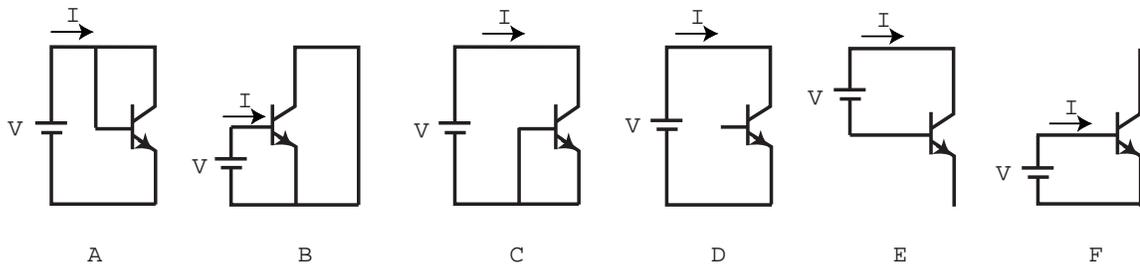


Homework #9 - November 18, 2005

Due: November 30, 2005 at recitation (2 PM latest)
(late homework will not be accepted)

Please write your recitation session time on your problem set solution.

1. [30 points] The figure below shows six possible ways of connecting an npn bipolar transistor that may yield a diode-like behavior. Using the ideal *Non-Linear Hybrid- π Model*, calculate the I-V characteristics of the two-terminal device in each configuration. Express your result as a function of I_S , β_F , and β_R .



Which of these configurations exhibit diode-like I-V characteristics?

2. [20 points] Problem P8.10 of Howe & Sodini. Don't do (e). Do instead:

e) Calculate the maximum amplitude of a sinusoidal signal applied to the input so that the output waveform does not clip. What makes the output waveform clip if this maximum signal is exceeded?

3. [50 points] I-V characteristics of npn Bipolar Junction Transistor

In this problem, you will characterize the current-voltage characteristics of an npn bipolar junction transistor through WebLab. This exercise involves three separate phases: (i) measurement and graphing, (ii) SPICE model parameter extraction, and (iii) comparison of SPICE model with measurements. Take the measurements specified below. When you are happy with the results, download the data to your local machine for more graphing and further analysis.

Important note: For all measurements, hold V_{BE} (or V_{BC}) between 0 and 0.9 V, and V_{CE} between 0 and ± 4 V.

Here is your assignment.

1. (5 points) Measure and download the *common-emitter output characteristics* of the BJT. This is a plot of I_C (linear scale) vs. V_{CE} (linear scale) with I_B as parameter, for positive V_{CE} . Do this for $0 \leq V_{CE} \leq 4$ V and $0 \leq I_B \leq 100$ μA with $\Delta I_B = 20$ μA . In your local machine and using your favorite software tool, graph the output characteristics. Turn in a printout of this graph (**graph 1**).
2. (5 points) Measure and download the *common-emitter transfer characteristics* of the BJT in the forward active regime (also known as *Gummel plot*). This is a semilog plot of I_C and I_B (logarithmic scale) vs. V_{BE} (linear scale). Do this for $V_{CE} = 2.5$ V. In your local machine graph the Gummel plot. Turn in a printout of this graph (**graph 2**).
3. (5 points) Measure and download the *reverse common-emitter output characteristics* of the BJT. This is a plot of I_C (linear scale) vs. V_{CE} (linear scale) with I_B as parameter, for negative V_{CE} . Do this for $-4 \leq V_{CE} \leq 0$ V and $0 \leq I_B \leq 100$ μA with $\Delta I_B = 20$ μA . In your local machine graph the reverse output characteristics. Turn in a printout of this graph (**graph 3**).
4. (5 points) Measure and download the *reverse common-emitter transfer characteristics* of the BJT (also known as *reverse Gummel plot*). This is a plot of I_E and I_B (logarithmic scale) vs. V_{BC} (linear scale). Do this for $V_{EC} = 2.5$ V. In your local machine graph the reverse Gummel plot. Turn in a printout of this graph (**graph 4**).
5. (6 points) From the forward and reverse Gummel plots, extract V_{BEon} and V_{BCon} , respectively. Define these voltages as the values of V_{BE} and V_{BC} that yield $I_B = 10$ μA . Derive $V_{CEsat} = V_{BEon} - V_{BCon}$.
6. (4 points) From the forward and reverse Gummel plots, extract the SPICE parameters **IS**, **BF** and **BR**.

7. (*20 points*) Using the SPICE parameter set just derived, play back the characteristics of the BJT and compare them with the measurement data. Construct the following graphs that include both measurements and SPICE model calculations. Use individual dots for the data points and continuous lines for model calculations.

graph 5: Common-emitter output characteristics in forward regime. Print this graph.

graph 6: Gummel plot in forward regime. Print this graph.

graph 7: Common-emitter output characteristics in reverse regime. Print this graph.

graph 8: Gummel plot in reverse regime. Print this graph.

8. (*optional*) The SPICE model can be refined by accounting for the finite output conductance of the device. From the forward output characteristics, extract the SPICE parameter **VA**.
9. (*optional*) Replay the common-emitter output characteristics of the device in the forward regime using the SPICE model set that incorporates **VA**.

Additional information and assorted advice

- For the SPICE parameter extraction portion of the exercise, there is no need to use an optimizer or any other fancy software. The ideal model does not match the experimental characteristics all that well. Simple extraction algorithms that you can devise should do an adequate job. Make sure the resulting values of the extracted parameters make physical sense.
- You have to exercise care with these devices. Please do not apply a higher voltage than suggested. The BJTs are real and they can be damaged. If the characteristics look funny, try a different device and let us know.
- For research purposes, the system keeps a record of all logins and all scripts that each user executes.