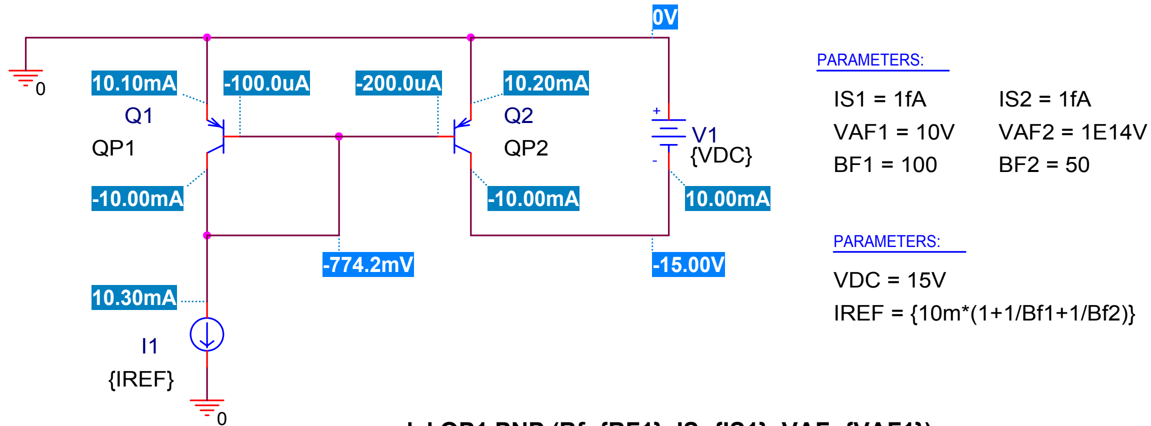
ECE 304 Fall '04 Lab 1

Objective

The behavior of a current mirror is simulated.

Schematic



.model QP1 PNP (Bf={BF1}, IS={IS1}, VAF={VAF1})

.model QP2 PNP (Bf={BF2}, IS={IS2}, VAF={VAF2})

FIGURE 1

Schematic for current mirror; dot-model statements for the two devices are shown

Discussion of non-ideal mirror behavior

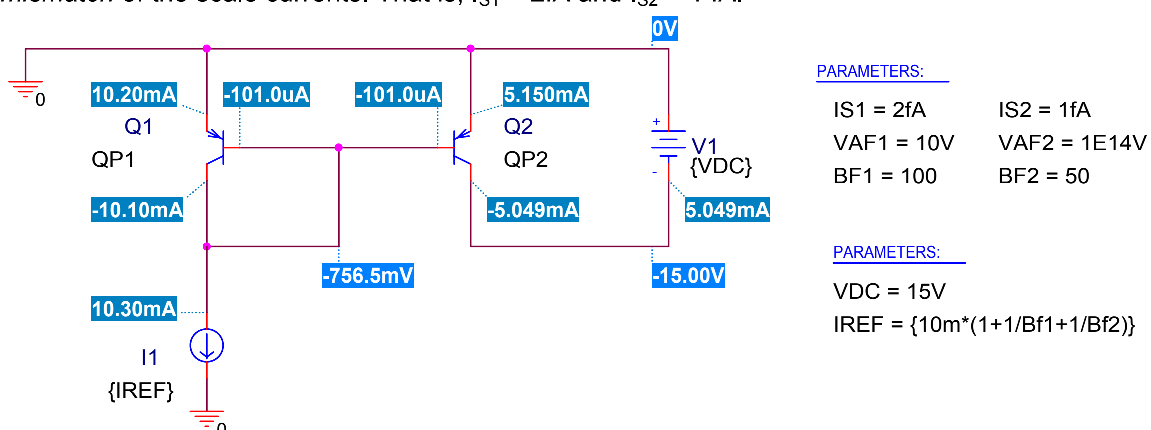
Ideally, the current at the mirror output is the same as the current I_{REF}. However, this ideal behavior is seldom observed for the following reasons:

1. Transistors draw base current

The schematic in Figure 1 shows a current mirror for which the current I_{REF} is bigger than the output current by the contribution of the two base current for Q1 and Q2. The situation can be even less ideal if the scale current I_S of the two transistors are different, as shown in Figure 2.

2. Transistors have different scale currents I_S.

In Figure 2 it is seen that the output current is only half the reference current because of *mismatch* of the scale currents. That is, I_{S1} = 2fA and I_{S2} = 1 fA.



.model QP1 PNP (Bf={BF1}, IS={IS1}, VAF={VAF1})

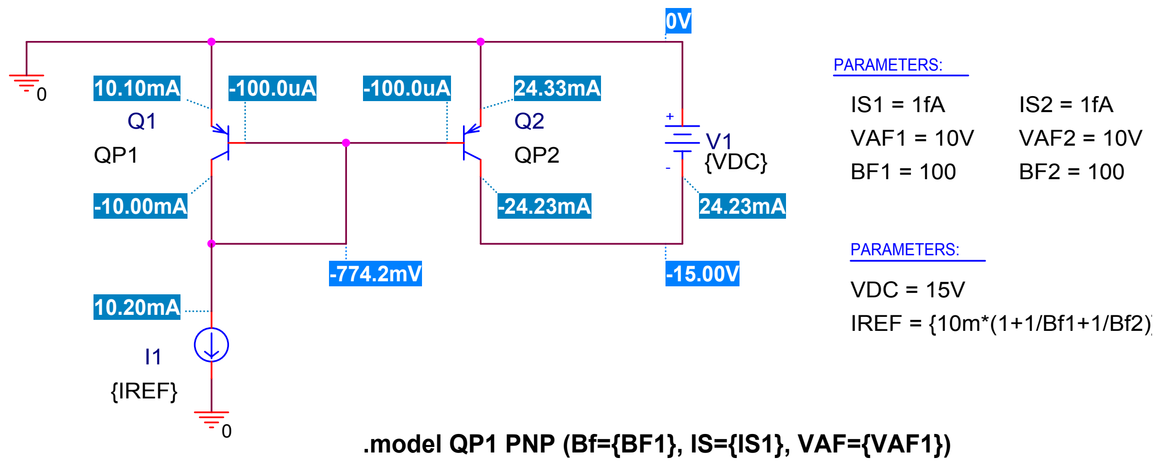
.model QP2 PNP (Bf={BF2}, IS={IS2}, VAF={VAF2})

FIGURE 2

Same circuit as Figure 1 but transistors have different scale currents: I_{S1} = 2fA, I_{S2} = 1 fA.

3. Early voltage and the Early effect

Another cause of non-ideal behavior is the Early voltage. In both Figure 1 and Figure 2 the Early voltage of Q2 is very large (V_{AF} = 1E14V). This means that the output current of Q2 is nearly independent of the collector-base voltage V_{CB}. On the other hand, the current in Q1 is for V_{CB} = 0V, so its Early voltage does not matter. In Figure 3, both transistors are identical, but Q2 has V_{BC} = (–774mV+15V) ≈ 14.2V, while Q1 has V_{BC} = 0V. Because of the Early effect, the output current is much larger than I_{REF}.



.model QP1 PNP (Bf={BF1}, IS={IS1}, VAF={VAF1})

.model QP2 PNP (Bf={BF2}, IS={IS2}, VAF={VAF2})

FIGURE 3

Matched transistors, but different values of V_{CB}

Exercise

Taking the *I-V* characteristic of the bipolar as

EQ. 1

$$I_C = I_S e^{V_{EB}/V_T}\left(1+\frac{V_{BC}}{V_{AF}}\right),$$

where V_T = thermal voltage (about 25.864 mV at 27°C) analyze the circuit of Figure 1 to find the current in terms of I_{REF}, I_{S1}, I_{S2} and V_{AF1}, V_{AF2}. Construct a spreadsheet to test your result. The spreadsheet should have the structure shown in Figure 4 with the CHARTS input page shown in Figure 5.

Current Mirror

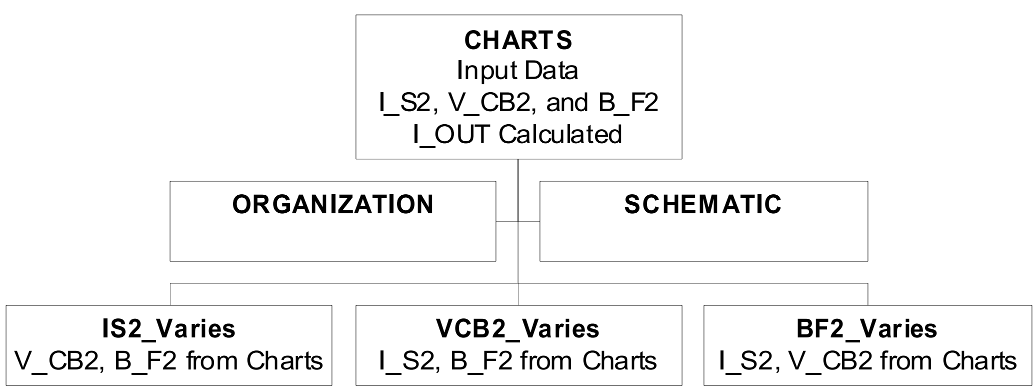


FIGURE 4

Organization of spreadsheet

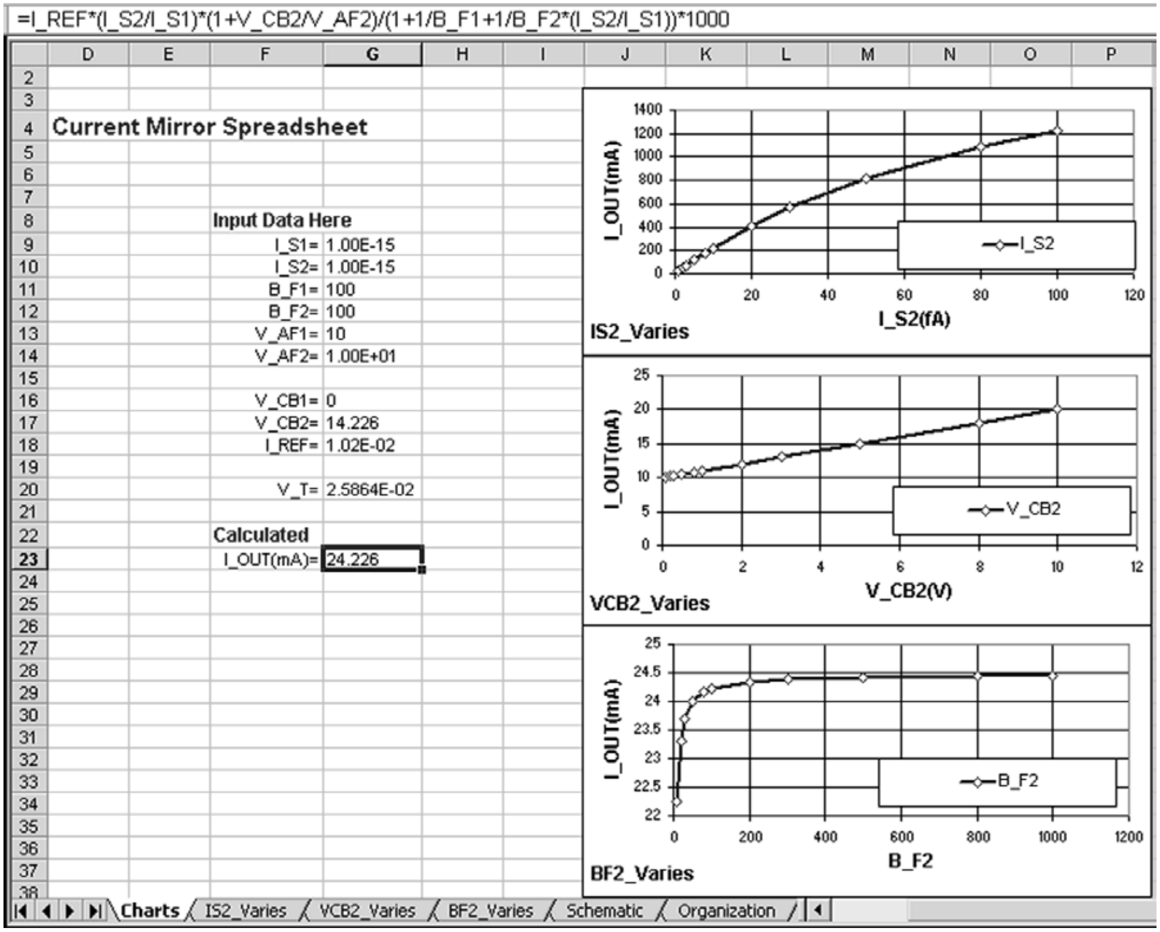


FIGURE 5

CHARTS worksheet; the formula you must derive is in the formula box

Verification of spreadsheet

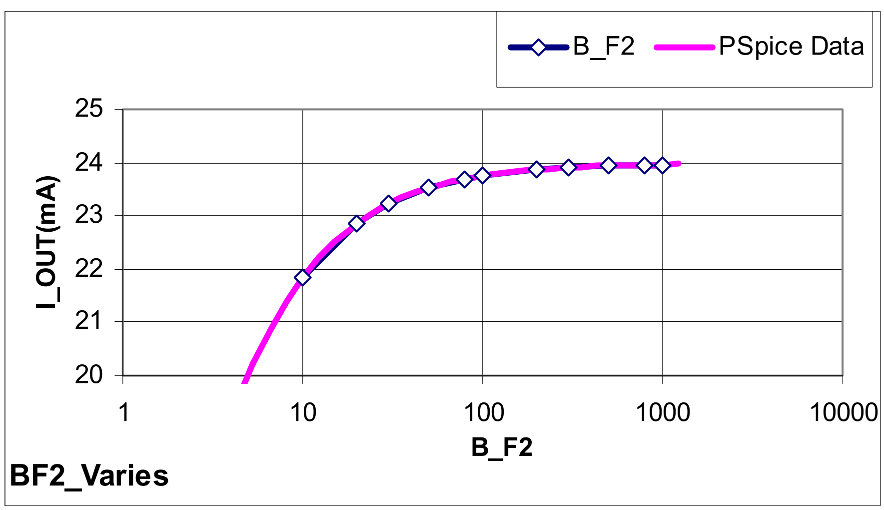


FIGURE 6

Comparison with PSPICE for case shown in Figure 7

PARAMETERS:

IS1 = 1fA	IS2 = 1fA
VAF1 = 10V	VAF2 = 10V
BF1 = 100	BF2 = 100

FIGURE 7

Parameters for Figure 6 except one parameter is swept

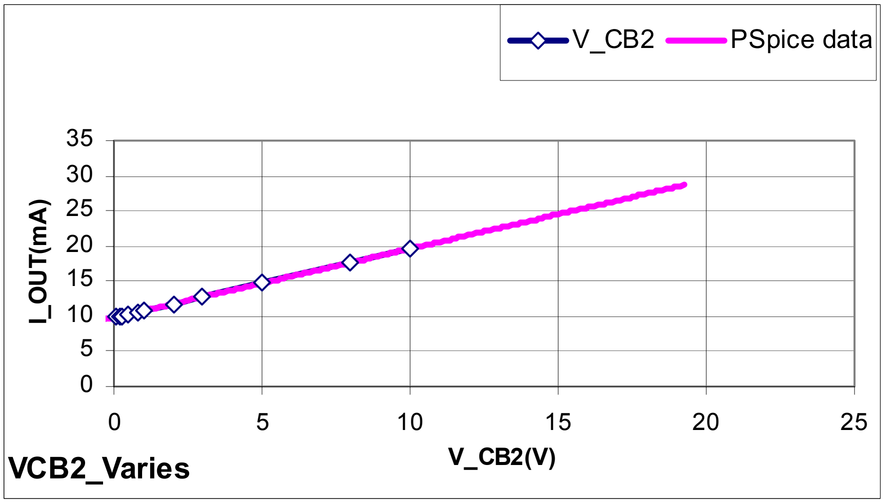


FIGURE 8

Comparison with PSPICE for case shown in Figure 7

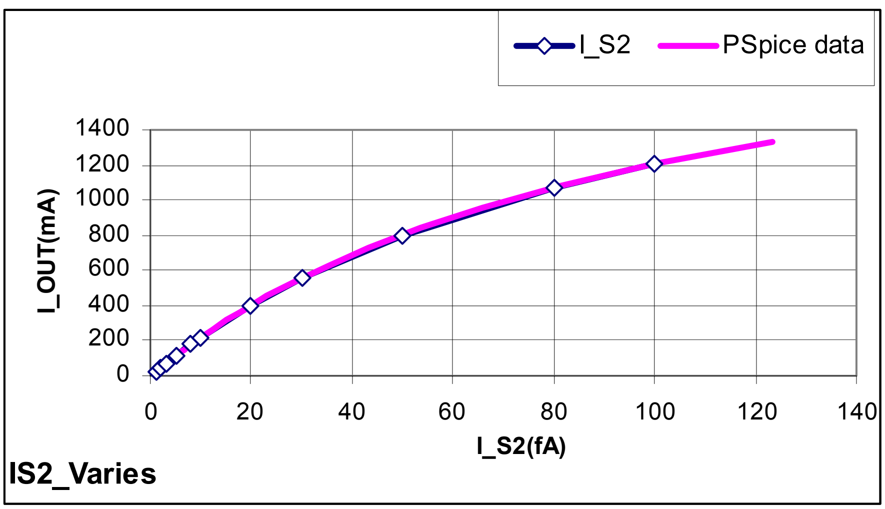


FIGURE 9

Comparison with PSPICE for case shown in Figure 7

The comparisons shown in Figure 6, Figure 8 and Figure 9 are made by doing a PSPICE DC SWEEP of the parameter involved. For example, for the V_{CB} sweep, the simulation profile uses the menu of Figure 10, where actually V_{DC} is the variable swept. Then to get a plot vs. V_{BC} we use the menu in PROBE shown in Figure 11.

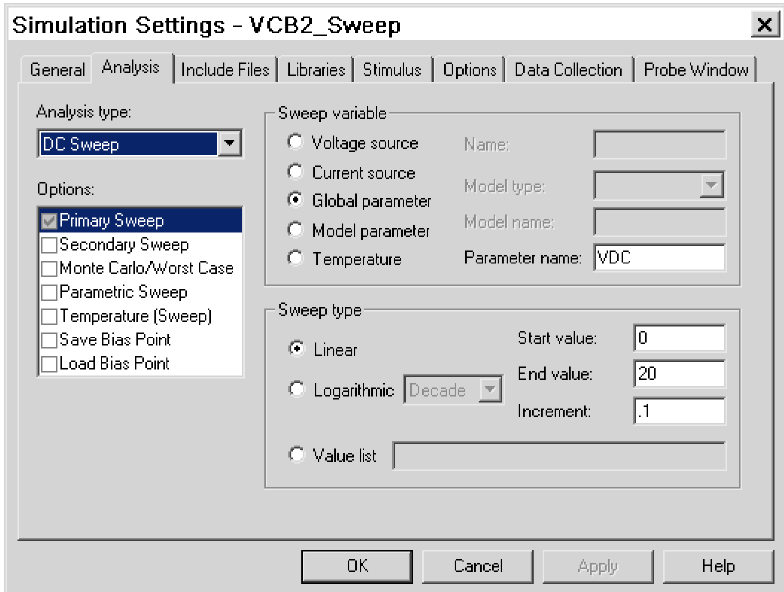


FIGURE 10

DC SWEEP menu for sweeping V_{BC}

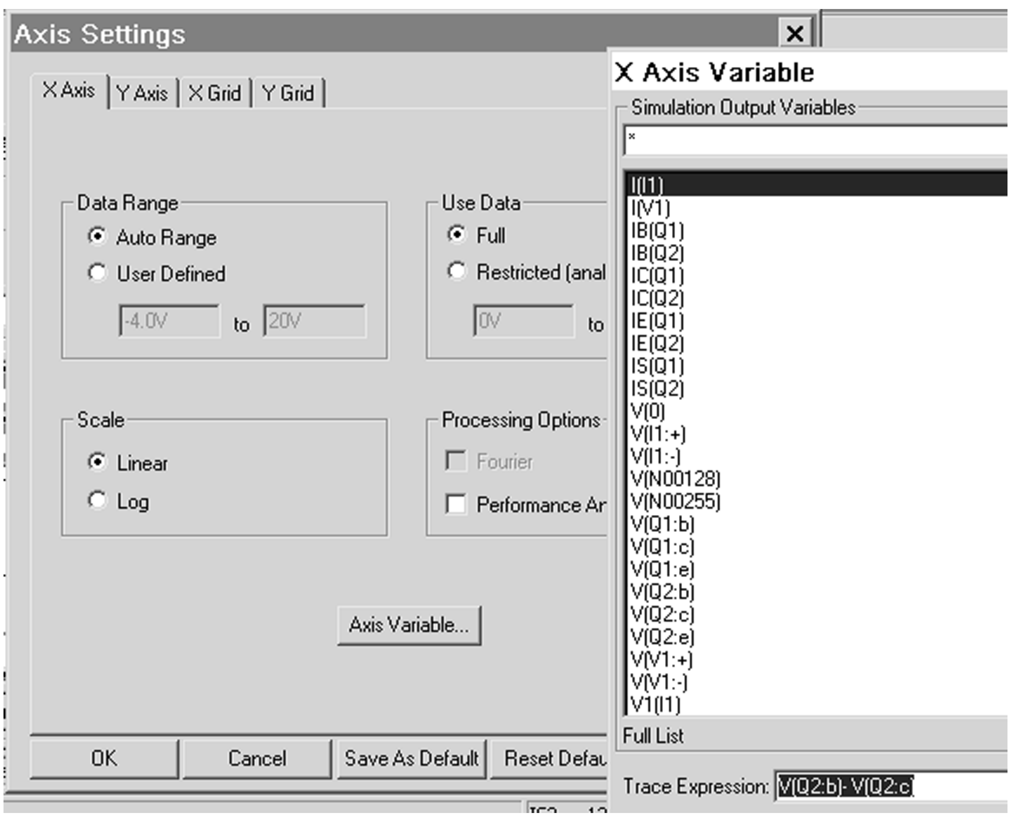


FIGURE 11

Using PLOT/AXIS SETTINGS to obtain the AXIS SETTINGS menu, and then hitting the button AXIS VARIABLE to allow us to set the *x*-axis as $V_{BC}(Q2)$

With the axis set up as indicated, the PROBE plot looks like Figure 12.

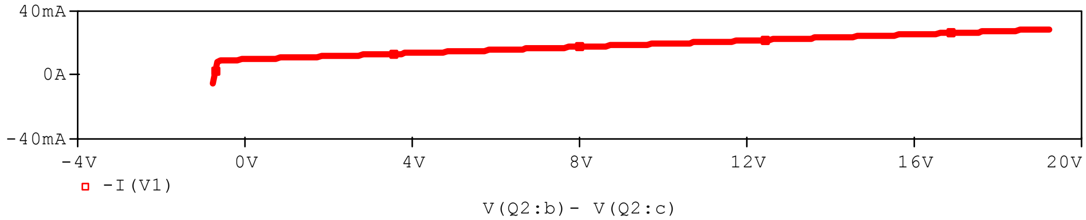


FIGURE 12

PROBE plot based on the menus of Figure 10 and Figure 11

Using Figure 12, we click on the title I(V1) to highlight it and then choose EDIT/COPY from the PROBE toolbar. Next, we go to the worksheet VBC2_Varies and place the cursor in a convenient location (say cell R7) right click and hit PASTE. The PROBE data is pasted into the spreadsheet. Right click on the chart and select SOURCE DATA/ADD. Fill out the menu to put the PSPICE data on the chart. Click on the LEGEND causing it to highlight. Place the cursor inside the legend and double click on the symbol for the PSPICE data. Move the cursor over the symbol for the PSPICE data and click to cause this symbol to highlight. Then double click to get the FORMAT LEGEND KEY menu of Figure 13. Fill out the menu.

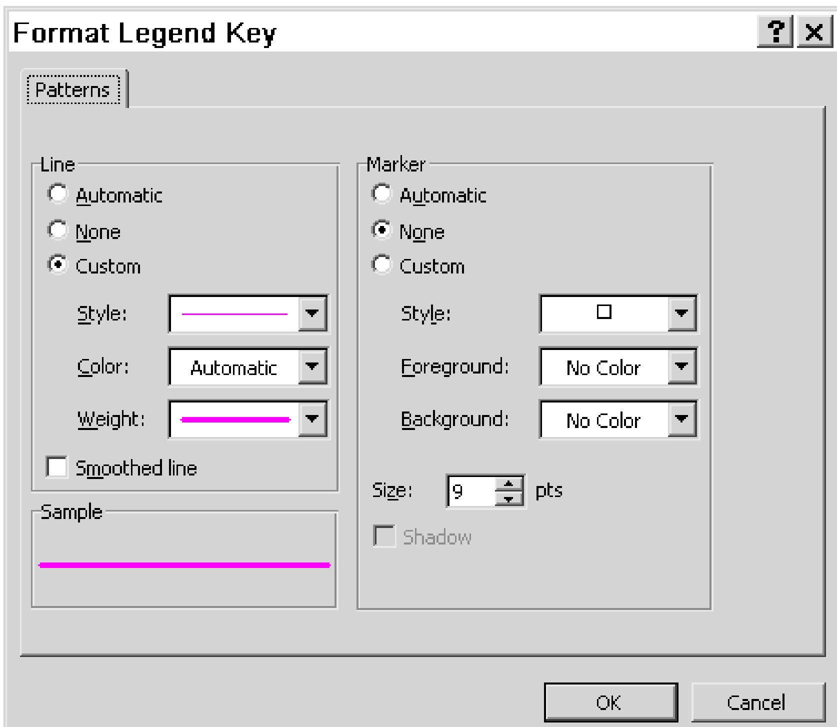


FIGURE 13

Setting the format for display of the PSPICE data curve

The result is the plot of Figure 8, which shows the calculated data (diamonds) lies on top of the PSPICE results, verifying the formula is working in providing the correct V_{BC}-dependence of the output current.

Summary

Here is what you have to deliver:

1. Derivation of I_{OUT}
2. Spreadsheet as described
3. Verification of spreadsheet using PSPICE
4. Report documenting each of the above steps, including detailed derivation