 50%
d) temperature increases by 50°C

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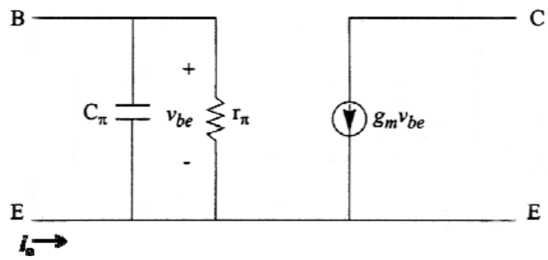
Problem 3: BJT small-signal model

Suppose an incremental emitter current i_e is suddenly applied at $t = 0$ to a BJT operated in active mode with quiescent (DC) current I_{E0} and base-emitter bias voltage $V_{BE,}$ so that $I_E = I_{E0} + i_e$. Using the simplified hybrid-pi small-signal circuit model shown below, show that the resultant small-signal base-emitter voltage v_{be} responds with the characteristic time constant

$$\tau_E \approx \tau_F + \frac{kT}{q}\frac{C_{J,BE}}{I_C}$$

This is one of the delays that affects the unity-gain frequency (f_T) of a BJT.



Hint: Apply Kirchoff's current law (to the emitter node) to obtain a differential equation for v_{be}, and find the solution for $v_{be}(t)$ by applying appropriate boundary conditions for $t = 0$ and $t \rightarrow \infty$. (You may assume that $v_{be}(t=0) = 0$.)

Problem 4: Base transit time and BJT transient response

Consider the Si NPN BJT of Problem 1, operating at the edge of saturation ($V_{BC} = 0V$), at a collector current I_C of 0.1 mA.

(a) Calculate the base transit time (τ_t).

(b) Calculate the excess minority-carrier charge stored in the base (Q_B). How will Q_B change as the BJT is biased into the active region (*i.e.* as V_{BC} is increased), with V_{BE} held constant?

(c) Suppose the BJT is operating in the active mode and the base current is suddenly doubled at time $t = 0$. Derive an expression for collector current $I_C(t)$ for $t > 0$.

(d) Does a BJT switch off more quickly if it is biased in the active mode *vs*. the saturation mode? Explain briefly.