Low-Cost Curve Tracer
Uses PC-Based Scope

Peter D. Hiscocks, James Gaston
Syscomp Electronic Design Limited
`phiscock@ee.ryerson.ca`
`www.syscompdesign.com`
June 22, 2007

1 Introduction

There are times when its extremely useful to know the voltage-current characteristic of some semiconductor device. Perhaps you're matching two transistors. Or you need to determine the characteristic of some unknown surplus transistor.

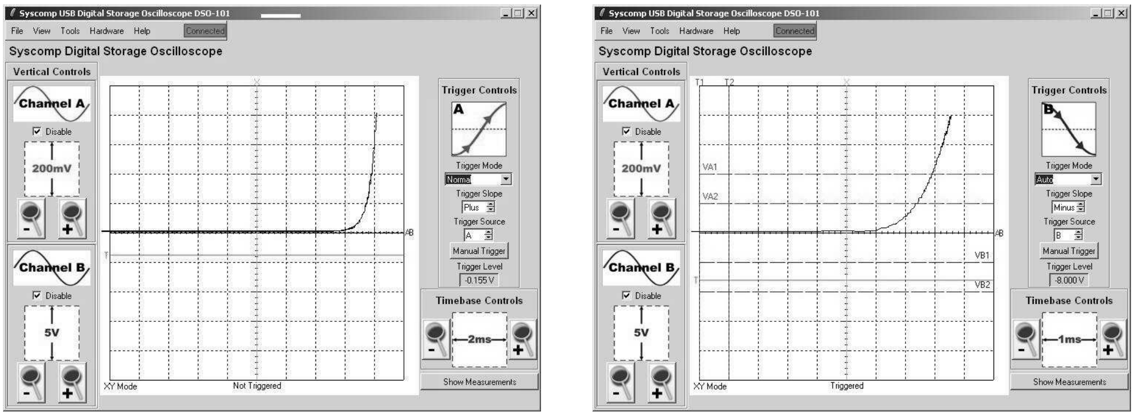
It's possible to obtain a VI Plot by hand with an ammeter, voltmeter and adjustable power source – and lots of patience. It is much more convenient to display the complete curve in an automated measurement using an instrument called a *curve tracer*.

On a curve tracer, a resistor appears as a straight line with slope inversely proportional to resistance. A diode shows no current in the reverse direction and substantial current in the forward direction (figure 1 shows an example).

Curve tracers are available from various manufacturers as an integrated instrument which includes the power supplies, switches and XY display (*see* Resources). They're convenient to use but they are expensive and take up significant bench space. For an occasional simple measurement or when constrained by modest finances, it is possible to create a curve tracer using the XY plotting facility of an oscilloscope and some simple external circuitry.

2 Example: Small Signal Diodes

Figure 1 shows how a curve-tracer can be useful, comparing two small signal diodes. Figure 1(a) is a type 1N4148 silicon diode. Figure 1(b) is an unknown type germanium point-contact diode.



(a) Silicon Diode 1N4148

(b) Point Contact Diode

Figure 1: Small Signal Diodes. The horizontal scale is simply the setting of Channel A: 200mV/div. The vertical scale is the setting of Channel B divided by the series resistance, 300Ω, that is, $5\text{V}/300\Omega = 16.6$mA/div.

Notice:

- The threshold voltage of the silicon diode (the forward voltage at which it begins to conduct substantially) is ≈ 0.6 volts.
- The threshold voltage of the germanium diode is much lower, ≈ 0.2 volts.
- The voltage across the germanium diode approaches that of the silicon device at higher current.

This information can be obtained with point-by-point measurement of the device characteristics. But a curve-tracer shows more information, and at a glance.

3 How it Works

Figure 2 shows the circuit for a simple curve-tracer. In the diagram, the test device is a diode, but it could be any two-terminal component.

The autotransformer provides an adjustable source of AC voltage, which is then isolated and stepped down by the transformer. Because the secondary of the transformer is isolated from ground the ground point of the oscilloscope can be established at the junction of the resistor and diode under test.

Then Channel A reads the voltage across the device (X axis on the curve tracer) and Channel B reads a voltage which is proportional to the current through the device (Y axis). The Channel B voltage is negative, so the oscilloscope is adjusted to invert that trace.

In the spirit of 'using what is on hand', the demonstration circuit used a 300Ω, 2 Watt resistor. A peak of 20 volts across 300Ω corresponds to 66mA peak current which is suitable for low-current testing of diodes and other components. (A choice of resistance such as 250Ω would yeild an integer value for the current scale.)

The autotransformer is adjusted upward while watching the current and voltage on the display.

An alternative design could eliminate the autotransformer and plug the transformer directly into the AC line. An adjustable power resistor would then control the peak current in the device under test. However, this arrangement applies full voltage to the device under test when it's switched on, and there might be fireworks if the device rating is exceeded. The autotransformer allows the voltage and current to be increased gradually while watching for signs of stress in the device.

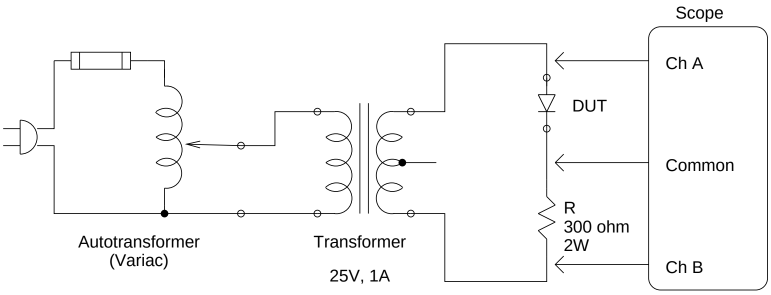
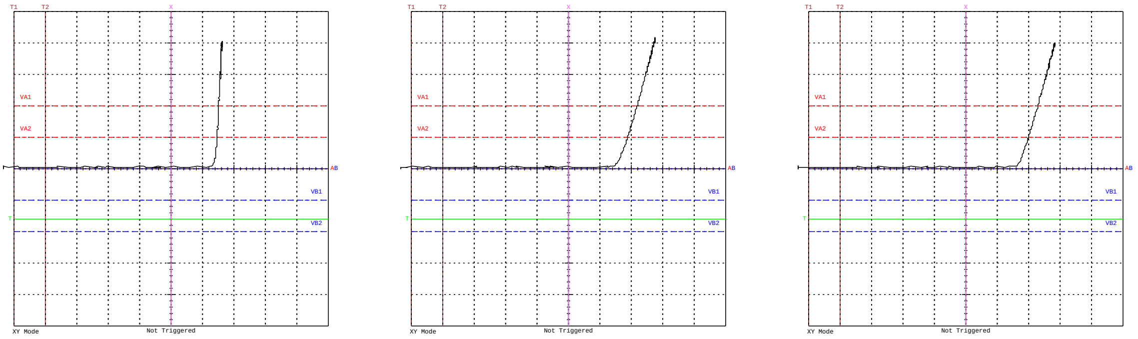


Figure 2: Diode Curve Tracer

4 Light Emitting Diodes

Figure 3 shows the VI characteristics of three light emitting diodes, captured using the ’save to postscript’ facility of the DSO-101 oscilloscope.



(a) Red (b) Yellow (c) Green

Figure 3: Light Emitting Diodes: X axis 1V/div, Y axis 16mA/div

All three LEDs have a threshold voltage in the order of 1.5 volts. Once conducting, the yellow and green LEDs show a significant resistance. For example, the incremental forward resistance of the yellow LED is given by the reciprocal of the slope:

$$r_f \approx \frac{\Delta V}{\Delta I} = \frac{1\text{V}}{50 \times 10^{-3}\text{A}} = 20\Omega$$

The incremental forward resistance would be useful in constructing an equivalent circuit for the LED in a simulation model.

5 Shottky Diode

Figure 4 shows the VI characteristic of a small-signal Schottky diode of unknown type. Notice the low threshold voltage (about 0.2 volts) and significant forward resistance, about 40Ω.

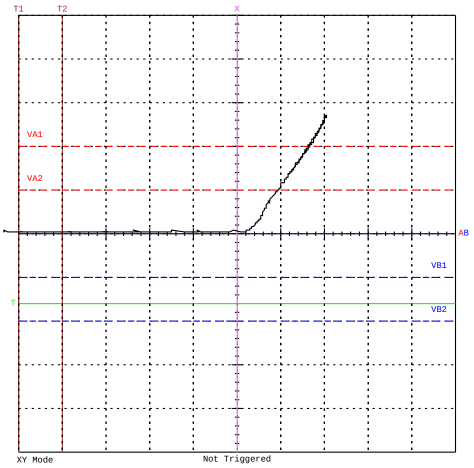


Figure 4: Shottky Diode: X axis 1 volt/div, Y axis 16mA/div

6 Zener Diode

Figure 5 shows the VI characteristic of a zener diode type 1N4691, 6.2V. As expected, the zener conducts at a threshold of 0.6V in the forward direction and 6 volts in the reverse direction. Notice the abrupt threshold and vertical descent at 6 volts. The transition is very sharply defined and the incremental resistance is small, both desireable qualities in a zener.

7 Incandescent Lamp

An incandescent lamp uses a resistive-wire filament, so one would expect it to appear on the curve tracer as a diagonal straight line. The temperature of the filament changes dramatically as current increases. That changes the resistance, which then changes the slope of the line.

Figure 6 illustrates this effect. It's a composite of the VI characteristic of a small incandescent lamp, type #53. At low peak current, the line is relatively steep. As the peak current increases, the slope decreases. The end points of the VI characteristic at various operating points are indicated by circles. The final trace has a significantly smaller slope (larger resistance).

8 JFET Constant Current Diode

Rectifier diodes and zener diodes are constant voltage devices. For example, the zener diode of figure 5 maintains a constant reverse voltage of 6 volts or so, independent of reverse current.

A Junction FET will function as a *constant current diode* if the gate is connected to the source terminal. (A diode must be inserted in the AC supply so that the JFET experiences only positive drain voltage with respect to the source. See the 1N4148 diode in figure 8.)

The VI characteristic of the constant-current JFET is shown in figure 7. Notice that the voltage across the JFET must exceed about 5 volts for the device to enter its constant current region, where the trace is approximately horizontal. The constant current value is ≈ 8.3mA

The slope of the constant-current region may be modelled as the internal resistance of the current source in the Norton

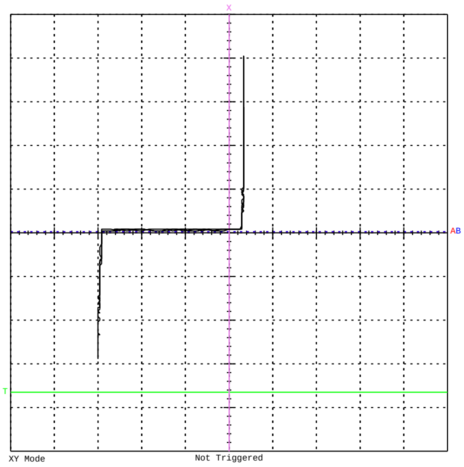


Figure 5: 1N4691, 6.2V Zener: X axis 2 volt/div, Y axis 16mA/div

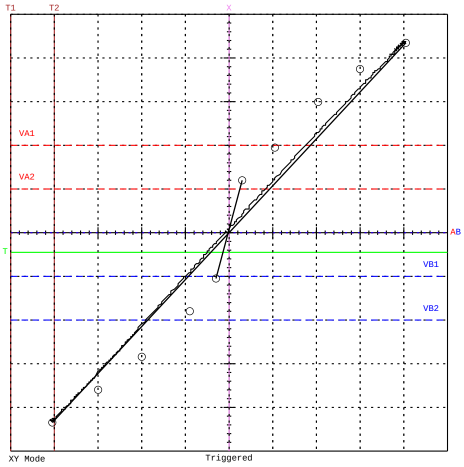


Figure 6: Incandescent Lamp: X axis 2 volt/div, Y axis 16mA/div

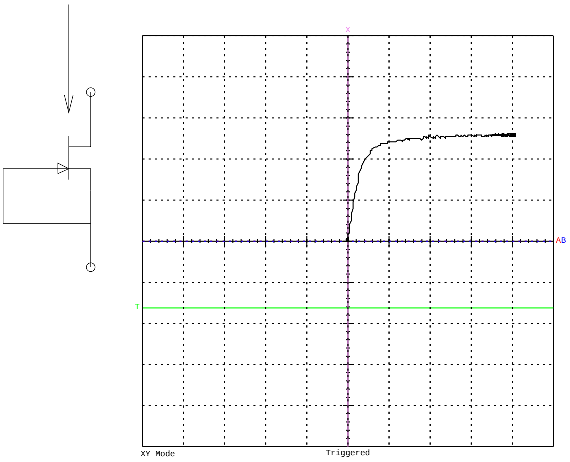


Figure 7: JFET Constant Current Diode: X axis 5 volts/div, Y axis 3.3mA/div

equivalent circuit. A careful examination of the curve[1] yeilds an incremental resistance

$$r_o = \frac{\Delta V}{\Delta I} = \frac{20\text{V}}{0.7\text{mA}} = 28\text{k}\Omega$$

9 JFET, Variable Gate Voltage

The JFET is a *depletion mode* device. It conducts maximum drain current for gate-source voltage V_{gs} equal to zero, as we saw for the constant-current diode above. The drain current is reduced by making the gate terminal negative with respect to the source. This is accomplished in figure 8 with the addition of a DC variable voltage supply V_{gs}.

In the absence of a variable DC voltage supply, a 9 volt battery with potentiometer could be used to control the gate voltage.

As the gate voltage is made more negative, the drain current decreases. The effect on figure 7 is to move the flat portion of the characteristic closer to the X axis as shown in figure 9.

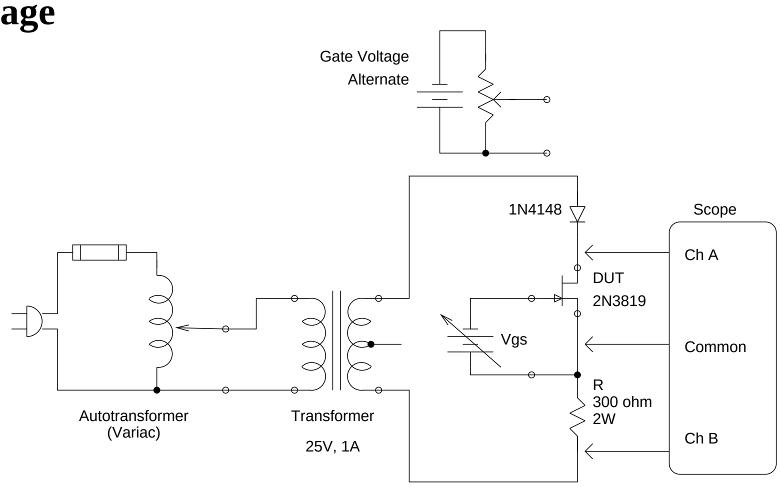
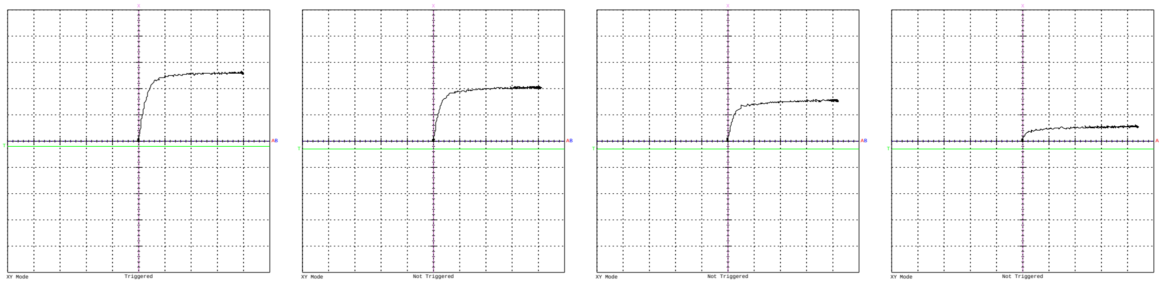


Figure 8: JFET Variable Bias Measurement

The transconductance g_m of the JFET (its *gain*) can be determined by the relative change in drain current per unit change in gate voltage: $g_m = \frac{\Delta I_D}{\Delta V_{gs}}$



(a) V_{gs}=0V (b) V_{gs}=-0.49V (c) V_{gs}=-0.96V (d) V_{gs}=-2.08V

Figure 9: JFET, Variable Gate Voltage: X axis V_{DS} 5V/div, Y axis I_D 3mA/div. As the gate voltage is made more negative with respect to the source terminal, the drain current decreases.

Figure 8 is the arrangement for testing an N-Channel JFET. For a P-Channel device, the 1N4148 diode would be reversed and the base voltage supply V_{gs} would be reversed.

---

[1] This can be aided by printing an enlarged version of a screen-capture image.

10 Junction Transistor, Variable Base Current

A bipolar junction transistor (BJT) can be tested in a similar setup to the JFET constant-current diode. The collector current is some multiple of the base current (a factor of beta, the current gain), so the circuit requires some method to inject current into the base terminal.

Figure 10 shows the measurement schematic. An adjustable DC power supply drives current through resistor R_b, around the base-emitter loop. The transistor base current is determined by the setting of the DC supply.

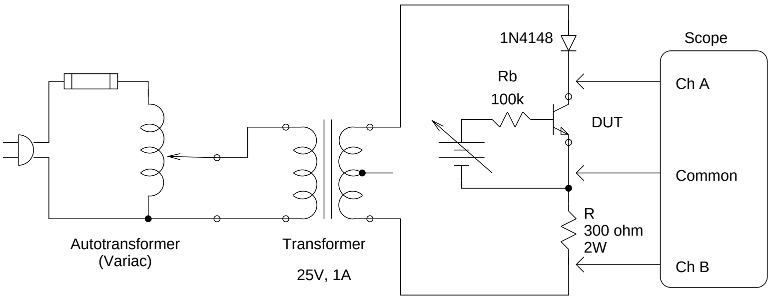
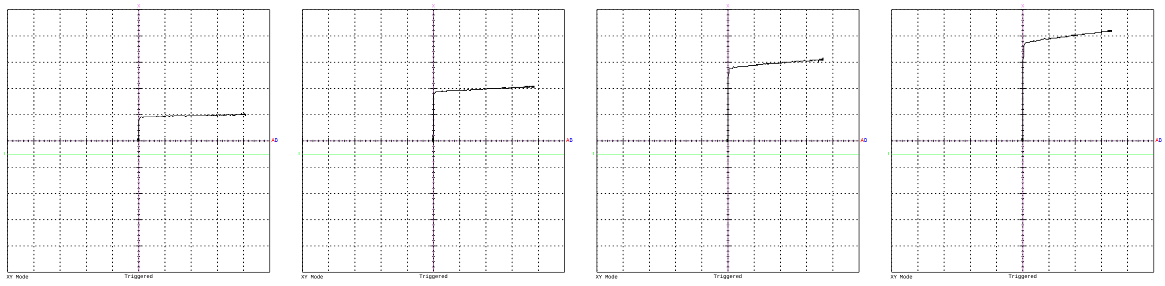


Figure 10: Junction Transistor Measurement



(a) $I_b = 22\mu$A (b) $I_b = 45\mu$A (c) $I_b = 66\mu$A (d) $I_b = 88\mu$A

Figure 11: BJT, Variable Gate Voltage: X axis V_{CE} 5V/div, Y axis I_C 3mA/div. As the base current I_B increases, the collector current I_C increases proportionally. Notice how the slope of the V_{CE}, I_C characteristic increases at greater collector current. This indicates that the incremental output resistance r_o is decreasing.

It is interesting to compare the JFET and BJT curves, figures 9(b) and 11(b), for example. The drain-source voltage of the JFET must be in the vicinity of 5 volts before it enters its constant-current region. The collector-emitter voltage of the BJT is much less to enter its constant-current region.

As the base current I_B increases, the collector current I_C increases proportionally. Notice how the slope of the V_{CE}, I_C characteristic increases at greater collector current. This indicates that the incremental output resistance r_o is decreasing.

Figure 12 confirms this with an expanded view of the BJT saturation region. The BJT requires $\approx$ 200mV to enter it's constant current region.

Consequently, the BJT can be made to operate lower supply voltages than the JFET.

The current gain β of the BJT can be determined by the relative change in collector current per unit change in base current:

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

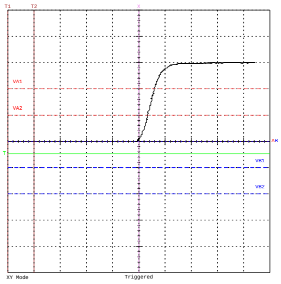


Figure 12: BJT Saturation Region: X axis V_{CE} 200mV/div, Y axis I_C 6.6mA/div

11 Equipment Setup

Figure 13 shows the equipment setup. From left to right:

- Autotransformer for adjustment of line voltage
- 117VAC to 24V transformer for isolation
- Device under test (lamp) and current sensing resistor
- DSO-101 oscilloscope hardware
- Laptop computer

The autotransformer in this setup is *much* larger than necessary. For low currents, a sine wave signal generator could be used instead.

Figure 13: Equipment Setup

12 Syscomp DSO-101 Oscilloscope

The Syscomp DSO-101 oscilloscope is an excellent choice for displaying the device curves, with the following features:

- The input signals can be displayed in XY mode - simultaneously with conventional X-Time mode waveforms. This is useful in checking that the input waveforms are not distorted
- The software supports trace inversion on both channels, and this allows a traditional voltage-current display with positive current up the screen and positive voltage to the right.
- The screen display can be captured and then incorporated in a document. For example, figure 1 was obtained by *screen capture*, which shows the control settings. Figure 3 was obtained by the *save to postscript* facility, which captures the screen area by itself.
- Some oscilloscopes have a limited range of input voltage for the horizontal axis display. The input channels of the DSO-101 can be adjusted over a wide range range in seven amplitude settings. This facilitates the display of large or small signals on either axis.

13 Summary

Characteristic curves for semiconductor devices can be measured using the simple arrangement of equipment shown in this paper. Different types of measurements require different circuits, but the wiring is simple and straightforward to set up and the cost is negligible compared to a commercial curve tracer.

This curve tracer circuit was used for small current and voltage measurements, but it would be simple to extend the circuit to large currents and voltages[2].

---

[2] The curve tracer circuits referenced in *Resources* are limited to small-signal values.

14 Resources

Syscomp DSO-101 PC-Based Oscilloscope
`www.syscompdesign.com`
The classic Tektronix 575 Curve Tracer:
`http://pcbunn.cithep.caltech.edu/jjb/Tektronix/tektronix.htm`

Measurement Concepts: Semiconductor Devices
John Mulvey, Tektronix, 1969
A detailed exposition on the measurement of semiconductor device parameters using a curve tracer.

Transistor Curve Tracer
Melvin Chan, Electronics World Magazine, January 1968, pp55-60,66
A tranistor curve tester using discrete components.

Electronically Stepped Curve Tracer
A.J.Sargent, Wireless World Magazine, December 1969, pp576,577
A simple transistor curve tracer.

Analog-Digital Circuit Turns Scope Into Curve Tracer
Robert D. Guyton, Electronics, October 25, 1971, p80
A transistor curve tester using discrete components.

Versatile Transistor Curve Tracer
Ian Hickman, Electronic World, August 2000, pp 602-607

PC Printer Port Controls I-V Curve Tracer
Maxim Semiconductor, www.maxim-ic.com, Application Note 253, July 2001
`http://server.oersted.dtu.dk/ftp/database/Data_CDs/Component_data/Maxim_2001/0003/APPNO085.HTM`