Experiment 4: Transistor Curve Tracer

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Purpose:

To generate a graphical display of the family of i-v curves over a range of inputs for a bipolar junction transistor and a MOSFET. For the BJT, the collector current i_C will be plotted vs the collector-to-emitter voltage v_{CE} for different values of base current i_B. For the MOSFET, the drain current i_D will be plotted vs the drain-to-source voltage v_{DS} for different values of gate-to source voltage v_{GS}.

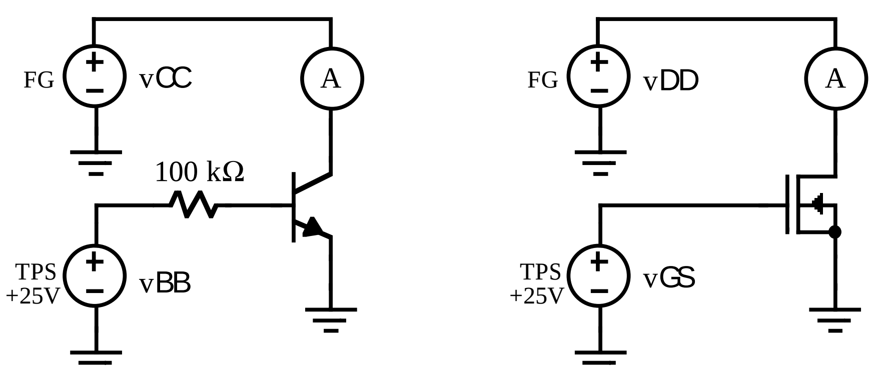
Method :

Using the MOSFET as an example, for each of a set of v_{GS} values, a sequence of v_{DS} values will be applied, and the graph of i_D vs v_{DS} produced for each case. Nested loops will be used to produce the two sequences. Each curve will be generated point-by-point as the sequences progress. The "retrace" line between the last point of one curve and the first point of the next curve will be suppressed.

Essentially the same procedure will be used for a bipolar junction transistor. In this case the base current i_B will also be measured, and the large-signal $\beta_F = i_C/i_B$ will be calculated and displayed for bipolar transistors. The small-signal $\beta_0 = \Delta i_C/\Delta i_B$ will also be obtained, as well as the transconductance $g_m = I_C/V_T$ (V_T is the thermal voltage, equal to 0.026 V at room temperature).

Hardware Setup:

The circuits for the BJT and the MOSFET are shown below.



Use a 2N2222 npn bipolar transistor and one of the n-channel MOSFETs on the CD4007 chip in your kit. The CD4007 chip contains three NMOS devices, one of which has an internal connection between source and body. Do not use that one. Either of the other two may be used for this experiment. Although its source and substrate will be connected together in this experiment, it will be used in Experiment 5 without that connection.

Note that no instrument is provided for measuring v_{CE} or v_{DS}. There is no need for one, because the voltage drop across an ammeter is negligibly small, so that the function generator output voltage is an excellent approximation to the desired terminal voltage in both cases. You should satisfy yourself that this is true. The 100 kΩ resistor can be retained in the MOSFET circuit, since no gate current flows. The circuits are then identical except for the active element.

Software Setup:

The usual instrument panels are needed for setting the default configuration of the function generator and the multimeter. The function generator operates in DC mode with load = infinity, and the multimeter measures DC Amps. The triple power supply needs a Direct I/O driver with an input terminal and the commands

WRITE TEXT "output on"
WRITE TEXT "appl p25v,",a,",0.001".

Also as usual, the real-time control of the function generator and the multimeter is done with component drivers, because they respond much faster than the instrument panels. The v_{BB} input to the triple power supply comes from a For Range object, as does the v_{CC} input to the **OFFSET** input terminal of the function generator driver. The nested FOR-loop function is implemented with a connection from the output terminal (not the sequence output pin) of the v_{BB} For Range box to the sequence input pin of the v_{CC} For Range box. In this way, each time a new v_{BB} value appears, the v_{CC} sequence is triggered. The next v_{BB} value does not appear until that sequence ends. If the sequence output pin were used, the v_{CC} sequence would be triggered only once, when the v_{BB} sequence ends.

The i-v curves will be viewed on an X vs Y Plot object, whose X input comes from the function generator **OFFSET** input pin, and whose Y input comes from the **READINGS** output of the multimeter driver. Include markers with the display. If the program is run at this point (with appropriate voltage ranges chosen for the two drivers) the family of curves will be displayed, but annoying "retrace" lines will appear, connecting the end of each curve with the beginning of the next. These can be eliminated by adding a control input terminal to the XY plot object (***Object Menu --> Add Terminal -- > Control Input --> Next Curve***). Connect this terminal to the sequence output pin of the v_{CC} For Range object. Now, when the program runs, a pulse appears at the XY plot control pin at the end of each v_{CC} sequence to tell the display that a new curve is about to appear, which should not be connected to the previous one.

It remains to calculate and display β_F when a bipolar transistor is being measured.
The i_C values are already available from the multimeter; i_B (in A) can be calculated from

$$i_B = \frac{v_{BB} - v_{BE}}{R_B} \approx \frac{v_{BB} - 0.65}{10^5} \qquad (4\text{-}1)$$

It is best to use the basic units (amperes, volts, and ohms) in all Agilent VEE calculations because the display objects use these units on their axes. The calculation is an approximation because the exact value of v_{BE} is not known, and the 100 kΩ resistor has a tolerance of ±10 percent or so. Your result will be more accurate if you use the measured value of the base resistor instead of the nominal one.

Connect the input terminal of the triple power supply driver to the **a** input terminal of a Formula object, and the multimeter driver output to the **b** terminal of the same object. The formula for β_F is

b/((a-0.65)/100k).

Finally, connect the output of this Formula object to an alphanumeric display. You should also display the values of i_B and v_{BB} , and collect the i_C values in an array that can be viewed.

Procedure:

Connect the 2N2222 BJT in the circuit. Set the v_{BB} range to 1 to 6 volts with a step of 1 volt, and the v_{CC} range to 0 to 8 volt with a step of 0.1 or 0.2 volt. Open the XY plot object and run the program. As usual, you may need to click on **Auto Scale** to place the curves in view. Use the markers to calculate the value of r_0, the inverse slope in the forward active region, for the lowest and the highest curves. Use the markers also to estimate V_{CEsat}.

Estimate the value of β_0, the small-signal β, defined by the differential quantity di_C/di_B. To do this, set the v_{BB} range to something like 3 V to 3.05 V, with a step of 0.6 V. Only two closely spaced curves will be drawn. The value of Δi_C can be obtained with use of the plot markers, and the two corresponding i_B values will be displayed during the two scans of v_{CC}.

Repeat the experiment with an NMOS transistor that has its substrate and source connected together externally, so that the body effect is eliminated. Again find r_0 values for the highest and lowest curves.

Find the Early voltage for both transistors. This is defined as $r_0 i_C$. It should be a constant, independent of the curve from which r_0 was calculated. Determine whether this is true, and compare the Early voltages for the BJT and the MOSFET. Which device approximates more closely a constant-current element?

Label and save both transistors for use in later experiments.

Repeat the experiment, using one of the PMOS transistors on the CD4007 chip. Be sure to make the necessary polarity changes in your circuit and software. Record and explain your results.

The program in its present form has an obvious defect. When a MOSFET is being measured, meaningless values of i_B (actually i_G) and β_F will be calculated and displayed. This problem can be solved by allowing the user to specify which device is being measured, and permitting display of i_B and β_F only when a BJT is present. This requires some additional logic components. Experiment with a Text Constant object, an If/Then object, and Gate objects. Remember that information on any object is available from ***Object Menu --> Help.***

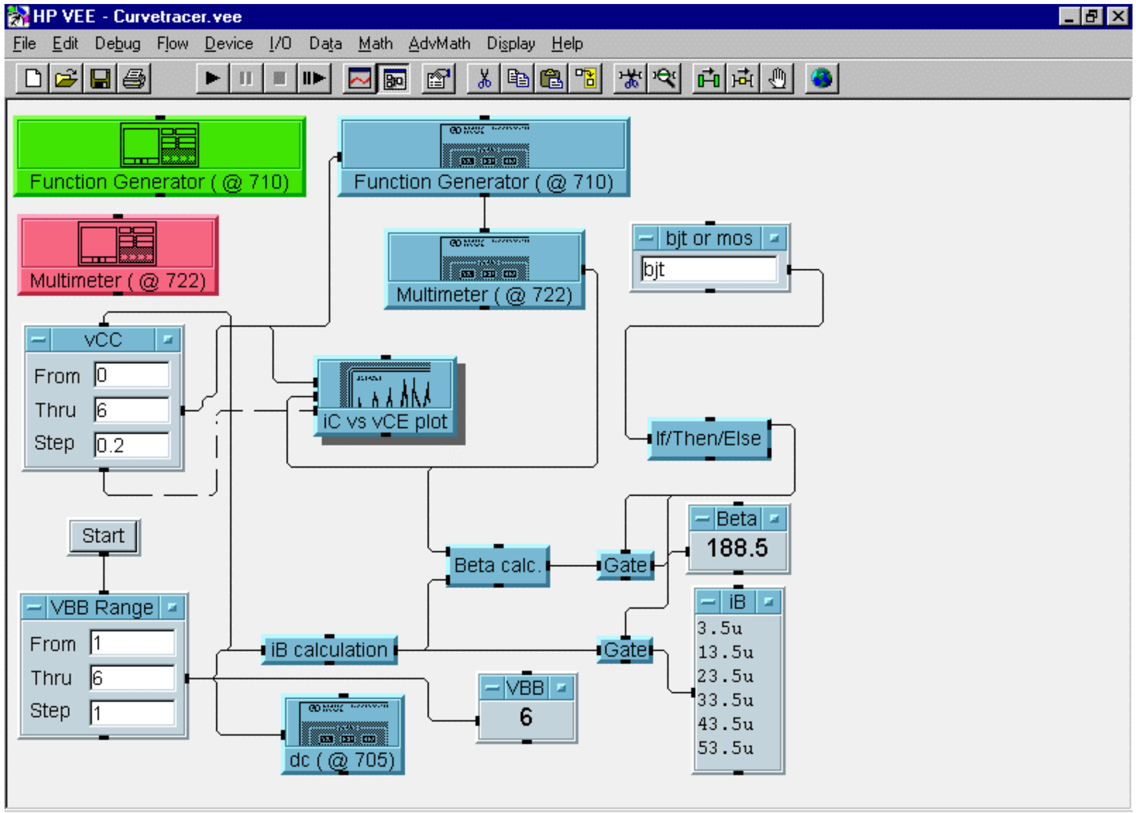


Fig. 4-2 Agilent VEE Setup