10 - BJT Advanced

Name:______________________________

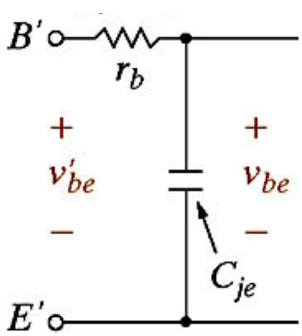
In-Class Problems

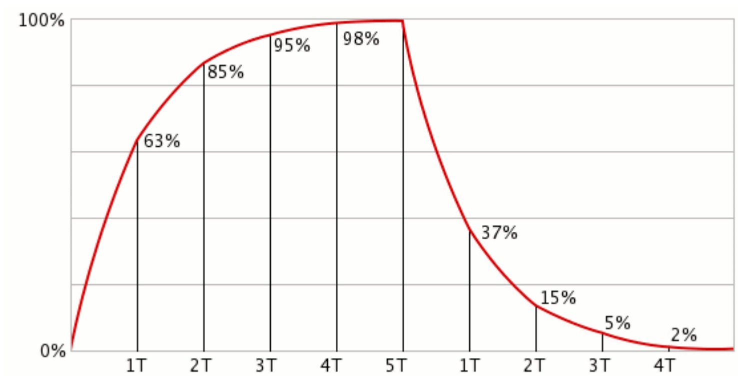
(1) Consider the simple RC network shown below. Which of the following is <u>true or false</u>:

(a) This simple τ=RC network charges up as $v_{be}^{'}$ is applied according to: $v_{be} = v_{be}^{'}(1-e^{-t/\tau})$ and discharges as $v_{be} = v_{be}^{'}e^{-t/\tau}$. TRUE

(b) RC time constant (τ) is the time required to charge the capacitor, through the resistor, by ≈ 63.2 percent of the difference between the initial value and final value, and is the time required to discharge the capacitor to ≈ 36.8 percent (1/e). TRUE

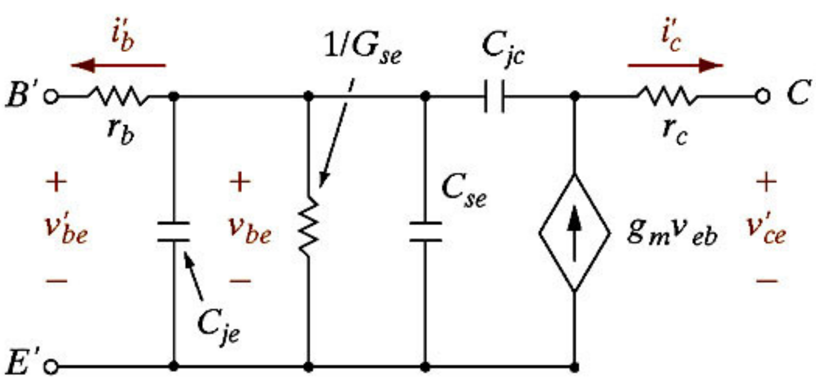
(c) Cuttoff frequency for input into this simple network would be calculated as: $f_c(Hz) = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi\tau}$

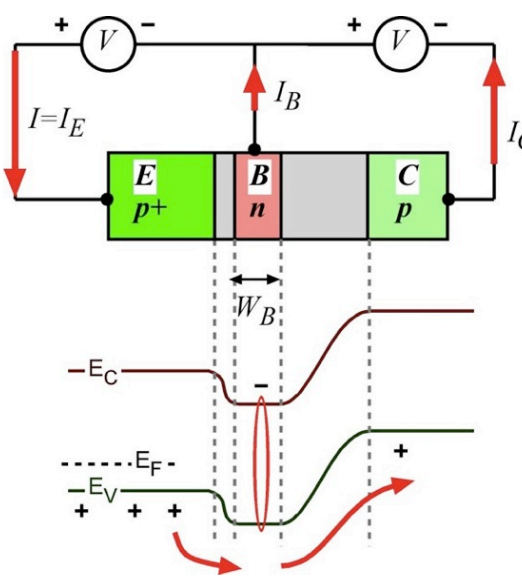




TRUE - All the above are true! A good refresher to start with!

(2) Now… a BJT is even more complex! So lets examine the hybrid-Pi circuit shown below.





Instructor – Prof. Jason Heikenfeld

(a) why for the circuit do we have a base resistance? *Hint, think of base geometry and doping level.*

Base is lightly doped (high resistivity) and thin and long, which together, make it large in resistance! So getting charge into the base to charge up the BJT is not instantaneous!

(b) why for the circuit do we have a collector resistance but no emitter resistance?

Emitter is p+ and collector lightly doped p, so emitter – collector series resistance dominates (who cares about emitter). **=**

(c) Which is larger, C_{je} or C_{jc}? Why? Brief answer, this is easy!

The model above is for normal forward active mode. So C_{je} should be largest, since that diode (EB) is forward biased whereas the diode associated with the base-collector is reverse biased.

(d) C_{se} is for forward bias (storage or diffusion capacitance), and typically dominates over the reverse bias capacitance (depletion capacitance), and is calculated <u>based on classic parallel plate capacitance</u> or <u>based on C=dQ/dV</u>?

dQ/dV! Remember, for a forward biased diode, you get a huge dQ for a small dV, so this capacitance is very large!

(e) We only have C_{se} for the base-emitter, not for the base-collector because the base-collector is reverse biased (no dQ for a dV across the base-collector). <u>True or false?</u>

True!

(f) The $1/G_{se}$ resistor, what are the units for G_{se}? This is easy.

Is conductance, 1/ohms or mhos.

(g) The $1/G_{se}$, with ONE word (one semiconductor term), explain what it represents.

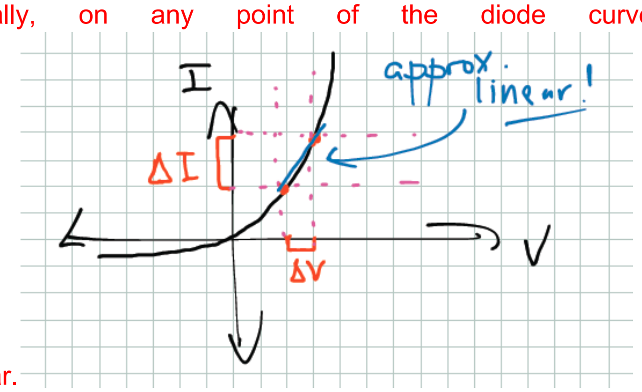
Recombination in the base!

(h) The g_m term, with ONE word (one term), <u>explain what it is called</u>, <u>and give its units</u> (should make sense, given how voltage is transformed into current by it).

Transconductance. A/V.

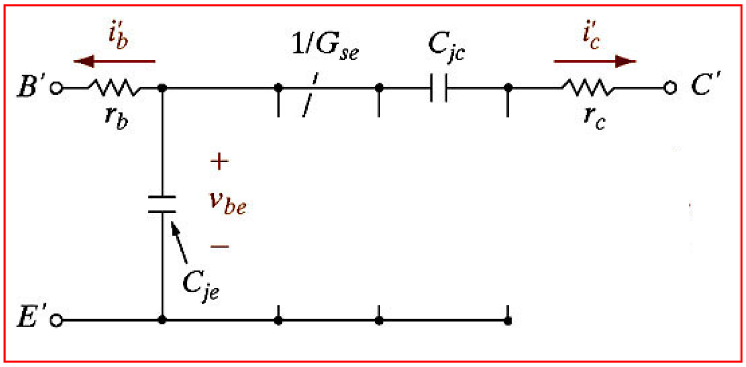
(i) The g_m term, linearly turns emitter-base voltage into collector current. For the DC model of the BJT it was not linear with voltage but was exponential with voltage. Draw a diode characteristic and explain why the small-signal AC input voltage is approximated in this circuit to provide a linear increase in collector output current.

Locally, on any point of the diode curve, you can approximate the curve as being



linear.

(j) The hybrid-Pi circuit is the small-signal (AC) model for the case where DC bias is applied and the BJT is in normal forward active mode (amplification). If the EB junction were reverse biased instead of normal forward bias, cross-out the components that should be removed to show what an incoming AC signal at the B would see.



(k) For a fixed I_B, you keep increasing V_{CE} and see the effect of base narrowing. Which components in the diagram will change? **FOUR OF THEM SHOULD CHANGE!**

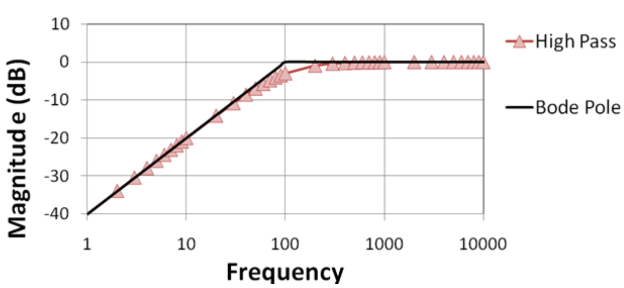
Obviously gm increases (base narrowing increases the amplification factor for a BJT).

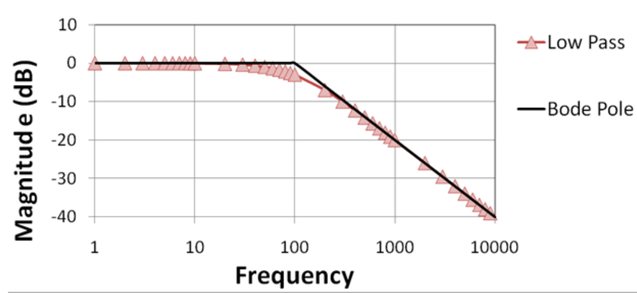
Obviously rb increases (base gets narrower! So more resistive!)

Base narrowing is caused by reverse bias voltage increase across BC, so Cjc must change too.

Lastly, if the base gets narrower, injected carriers from the emitter will make it across easier with less recombination with base carriers, so Gse will increase.

(3) Lets look at the frequency response of a semiconductor amplifier from an even simpler standpoint that you deal with in electronics. Here are Bode plots for generic high-pass and low-pass circuits.





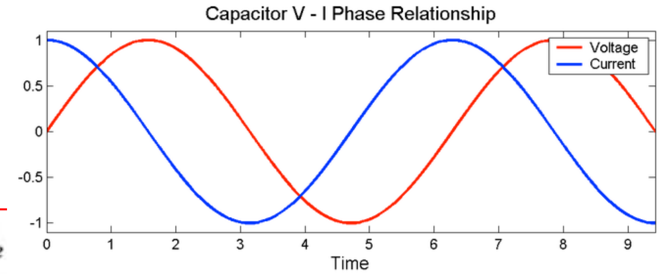
(a) This should be easy. If you were creating a Bode plot for a stand-alone BJT using the Hybrid Pi model, which would you be more concerned with, the high-pass or low-pass Bode plot?

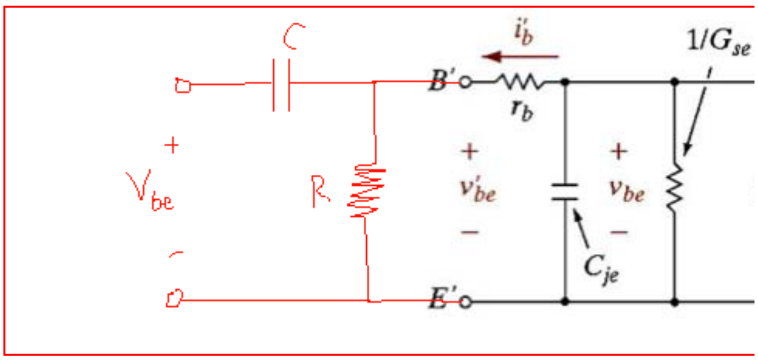
Simple, the low-pass. The hybrid-Pi model simply shows that at certain frequency your input resistance of the base coupled with all the capacitances will lead to an RC time constant (above a certain frequency the gain of the BJT will start to fall off!).

(b) This should be easy too. Lets say you wanted to filter out very low frequencies as well coming into your BJT. You achieve this by adding only two components to the hybrid-Pi model as shown below, but it does not work. What is the problem w/ this setup? *Hint: think of the DC conditions needed to setup the BJT for high-frequency AC amplification.*

$$Z = R + \frac{1}{j\omega C}$$

$$\omega = 2\pi f \qquad j \text{ because } \frac{\pi}{2} \text{ phase shift}$$

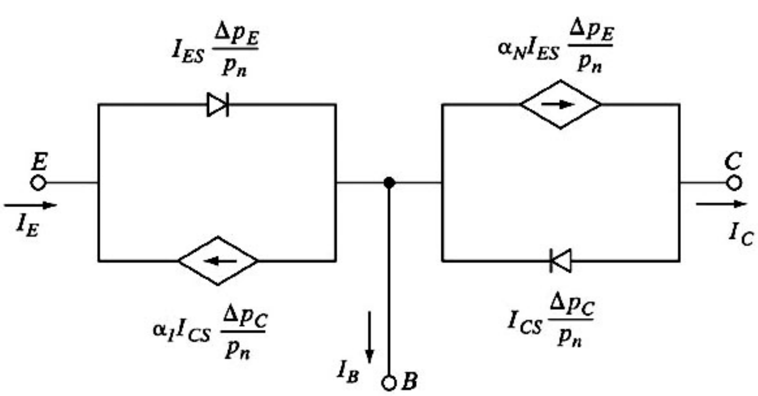


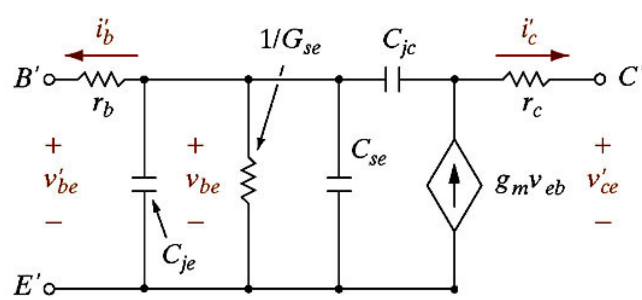


Capacitor blocks the DC voltage/current that puts the BJT emitter-base into amplification mode.

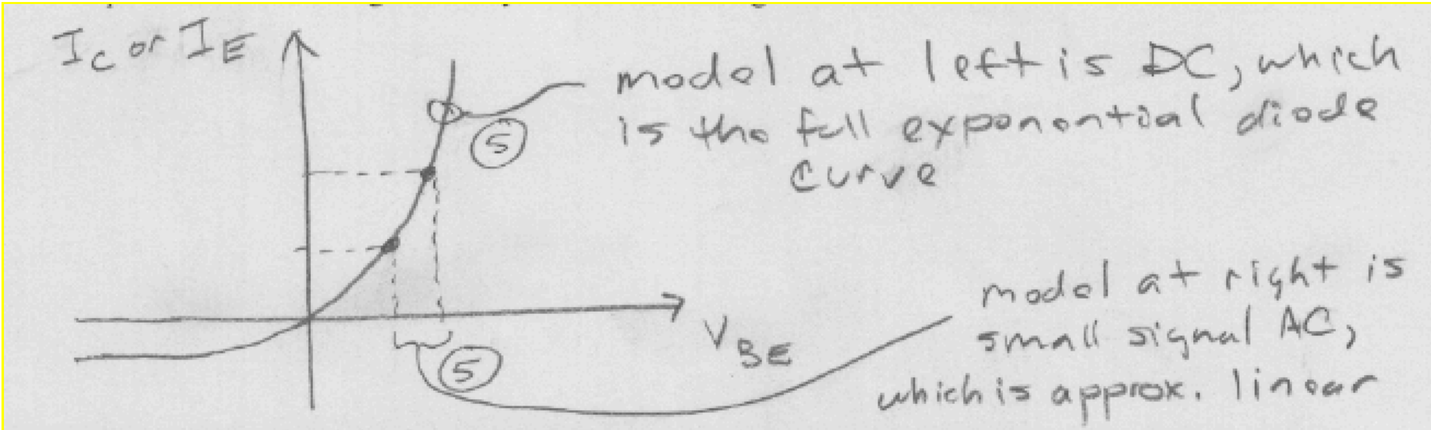
(4) Two models are shown below, one on the left, and one on the right. I will generally refer to them that way. So here are some tougher questions to see really knows their stuff!

$$\Delta p_E = p_n\left(e^{qV_{EB}/kT} - 1\right)$$

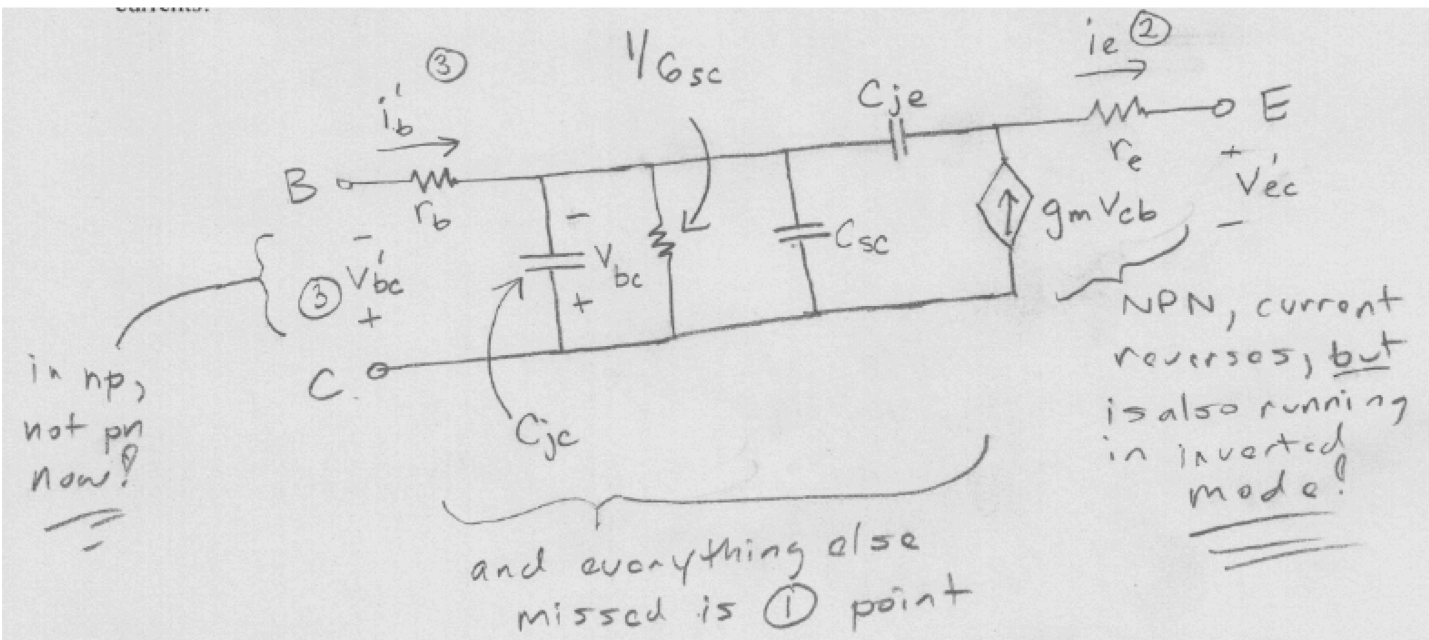




(a) [10 pts] Draw a diagram, only one diagram, and mark/annotated it, to explain why for the model at left the current sources are exponential with voltage and why in the model at right the current sources are linear with voltage.



(b) Redraw the model on the right, for a NPN BJT operating in inverse mode (opposite of normal forward active mode). Make sure you list out everything you see in the model, components, voltages, and currents!



*** at this point you can stop and go over problems for the old test, or you can do this last problem which is also good review for the test ***

(5) Whew, your LAST calculations for a PNP BJT, some review basically…

	Emitter	Base	Collector
$Wb = 0.2\mu m$	$N_a = 5x10^{18} / cc$	$N_d = 10^{16} / cc$	$N_a = 10^{15} / cc$
$Area = 10^{-4} cm^2$	$\tau_n = 100\ ps$	$\tau_p = 2500\ ps$	$\tau_n = 2\ \mu s$
	$\mu_p = 100\ cm^2 / V-s$	$\mu_n = 1500\ cm^2 / V-s$	$\mu_p = 450\ cm^2 / V-s$
	$\mu_n = 150\ cm^2 / V-s$	$\mu_p = 400\ cm^2 / V-s$	$\mu_n = 1500\ cm^2 / V-s$

(a) First, some easy review. As shown in the parameters above, why does carrier lifetime increase from emitter, to base, to collector?

Because doping levels decrease. Less majority carriers means it take more time for a minority carrier to pair up and find a majority carrier to recombine with.

(b) Some more easy review. Calculate Ln in the emitter and Lp in the base, based on doping Ln should be significantly less than Lp! Please comment on Lp compared to Wb, and why that is important for BJT operation.

In emitter, $L_n^E = \sqrt{\mu_n \cdot \frac{kT}{q} \cdot \tau_n} = \sqrt{150 \frac{cm^2}{V \cdot s} \cdot 0.0259V \cdot 10^{-10}s} = 1.97 \cdot 10^{-5}cm = 0.197\mu m$

In base,

$$L_p^B = \sqrt{D_p \tau_p} = \sqrt{\mu_p \cdot \frac{kT}{q} \cdot \tau_p} = \sqrt{400 \frac{cm^2}{V \cdot s} \cdot 0.0259V \cdot 25 \cdot 10^{-10}s} = 1.61 \cdot 10^{-4}cm = 1.61\mu m$$

Lp in the base is almost an order of magnitude larger than the base width, which is good, because we want holes to be able to diffuse across the base before they recombination (Lp is a statistical diffusion length before recombination occurs). If this was not the case, we would not have mainly recombination of emitted holes in the base and no amplification because base current would then need to be equal to the emitter current.