ELEC ENG 2EI5
ELECTRONIC DEVICES and CIRCUITS I

Term II, January – April 2005

PSPICE Demonstrations and Exercises (SET: 14)

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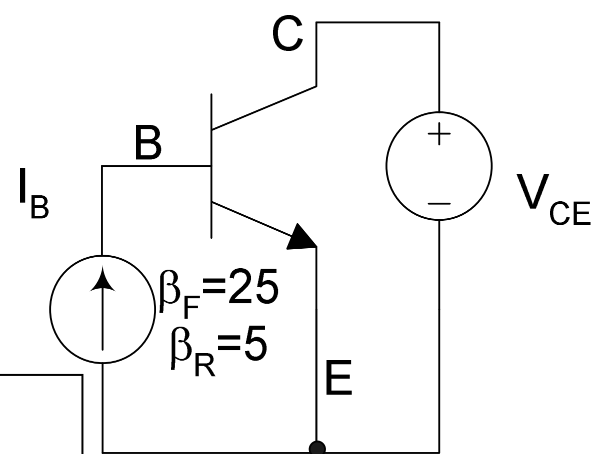
Objective: To learn and use the PSpice model and its parameters for Bipolar Junction Transistors(BJT). To understand and explain the output and transfer characteristics of the BJT.

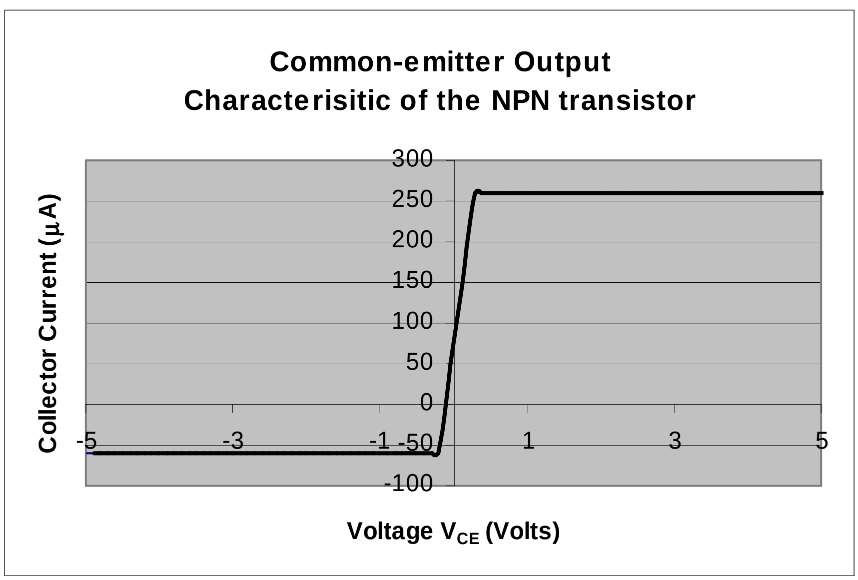
Example 1) Sketch the common-emitter output characteristic for the npn Bipolar Junction transistor in the shown circuit for I_B=10µA. Verify your result using a simulation in PSpice. Vary the collector-emitter voltage V_{CE} between -5V and 10V with a step size of 10mV. Perform this sweep for base currents I_B ={10µA, 30µA, 50µA}. Plot the resulting collector current waveforms. For the BJT the saturation current is I_S=0.1fA



Analysis:

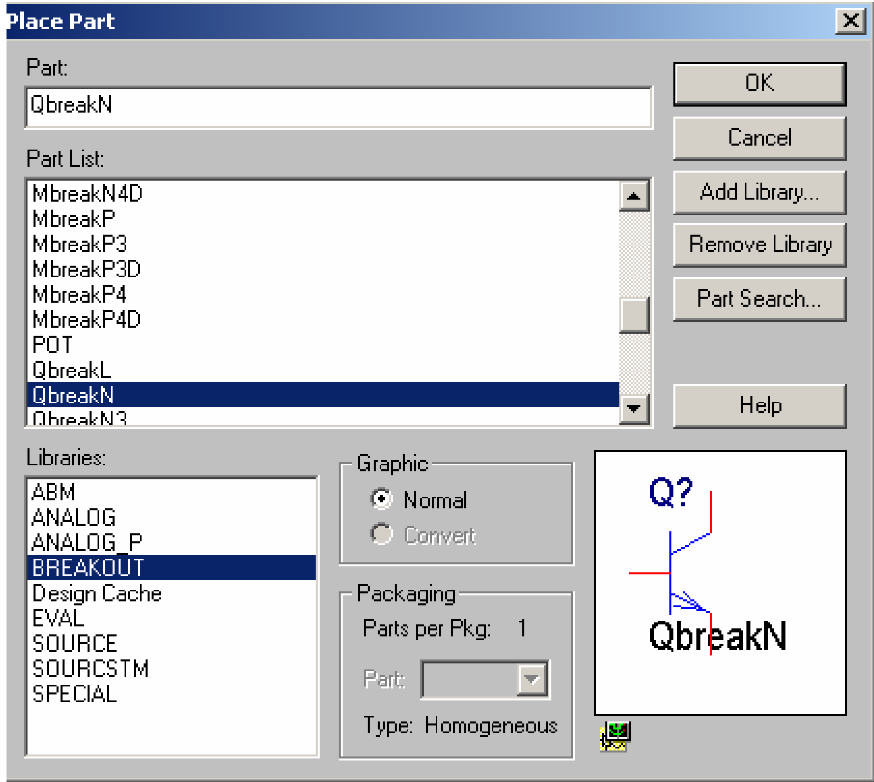
To determine the shape of the output characteristic calculate the collector current as a function of the collector-emitter voltage V_{CE}. For V_{CE}<0.2 (an assumed small voltage). The transistor is operating in the reverse-active region. $I_E=-\beta_R I_B$=-50µA. $I_C=I_E/\alpha_R$=-60µA. For -0.2<V_{CE}<0.2V the transistor is operating in the saturation region and appears as a closed switch with varying currents maintaining $I_B+I_C-I_E=0$. For V_{CE}>0.2 the transistor is operating in the forward active region. $I_C=\beta_F I_B$ and $I_E=I_C/\alpha_F$=260µA.

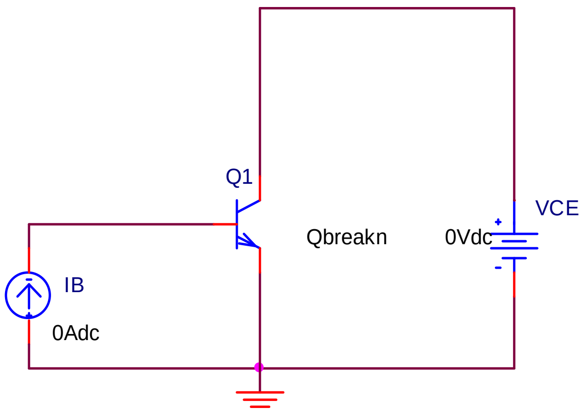
The ±0.2V value is an assumed small voltage range around 0V.



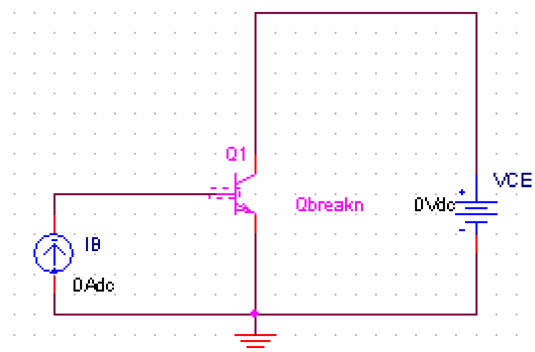
Building the Circuit:

The circuit consists of 3 components: A current source, voltage source and an npn BJT. The name of the generic model for the npn BJT is QBreakN. Similarly the pnp transistor is referred to as QBreakP. These devices can be found in the BREAKOUT library. Construct the circuit as shown.



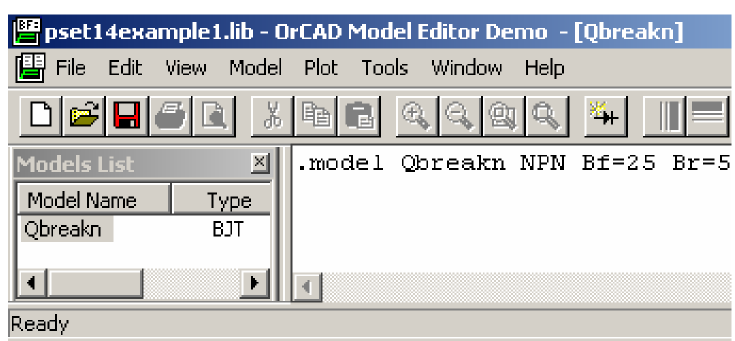


Rename the ground node to be “0”. Now edit the PSpice model parameters for the npn transistor: Select the npn transistor by clicking on it and then from the edit menu click PSpice Model to load the model editor. The QBreak model for the BJT has many parameters. Some of them are summarized in the shown table.



Symbol	Spice Name	Model Parameter	Default Value
I_S	Is	Saturation Current	0.1fA
β_F	Bf	Forward current gain	100
V_{AF}	VAf	Forward Early Voltage	∞
r_B	Rb	Base ohmic resistance	0Ω
β_R	Br	Reverse current gain	1

In the *PSpice Model Editor* change the forward and reverse Beta parameters to 25 and 5 respectively as given in the problem statement. Save the changes and return to the schematic editor.



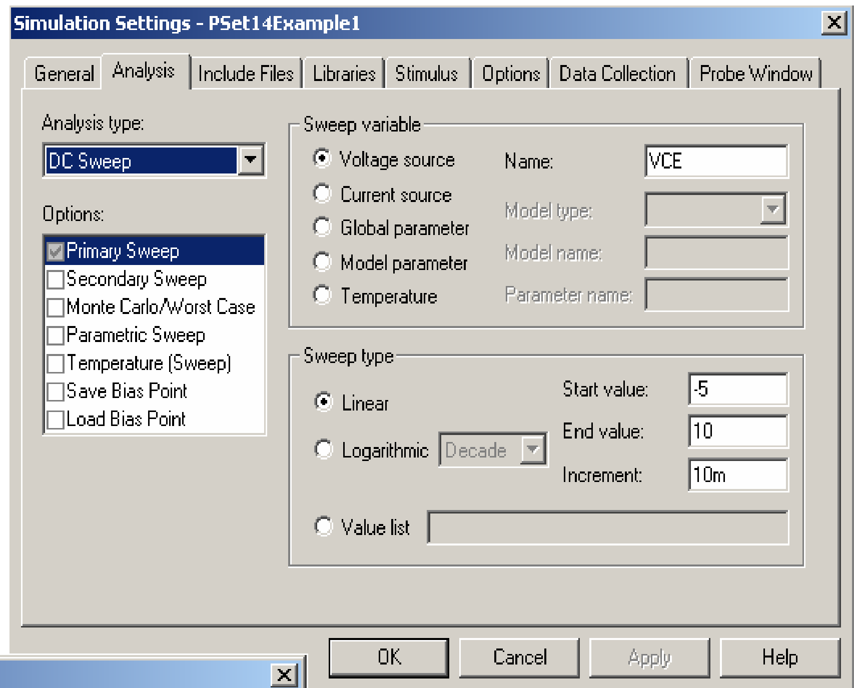
View the netlist to see how PSpice represents the BJT in this format.

Netlist:

```
* source PSET14EXAMPLE1
Q_Q1      N00065   N00118    0 Qbreakn
V_VCE     N00065   0         0Vdc
I_IB      0        N00118    DC 0Adc
```

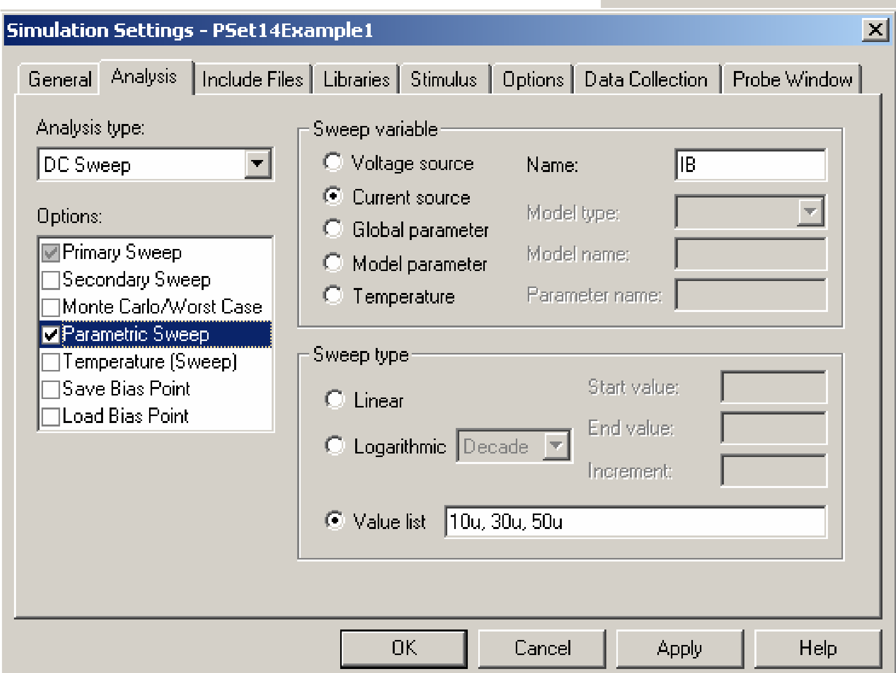
The model for the operation of the BJT transistor used in Jaeger is actually a simplified version of a more complex model called the Gummel-Poon Model. It is this complex model that forms the heart of the model used by PSpice for simulation. Calculations using the simplified model should not exhibit very much deviation from the more complex and accurate model used by Spice however the results may differ slightly.

The BJT statement begins with Q followed by a unique name. The nodes to which the element is connected are then listed in the order of those connected to the collector, base, and emitter. Take note that the collector current I_C is the negative(-) of the current through the source V_{CE}.



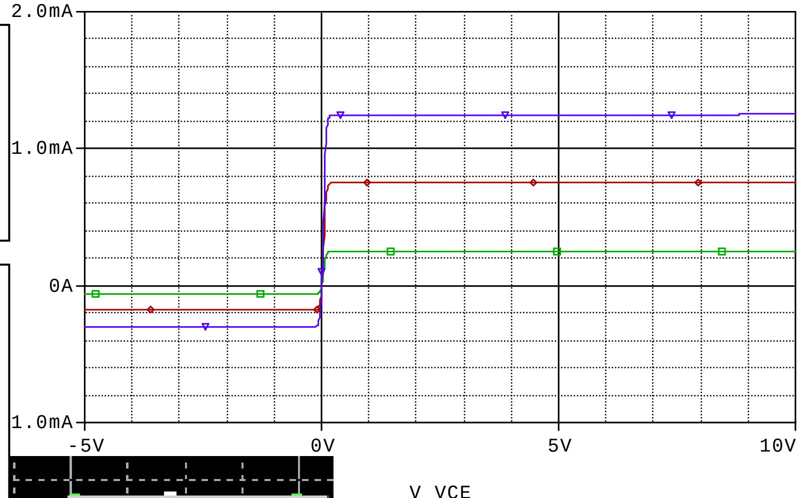
Simulating the Circuit:

To construct the common-emitter output characteristics for the npn transistor a DC Sweep simulation must be performed on V_{CE} for each of the requested values of I_B. Create a new simulation profile and for the analysis type select DC Sweep. Set up the primary sweep of VCE as shown.

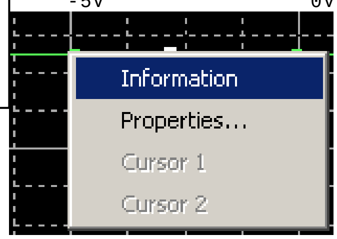


Select a Parametric Sweep as shown and set it up to sweep the current source I_B for the values specified in the problem statement. Ensure the box beside the Parametric Sweep option contains a checkmark and click OK to complete the set-up and return to the schematic. Run the simulation.

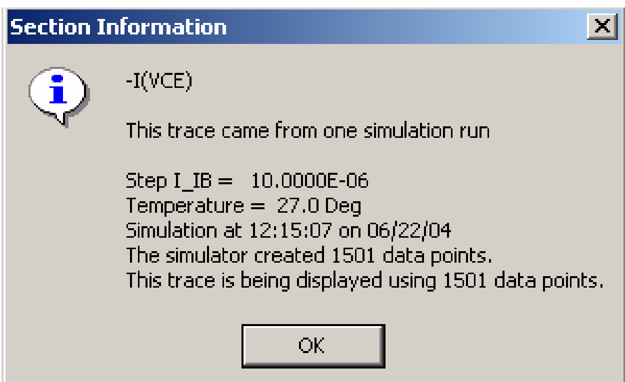
The probe window appears. Click the Add traces Button and add a trace for the collector current I_C which is given by the negative of the output variable I(VCE). The resulting graph is shown.

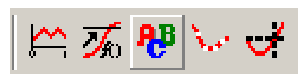


To determine which curves corresponds to which value of the current I_B click on a curve with the right mouse button and select information. A dialog will appear containing information about the state of the circuit when the simulation was performed. Thus the green curves corresponds to I_B=10µA.

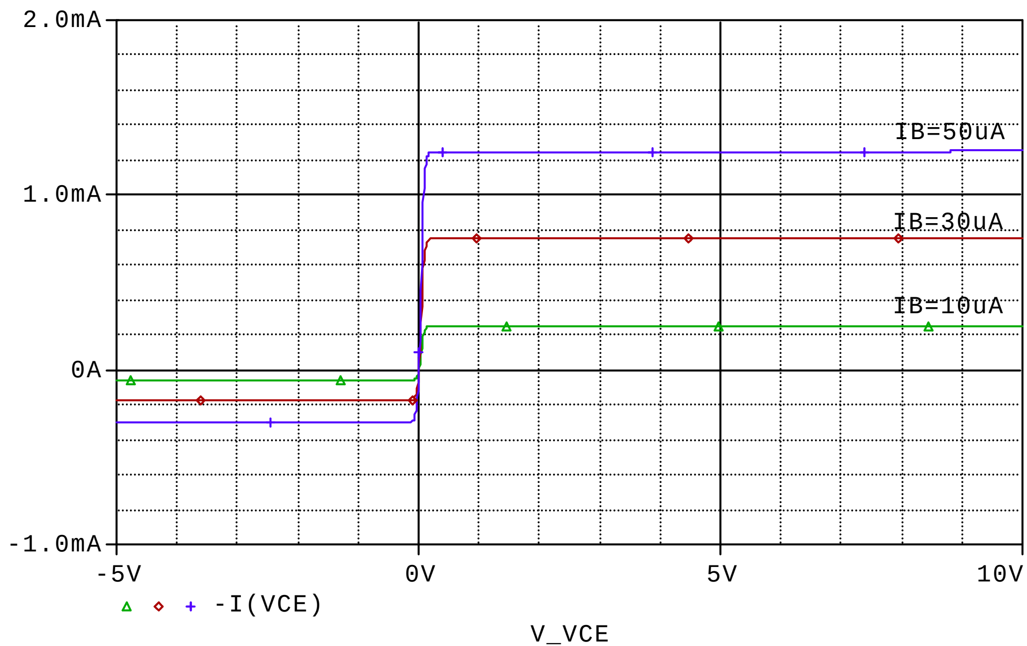


Labels can be added to each curve using the Text Label Button. Click the text label button and type I_B=10uA.





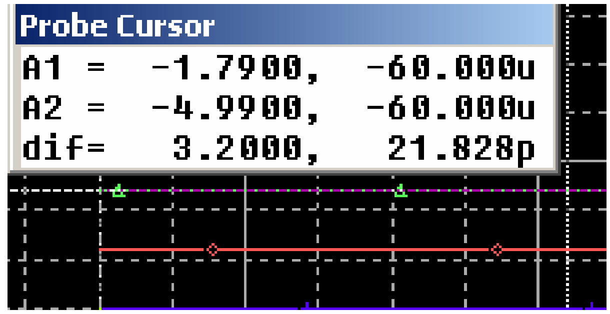
Click OK and stamp the label beside the green curve to which it corresponds. Repeat for the other two plots which correspond to 30µA and 50µA.



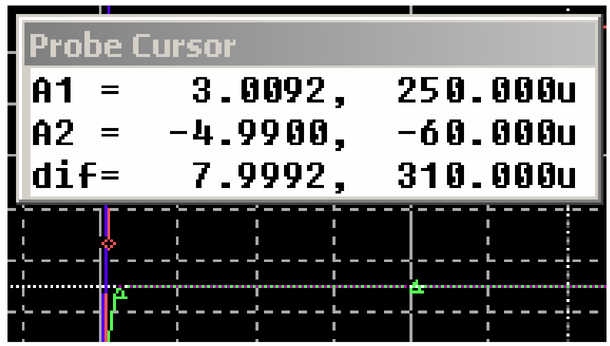
Notice that the collector current is higher when I_B is higher. Note that in the reverse and forward active regions the collector current is virtually constant and does not depend on V_{CE} but in the saturation region the current varies quite dramatically with small changes in V_{CE}.

Using the cursor measure the collector current in the reverse and forward active regions to determine if our calculations were correct. Click the Toggle Cursor button to activate the cursor.

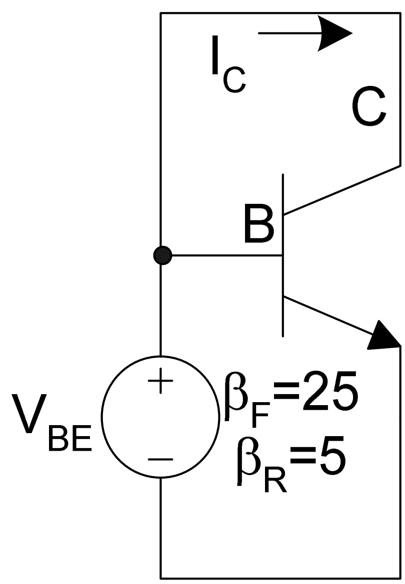
Use cursor A1 and its controlling left mouse button to move the cursor to any point in the reverse active region on the curve corresponding to I_B=10μA. the value is read from the second column as -60μA. This is exactly the value previously calculated.



Now move the cursor to any point on the same plot in the forward active region. The value is again read from the second column as 250μA. The value calculated was 260μA and thus there is a minor and negligible difference between the two results.

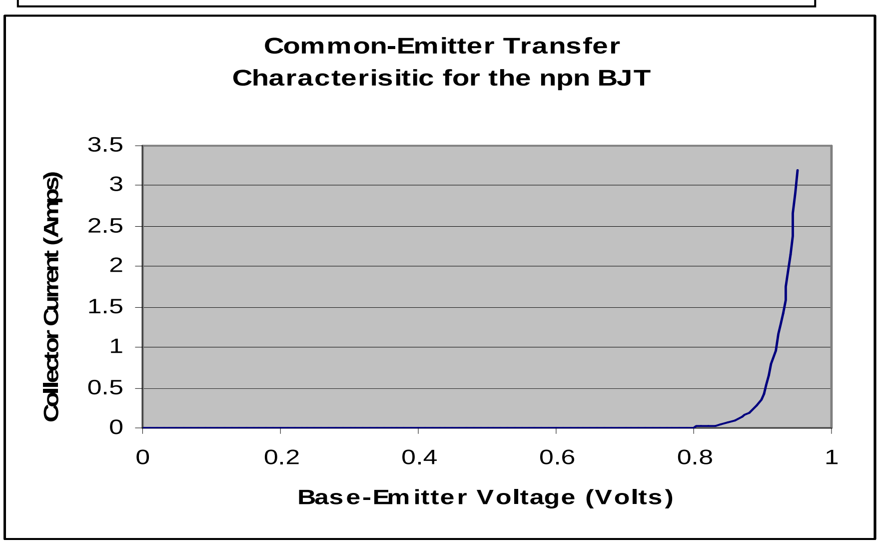


Example 2) Sketch the common-emitter transfer characteristic for the npn Bipolar Junction transistor for the case when V_{BC}=0. The CE transfer characteristic shows the relationship between the collector current I_C and the Base-emitter voltage V_{BE}. Verify your result using a simulation in PSpice. Discuss the similarities between this characteristic and that of a pn junction diode. For the BJT the saturation current is I_S=0.1fA



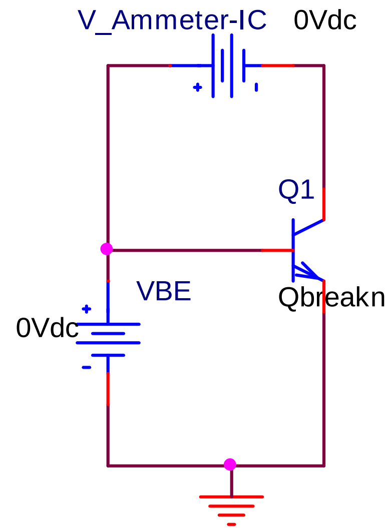
Analysis:

Since V_{BC}=0 the equation for the collector current reduces to $I_C = I_S\left(\exp\left(\frac{V_{BE}}{V_T}\right)-1\right)$. This is exactly the formula for the diode current.



Building the Circuit:

The circuit is basically the same as that used in Example 1 above. Again a 0Vdc voltage source is used to function as an ammeter to monitor the collector current I_C. The Circuit is shown to the right.

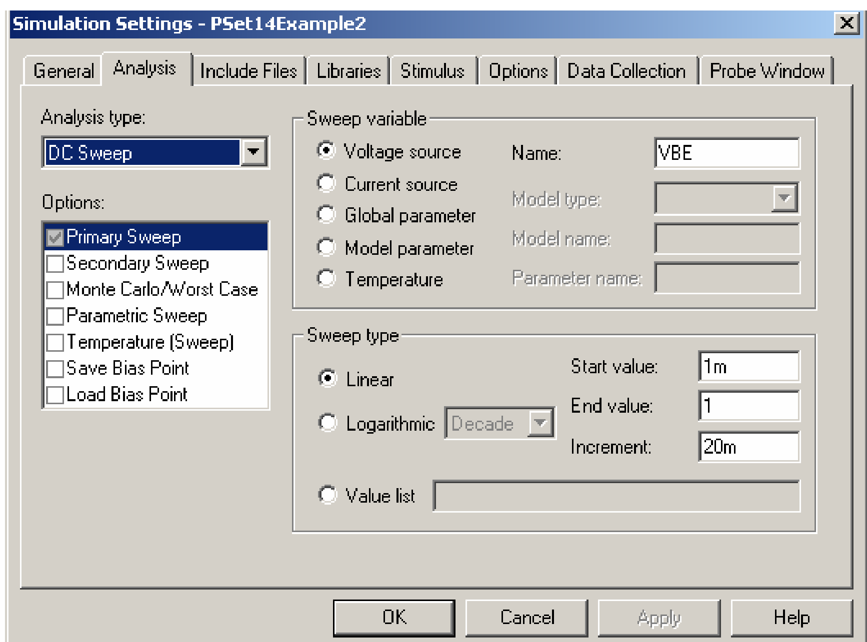


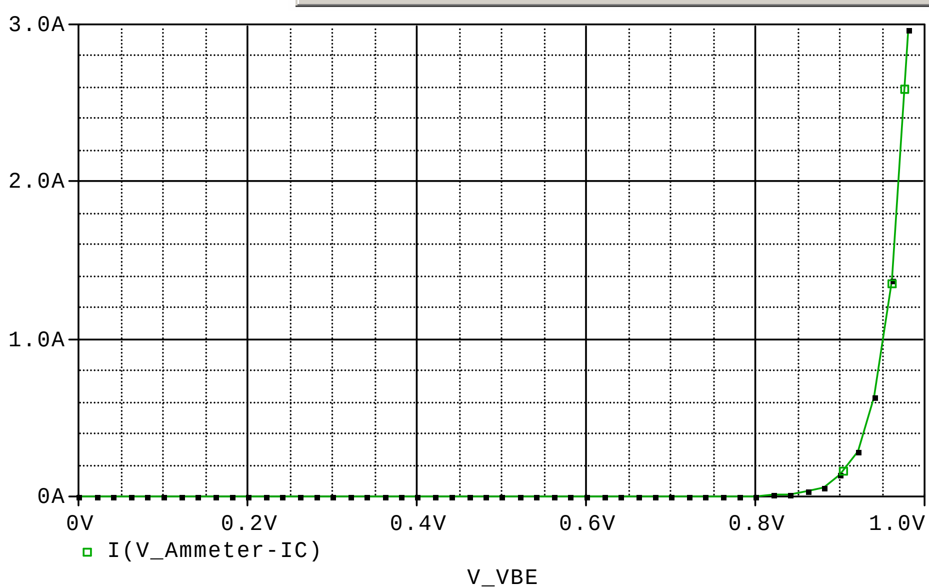
Netlist:

```
*source PSET14EXAMPLE2
Q_Q1              N00087     N00007 0 Qbreakn
V_VBE             N00007     0 0Vdc
V_V_Ammeter-IC    N00007     N00087 0Vdc
```

Simulating the Circuit:

Create a new simulation profile and set-up a DC Sweep for the voltage V_{BE} as shown. Run the simulation and add a trace for the collector current which corresponds to the current through the 0Vdc ammeter voltage source. The resulting plot is shown below.

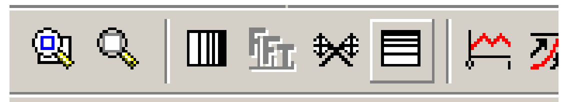


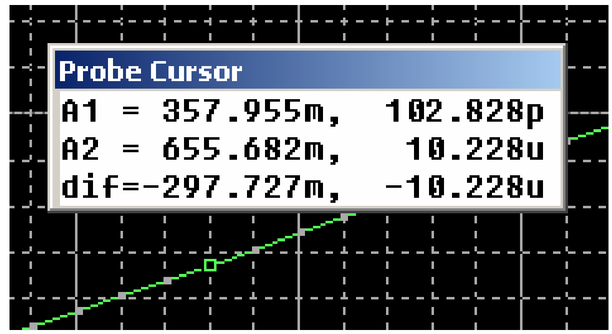


View the semi log plot of the transfer characteristic by clicking the Log Y Axis button. The plot appears as a straight line. To find the slop of this line we use the cursor. Applying cursor 1 at approximately 100pA and cursor 2 at approximately 10µA account for 5 decades. Thus the voltage difference between these two points divided by 5 gives the voltage difference per decade.

$$\frac{\text{Voltage}}{\text{decade}} = \frac{297.727\text{mV}}{5\text{ decades}} = 59.5\text{mV/decade} \cong 60\text{mV/decade}$$

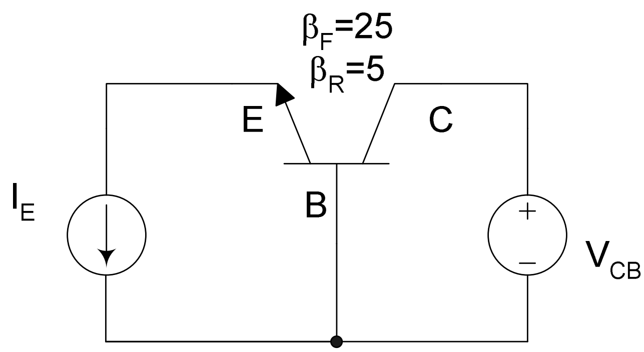
An increase of only 60mV in the base-emitter voltage will increase the collector current by a factor of 10.





Similar Circuits and Exercises:

Problem 1) Sketch the common-base output characteristic for the npn Bipolar Junction transistor in the shown circuit for I_E=0.2mA. Verify your result using a simulation in PSpice. Vary the collector-base voltage V_{CB} between -0.85V and 5V with a step size of 10mV. Perform this sweep for emitter currents I_E ={0.2mA, 0.6mA, 1mA}. Plot the resulting collector current waveforms.



Problem 2) Sketch the common-emitter output characteristic for the pnp Bipolar Junction transistor in the shown circuit for I_B=10µA. Verify your result using a simulation in PSpice. Vary the emitter-collector voltage V_{CE} between -5V and 10V with a step size of 10mV. Perform this sweep for base currents I_B ={10µA, 30µA, 50µA}. Plot the resulting collector current waveforms.