ECE394 – Lab 5-1: Dynamic Curve Tracer

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The following images follow the results of Lab 5-1 from *The Student Manual for The Art of Electronics*.

1 Setup

We wish to view the I/V characteristics of a device on an oscilloscope. The general idea is to use one channel of the oscilloscope to measure the voltage over the device, and the other channel to measure the voltage over a resistor in series with the device. Since the resistor has a linear I/V characteristic, the second channel is also a measure of current.

We can use the X-Y mode of the oscilloscope to display the channel 2 output (I) as a function of the channel 1 output (V).

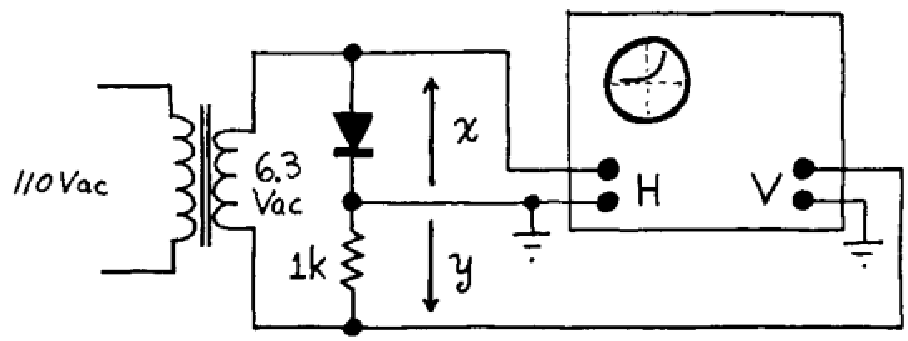


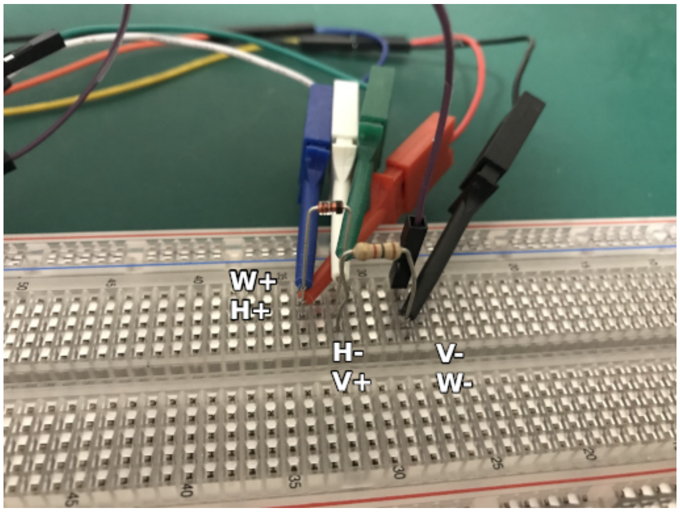
Figure 1: Dynamic Curve Tracer Schematic (source: student manual)

The student manual shows the use of a transformer so that we can set the ground to the central node. However, we can simply use a function generator to power the circuit if we have differential probes. (We simulate the transformer in LTSpice but use a function generator and differential probes in the built circuit.)

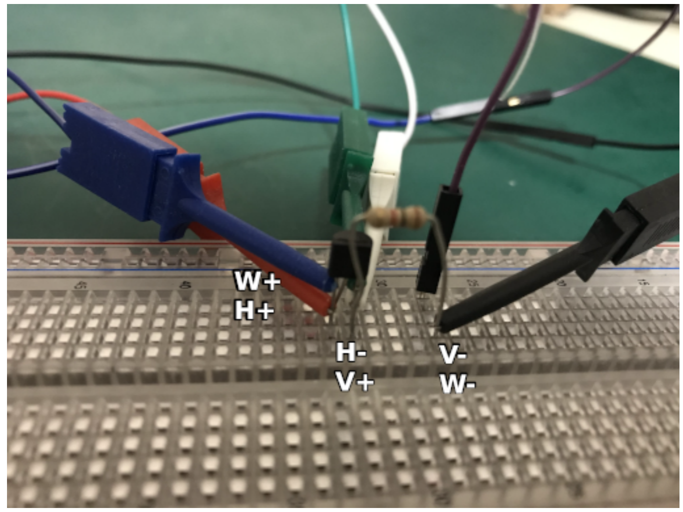
As the student manual states, we hope to show the (nonlinear) I/V curve of a diode or transistor. The Ebers-Moll model gives the I/V characteristic:

$$I = I_S \left(\exp \frac{V_{BE}}{V_T} - 1 \right)$$

1.1 Circuit setup



(a) 1N914 Setup



(b) 2N3904 Setup

Figure 2: Built circuit setup

In both setups, the function generator leads W+ and W- are connected on the ends. The first scope channel is connected across the device under test (across the diode, or across the BE-junction). For the transistor, the collector and base are tied together. The second scope channel is connected across the resistor.

Since the resistor is 1kΩ, the voltage value has to be divided by 1000 to get the correct current value (or the value can be taken in units of milliamps).

2 Part A. Diode

2.1 Forward-active diode

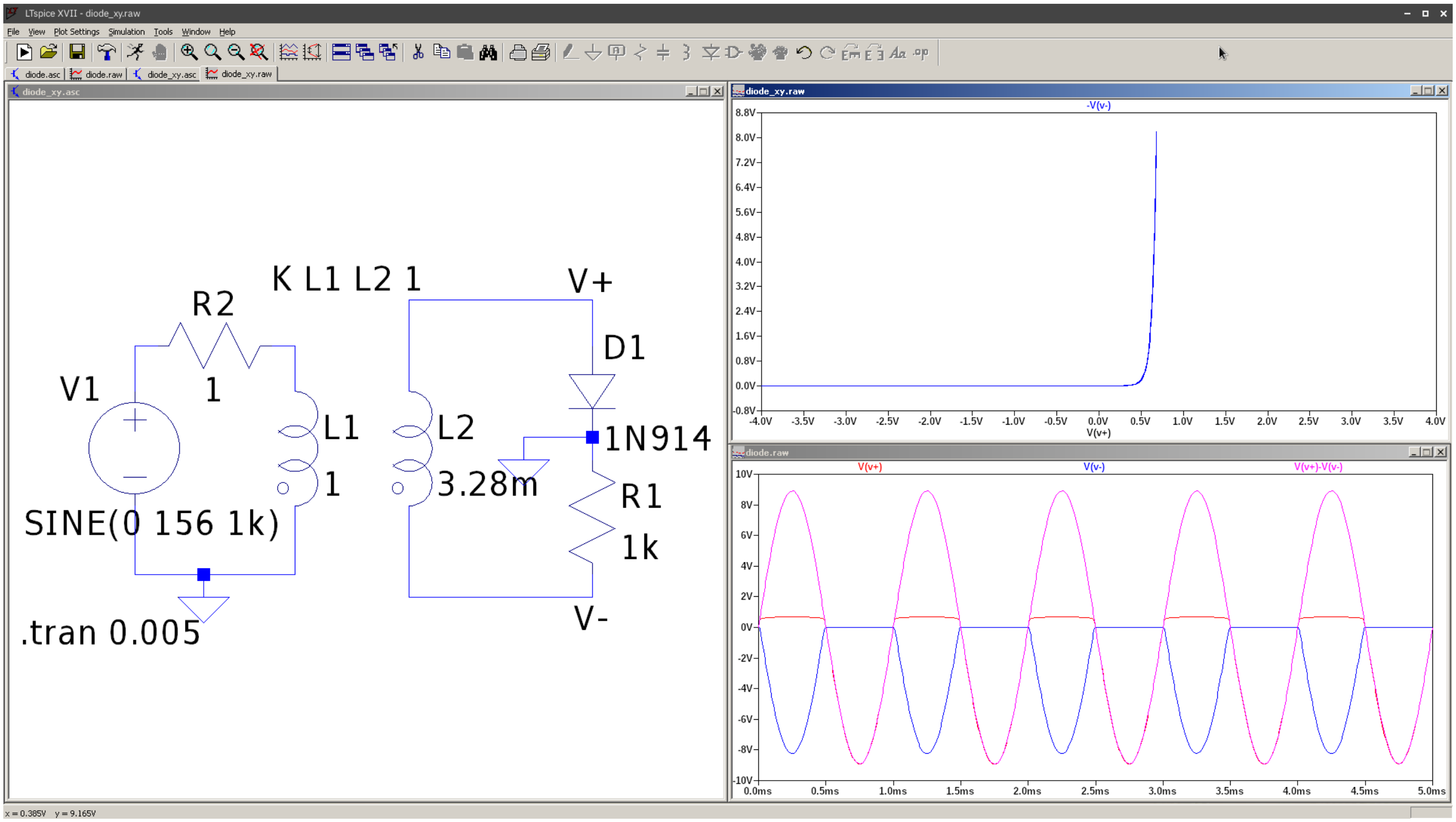


Figure 3: 1N914 Diode LTSpice simulation

The handbook notes that the slope of the V/I curve should be roughly 100mV/decade. This value can be derived from the Shockley diode equation:

$$I_D = I_S \exp \frac{V_D}{nV_T}$$

$$V_D = nV_T \ln \frac{I_D}{I_S} = V_T(\ln I_D - \ln I_S)$$

We want our result w.r.t the I_D on a logarithmic scale (in units of decades):

$$V_{BE} = nV_T \left[\frac{\log_{10} I_D}{\log_{10} e} - \ln I_S \right]$$

$$\frac{\partial V_D}{\partial \log_{10} I_D} = n \frac{V_T}{\log_{10} e}$$

At room temperature, we have $V_T \approx 26\text{mV}$, and the non-ideality factor for the 1N914 (given by LTSpice) is 1.752, so the slope has a value of 105mV/decade.

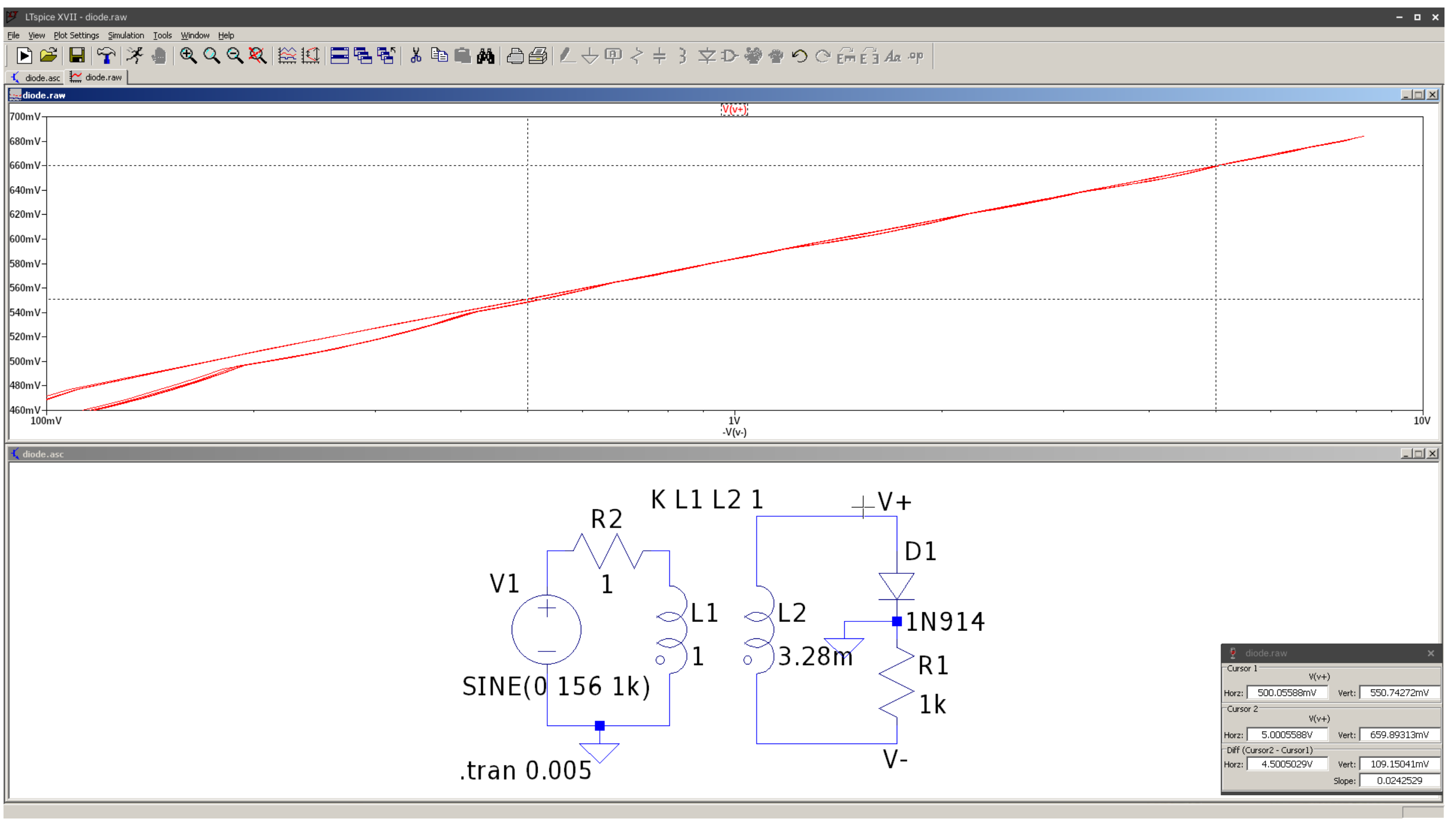


Figure 4: 1N914 Diode LTSpice simulation: showing V as a function of $\log_{10} I$; $\Delta V/\Delta I = 109.15\text{mV/decade} \approx 100\text{mV/decade}$

Figure 5: 1N914 Diode I/V characteristic

For this plot, the theoretical results are shown as blue points taken from the X-Y plot on Scopy. The X-axis is voltage (V) and the Y-axis is current (mA). The theoretical equation uses a value for I_S that was found on the Internet for the 1N914. I forgot to add the non-ideality factor, which may account for the slight discrepancy near the origin.

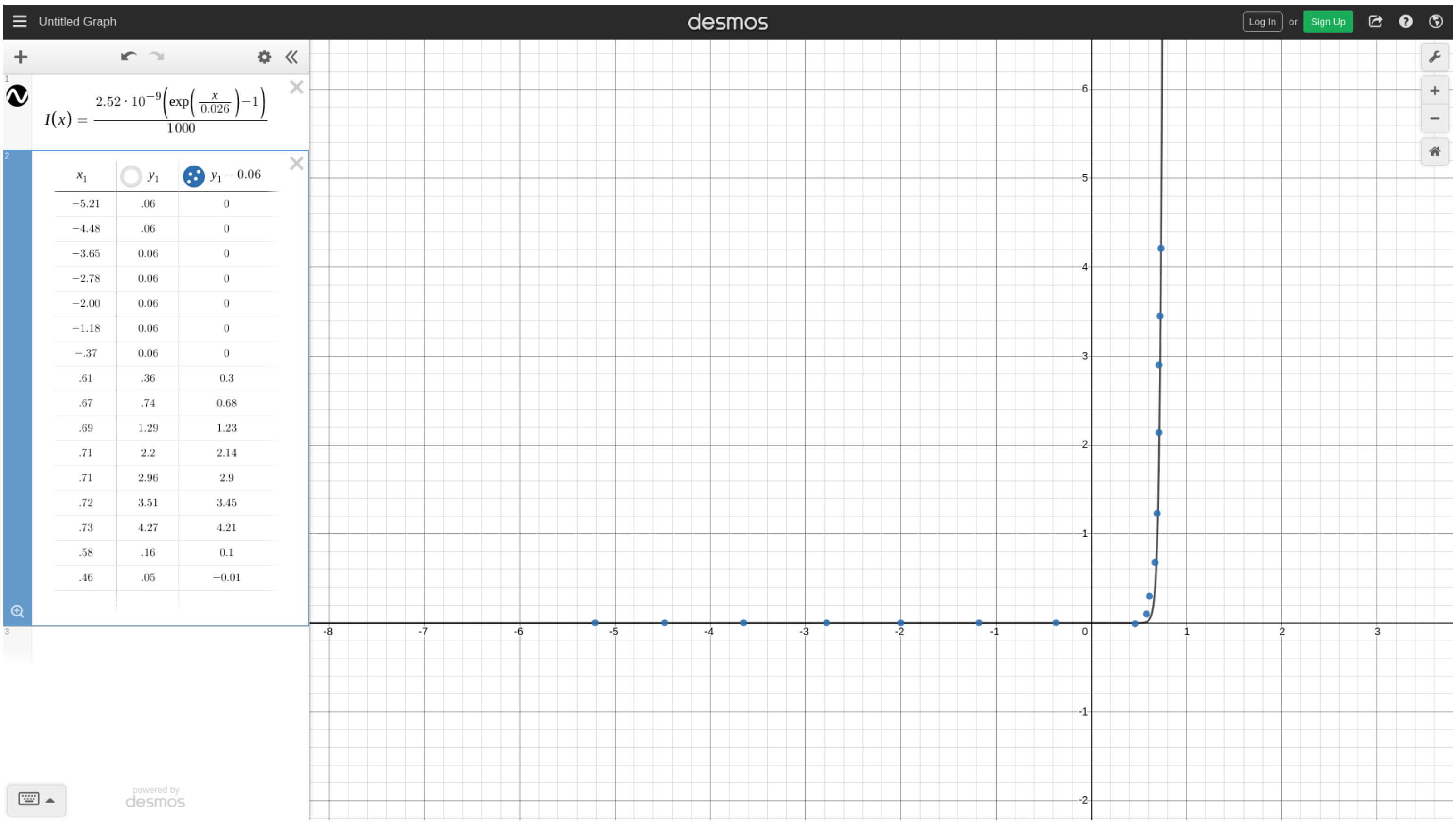


Figure 6: 1N914 Diode I/V Experimental vs. Theoretical

2.2 Reversed diode

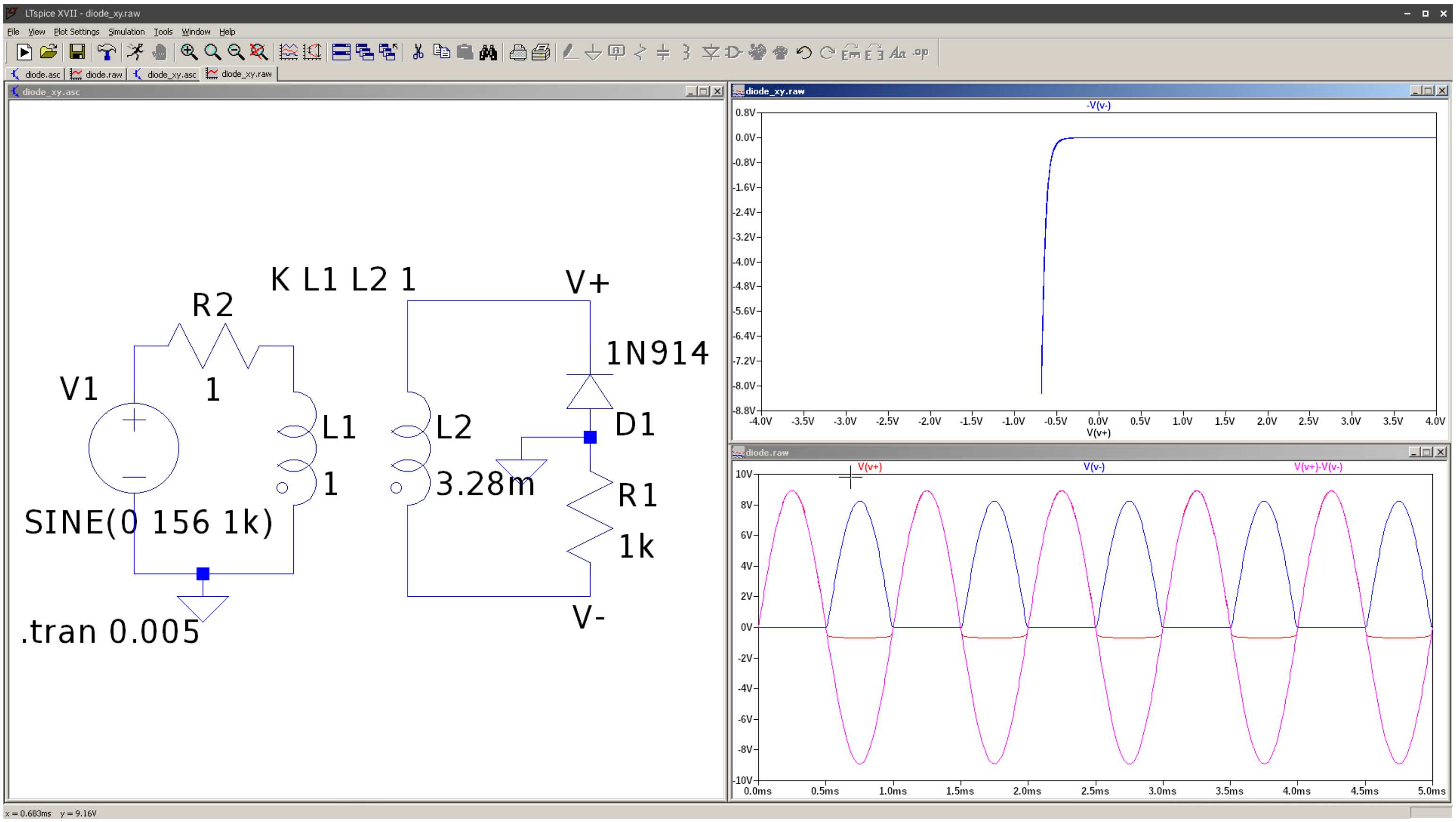


Figure 7: 1N914 Diode Reversed LTSpice simulation

2.3 Zener diode and breakdown

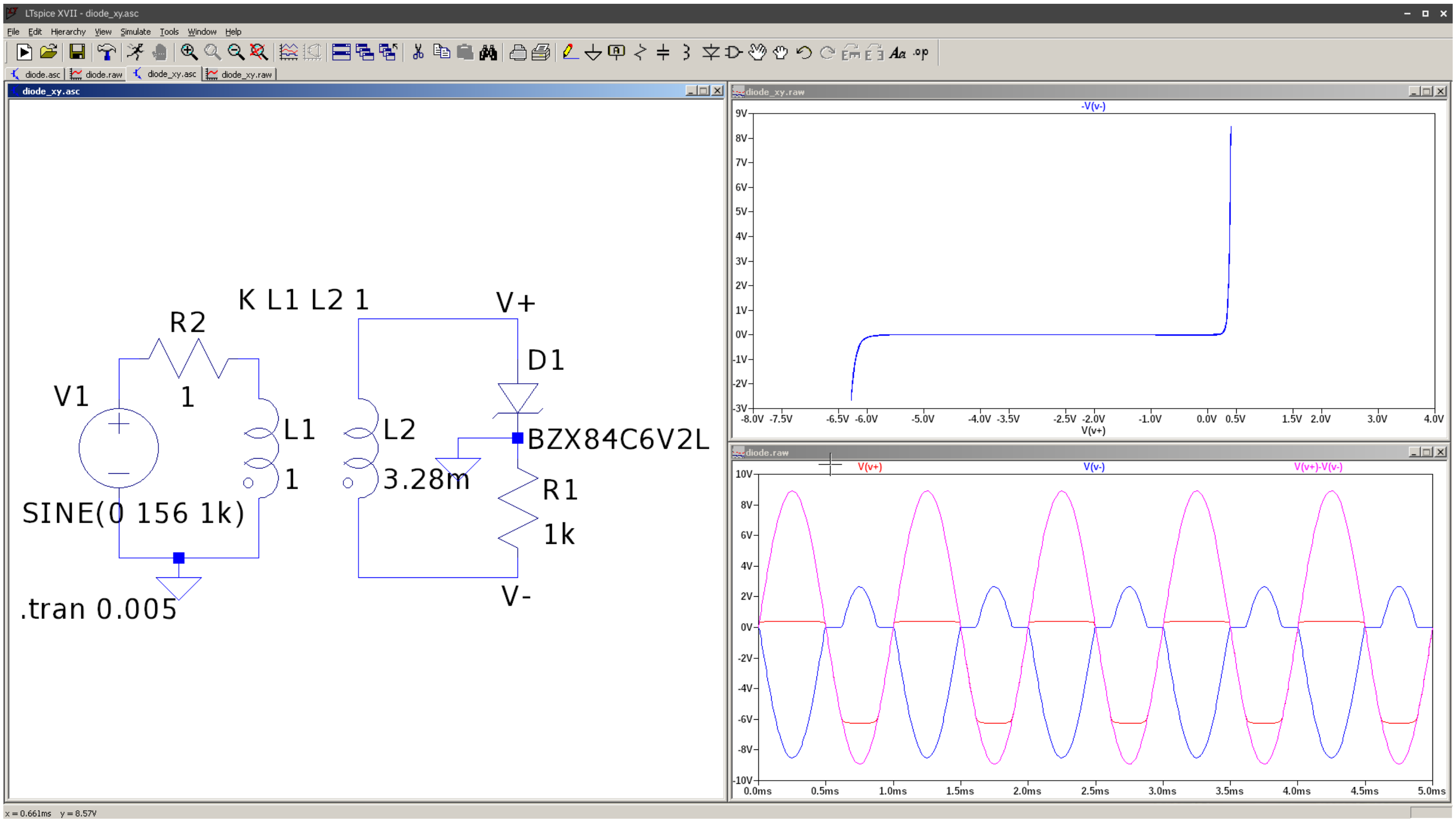


Figure 8: BZX84C6V2L Zener Diode LTSpice simulation ($V_{BD} = 6.2\text{V}$)

3 Part B. Transistor

The 2N3904 datasheet states that the breakdown voltage of the 2N3904 is 6V, but LTSpice does not support the breakdown voltage of the BE-junction of a BJT.

3.1 Without protection diode

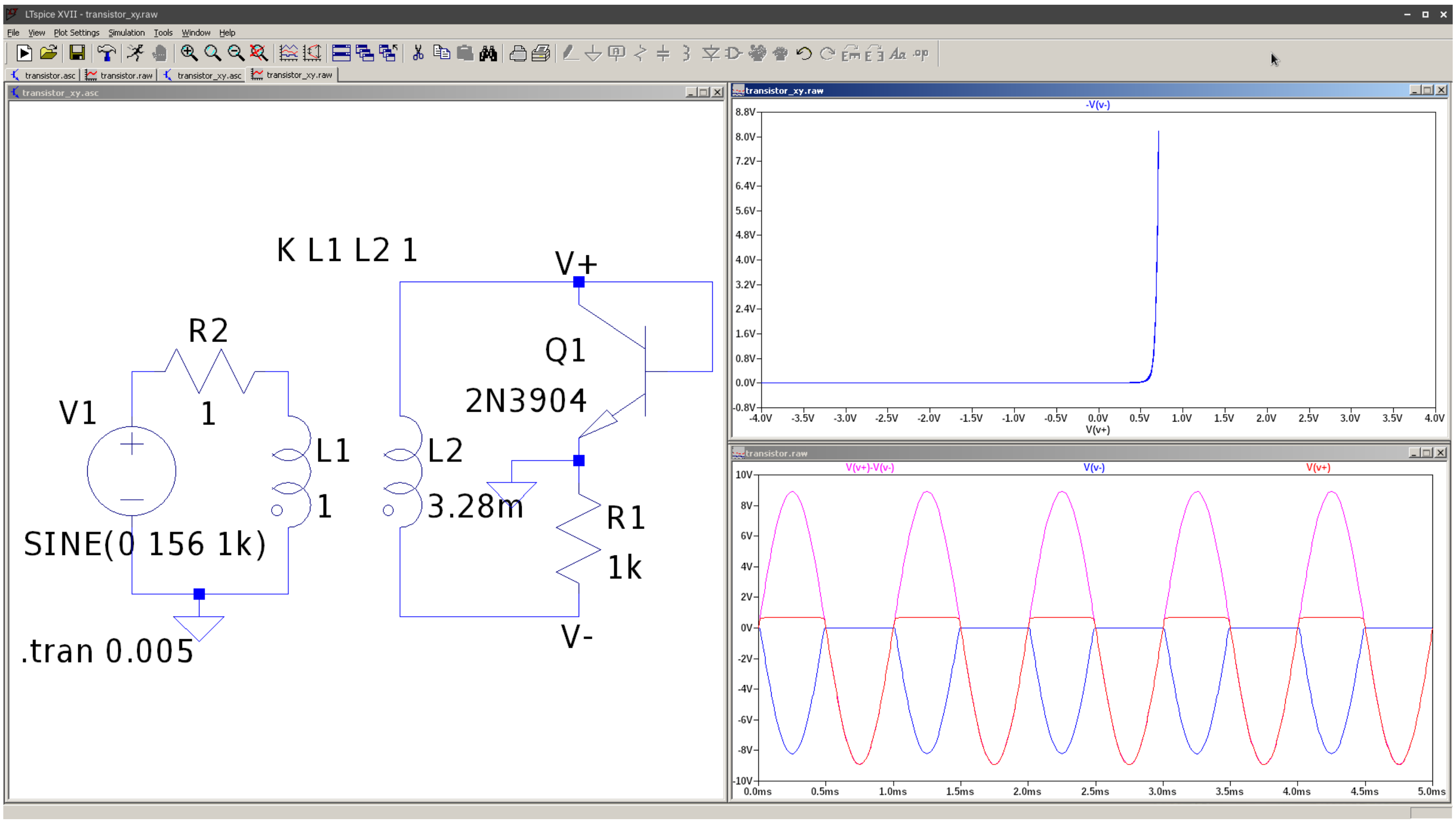


Figure 9: 2N3904 NPN LTSpice simulation

The handbook notes that the slope of the V/I curve should be roughly 60mV/decade. This value can be derived from the Ebers-Moll equation:

$$I_C = I_S \exp \frac{V_{BE}}{V_T}$$

$$V_{BE} = V_T \ln \frac{I_C}{I_S} = V_T(\ln I_C - \ln I_S)$$

We want our result w.r.t the I_D on a logarithmic scale (in units of decades):

$$V_{BE} = V_T \left[\frac{\log_{10} I_C}{\log_{10} e} - \ln I_S \right]$$

$$\frac{\partial V_D}{\partial \log_{10} I_C} = \frac{V_T}{\log_{10} e}$$

At room temperature, we have $V_T \approx 26\text{mV}$, so the slope has a value of 59.9mV/decade.

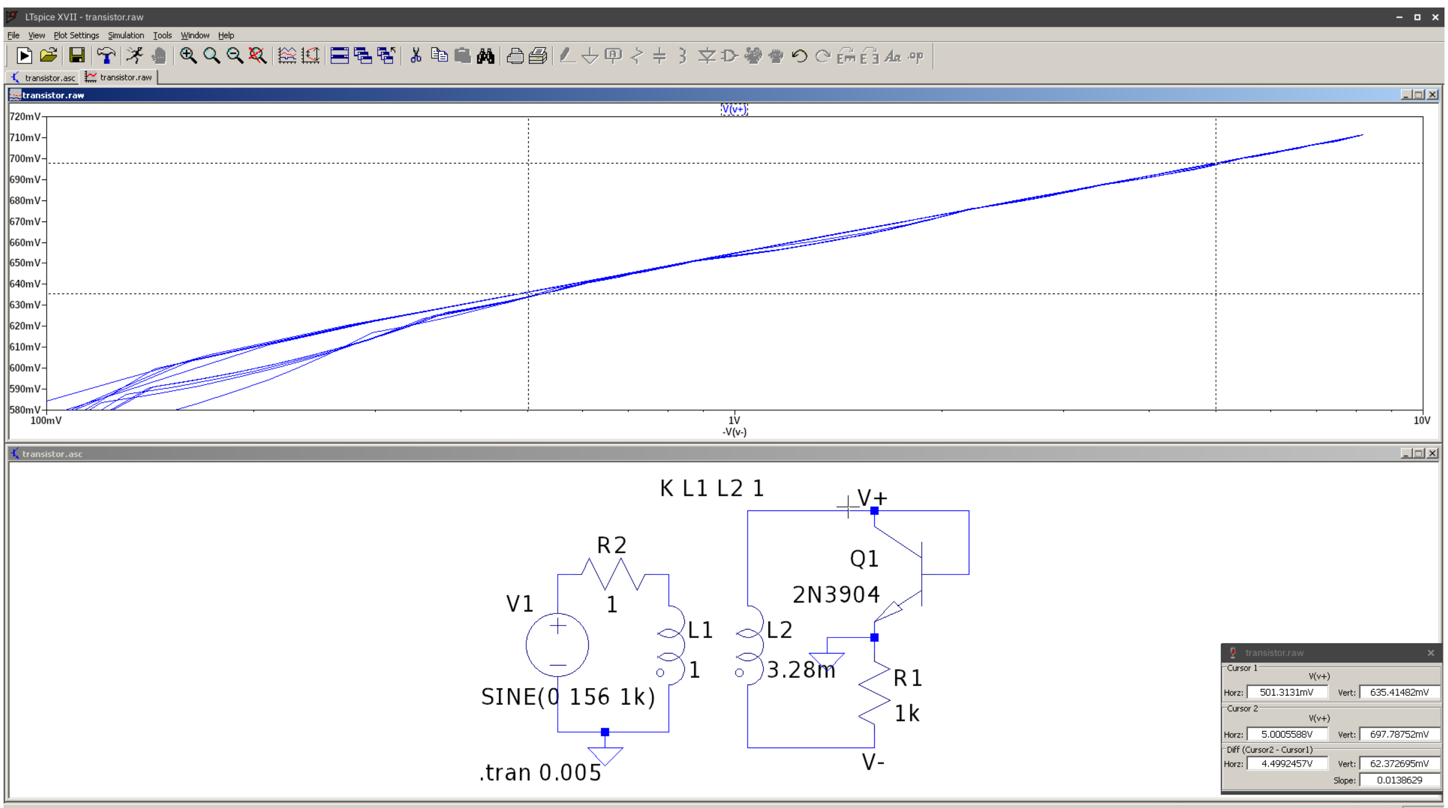


Figure 10: 2N3904 Diode LTSpice simulation: showing V as a function of $\log I$; $\Delta V/\Delta I = 62.37\text{mV/decade} \approx 60\text{mV/decade}$

Figure 11: 2N3904 NPN I/V characteristic

The X-axis is voltage (V) and the Y-axis is current (A). This was done a little differently than for the diode – I calculated a value for I_S using a sample quiescent point, rather than using one off of the Internet.

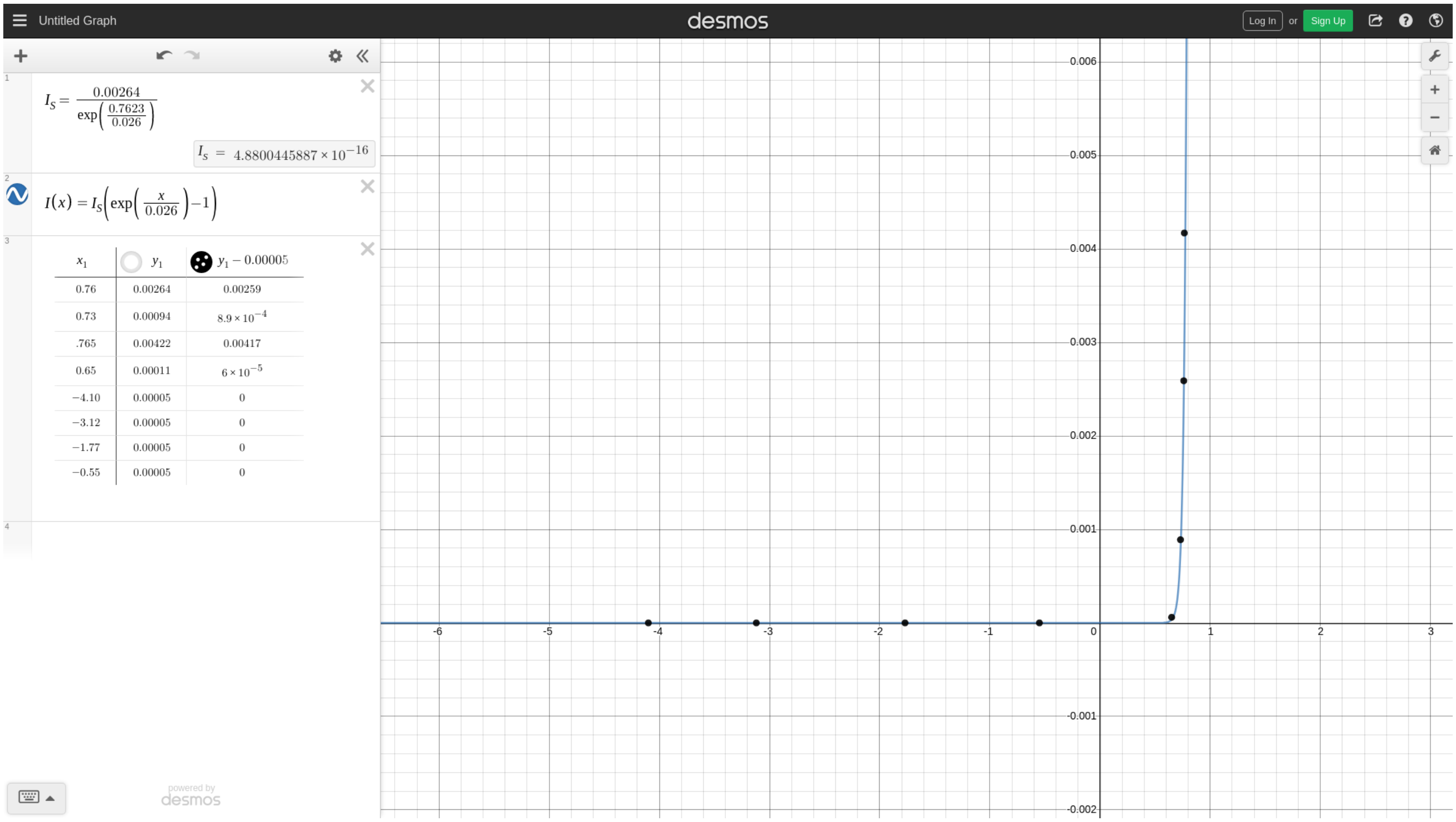


Figure 12: 2N3904 NPN I/V Experimental vs. Theoretical

3.2 With protection diode

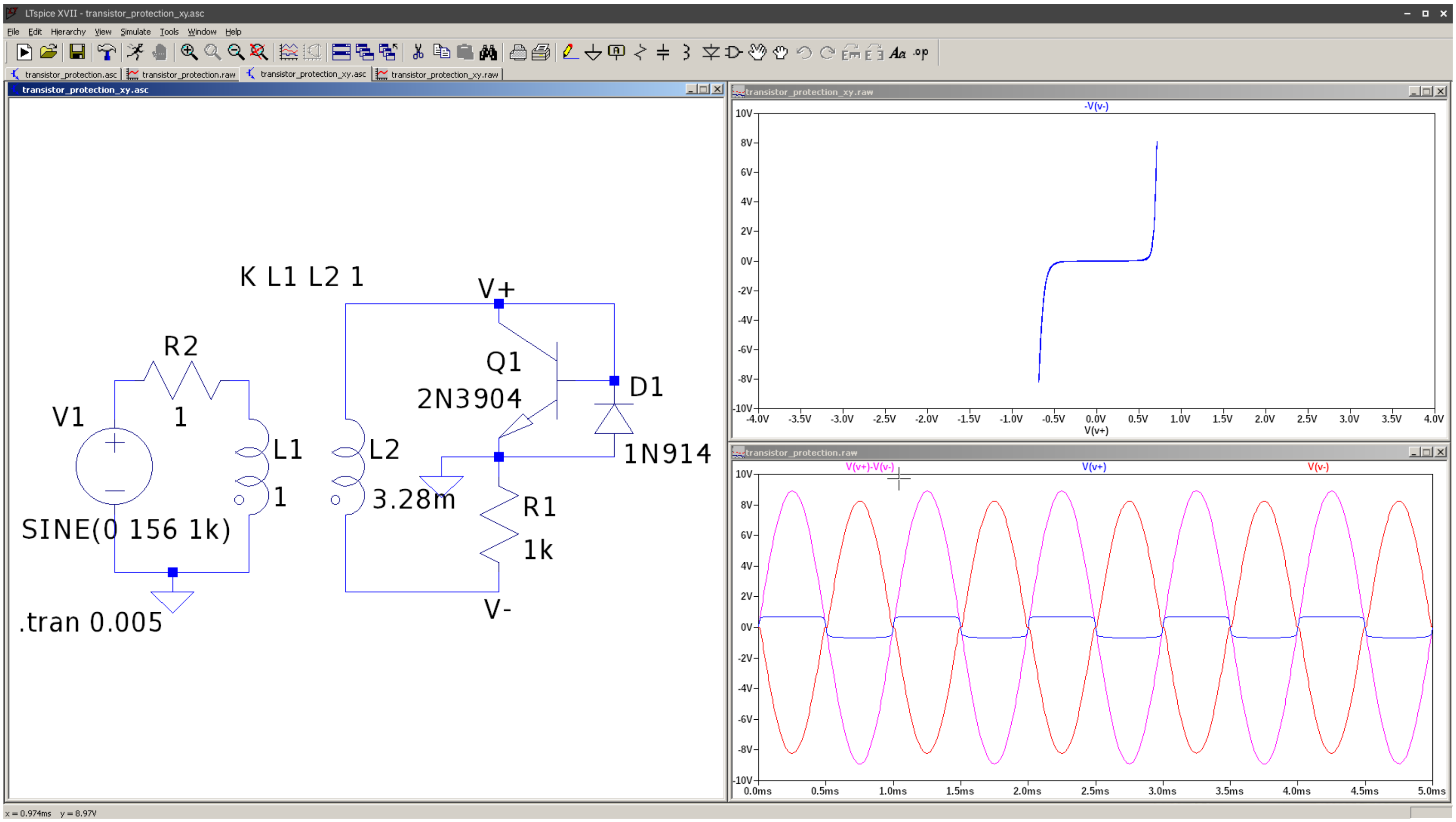


Figure 13: 2N3904 NPN LTSpice simulation with protection diode

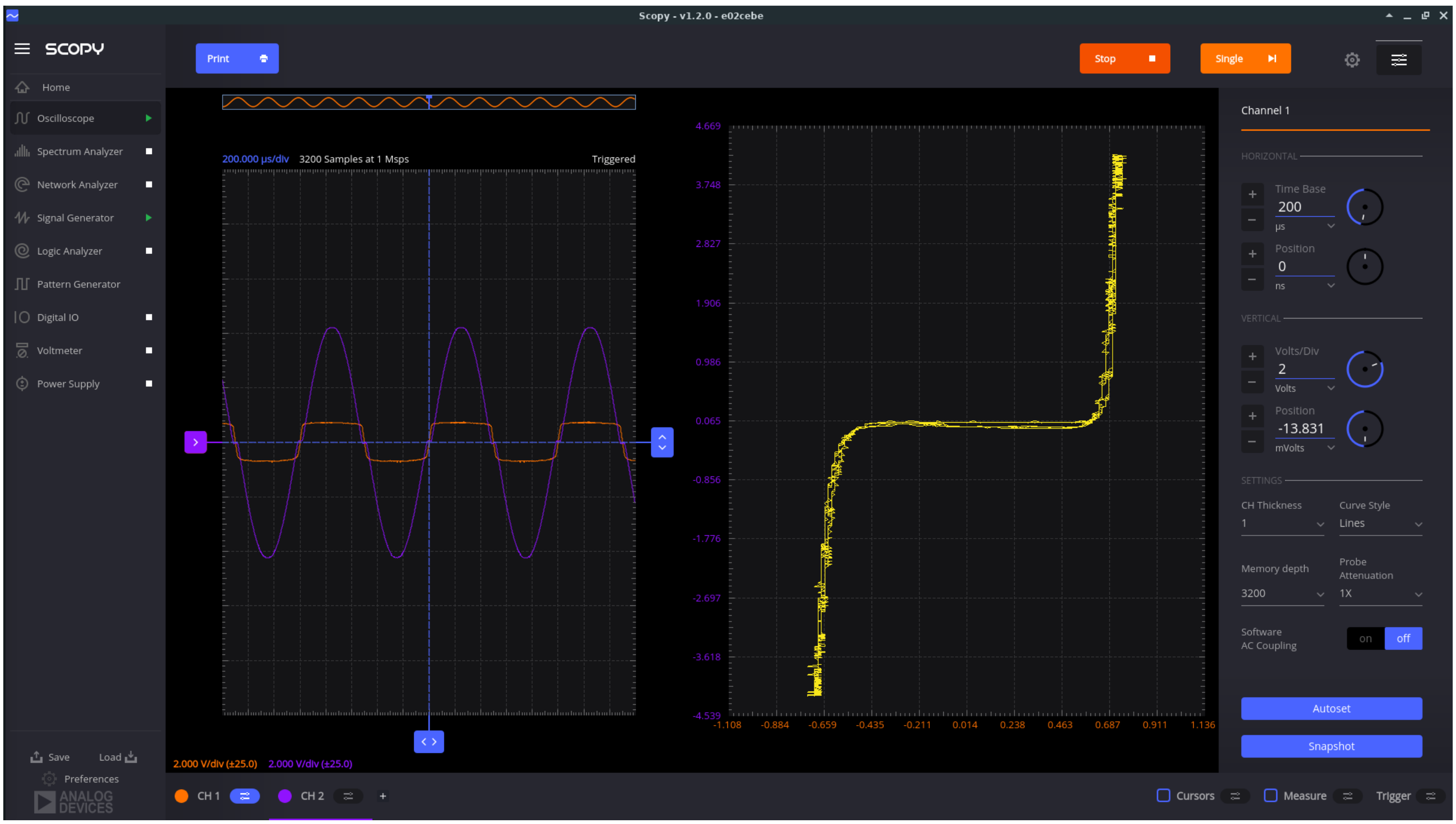


Figure 14: 2N3904 NPN with Protection Diode I/V Characteristic