Lab 6: Silicon Diodes

Object: To explore the behavior of silicon diodes (both conventional and Zener), a half-wave rectifier, and a full-wave bridge rectifier. This experiment involves forward and reverse-biased diodes, I-V characteristics, turn-on and Zener voltages, rectification, power supply ripple, and voltage regulation.

Apparatus: Tektronix TDS2004B Four Channel Digital Storage Oscilloscope, HP 200CD Oscillator, Fluke 73 Digital Multimeter, Circuit Chassis, 1N4001 Silicon Diodes, 1N4730 Silicon Zener Diode, 10 kΩ Resistor, Coaxial Cables with BNC Connectors and BNC 'T'.

Introduction: To date we have used only *linear* circuit elements: resistors, capacitors and inductors. In this experiment, we take up the diode, a *nonlinear* device. Diodes provide signal conditioning, voltage regulation, and the conversion of A.C. voltages and currents into D.C.   In this experiment, you will measure a silicon diode's "I-V characteristic." You will also use four diodes to build a full-wave rectifying bridge, an important circuit in the design of power supplies.
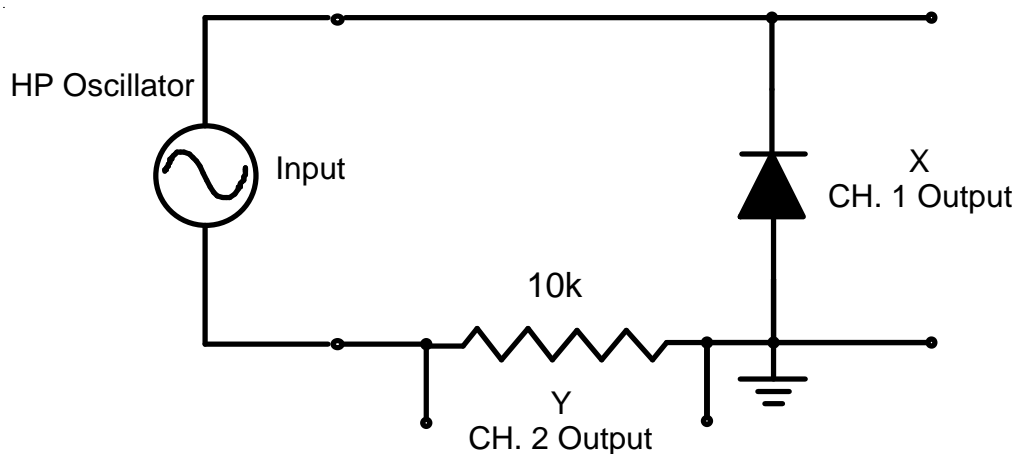

Fig. 1: Circuit for observing the diode I-V curve.

Exercises:
1. Obtain a 1N4001 silicon diode and test its function with the Fluke meter set to its *diode-testing mode.* In this mode, the Fluke checks the effective resistance of a diode by attempting to force a positive current out through its "+" or read lead, through the external diode, and back into its "-" or black lead. When the Fluke displays a small result such as 0.5 rather than a large off-scale indication of ".OL", one may infer that the red lead is connected to the *anode* and the black lead to the *cathode* of the diode, and the diode is conducting in its "easy" direction. Note how the diode is marked to indicate which end is the anode.
2. Proceed to construct the circuit shown in Fig. 1. Make sure that the grounding strap on the HP 200CD Oscillator is disengaged so that its two maroon binding posts "float" relative to ground. Use the banana connectors on your chassis to

bring the signal from the floating oscillator into the chassis without grounding either conductor.

3. Your objective here is to measure the "I-V characteristic" for the 1N4001 diode. The I-V characteristic is the relationship between the current through and the voltage across a circuit component. From this curve you can also determine the *forward turn-on voltage V_F* of the diode. Apply the voltage across the diode to CH 1 of the oscilloscope and the voltage across the 10k resistor to CH 2. The resistor in this circuit is being used to convert the current (which is the same in the resistor and the diode) to a voltage that can be displayed and measured with the oscilloscope. The CH 2 signal is $I_{diode}R$. Set the scope to its XY display mode. Make sure that the signal on both input channels is DC coupled and set for 1X probe attenuation. Set the oscillator to 30 Hz with its amplitude knob turned all the way down. Make sure that the spot on the oscilloscope screen appears in the middle of the screen, indicating that there is no position offset on either input channel. Slowly increase the oscillator's amplitude from zero until the flat I-V curve begins to "turn a corner" at its left end. This corner indicates that the diode is finally getting sufficient forward bias to turn the diode on and unleash conduction. Determine V_F for your diode by measuring from the scope screen the voltage different between zero and the beginning of the corner. Even though the roundedness of the corner makes it difficult to be precise, make the best measurement you can.

4. Now increase the amplitude of the oscillator further to trace out more of the diode's I-V characteristic. Why is the orientation of this curve different from the usual form sketched in lecture? Also think about why the circuit must be connected this way. If the curve looks noisy, you might try using the signal averaging feature of the digital scope. Once you have obtained a scope image that nicely displays the behavior of the diode save your data to your USB Flash Drive. The scope can export data in several formats. For our purposes it is best to save and export the actual digitally sampled data points (as opposed to an image file of the display) so that we can plot, manipulate and analyze the data using a program like Excel or Kaleidagraph. This requires that we save the data in channels one and two separately. So, without making any other adjustments to the scope, put it in YT display mode. Press the RUN/STOP button to capture the data and to make sure that you are saving the data you want. Insert your flash drive into the USB port on the front of the scope. Press the SAVE/RECALL button and, from the menu options figure out how to save the channel one and channel two data (in separate files) to a spreadsheet format file (a .CSV file). Make note of the filename for each channel.

5. Now that you are in YT display mode, observe the behavior of the CH 2 signal (voltage across the current sampling resistor) as you vary the amplitude of the oscillator. Record representations (hand drawn is fine) of the waveforms in your notebook for the three cases: $V \ll V_F$, $V \cong V_F$, and $V \gg V_F$. The last case illustrates the ability of diodes to "rectify" oscillating voltages, or to convert symmetric AC signals into ones that, on average, have a DC component. The present circuit is a "half-wave" rectifier. In this case, the diode acts to turn off

current flow for one half of each input cycle. In part 8 you will construct a "full-wave" rectifier that effectively puts out the absolute value of the input voltage.

6. Replace the 1N4001 with a 1N4730 Si Zener diode and repeat the measurements you made above. What is the reverse-bias breakdown voltage (or "Zener voltage") for this Zener diode?

7. Take your data to one of the computers in the intro lab and open the data files with Excel. Figure out how the data is formatted. Manipulate the CH 2 data to generate values of the current through the diode, and reverse the sign of the voltage across the diode so you can plot the I-V curve in its canonical orientation. Move the data to Kaleidagraph so that you can plot the I-V characteristics for your diodes. For the conventional diode try fitting part of the I-V curve (where $V > -1$ V) to the following theoretical equation:

$$I = I_o \left(\exp(V/V_T) - 1\right), \qquad (1)$$

The parameter I_o is the current carried by minority carriers when the diode is reverse biased. The other parameter is temperature-dependent, $V_T = kT/e$ and should have a value of about 25.3 mV at room temperature (20 °C).

8. Obtain three 1N4001 diodes in addition to the one you already have and construct the full-wave rectifying bridge circuit in Fig. 2. Notice that, as in the previous circuit, the oscillator output must be floating relative to ground. You can not observe the input (oscillator) voltage on the oscilloscope without shorting out a portion of the circuit.
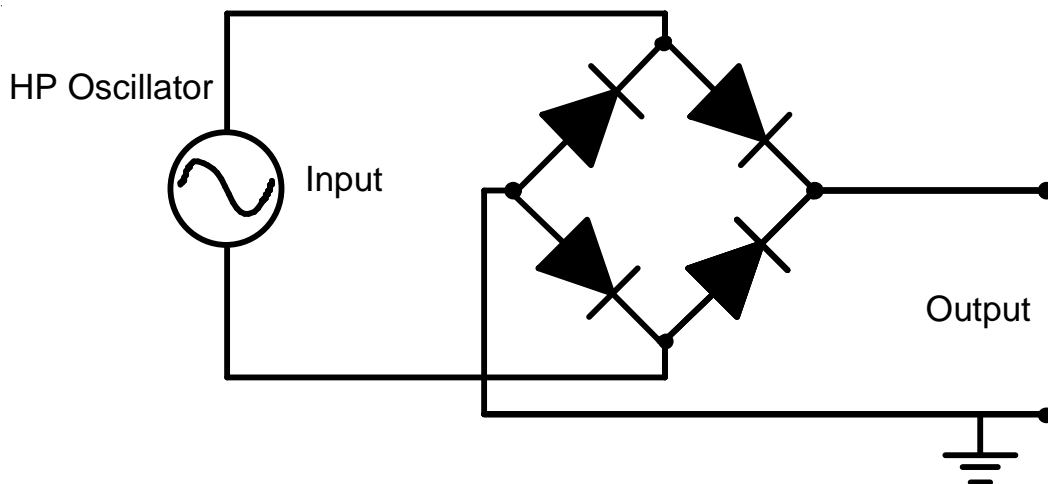

Fig. 2: Full-wave rectifying bridge circuit.

9. Observe the full-wave rectified on the output. The full-wave bridge is commonly used in DC power supplies. The 120 V AC at 60 Hz from the wall outlet is stepped up (or down) with a transformer to provide the AC input to the bridge. A capacitor is used filter the output ripple. The size of the required capacitor depends on the anticipated load current that the power supply will have to provide. The RC time calculated from the load resistance and the filter capacitance should be longer than the ripple period to provide good filtering. Estimate what capacitance you need to filter the ripple from your rectifier where

the load resistance is the 1 MΩ input resistance of the oscilloscope (Note, this is not a very demanding load. In most real power supplies, a hefty capacitor is required to maintain a steady DC output). Obtain a capacitor from the instructor and install it in your circuit. Observe the magnitude of the ripple. To see that the ripple is enhanced for larger load currents, put a 10k resistor across the output of your circuit (in parallel with the oscilloscope).

10. If time permits, try using your Zener diode as a crude voltage regulator. See Fig. 2.11 on p. 68 of Horowitz and Hill.