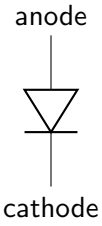
Lab 6: Diodes

Before you begin today's lab

- In this lab, we will use the variable supply on your protoboard. Use a multimeter and the knobs at the top of the protoboard to set V_+ (yellow rail) to $+15\,\mathrm{V}$.



Diode Circuits

(a) Why do we call a diode a nonlinear device? Does it have a resistance/reactance? How does this differ from components such as resistors or capacitors? (It might help to draw a plot of I vs V below.)

The voltage across a diode is not proportional (= linear) to the current flowing through it.

If we defined a "resistance" of a diode by the ratio between the voltage and the current, it would not be a constant, but dependent on the current or the voltage.

We can see this in the fact that the I-V curve is not a straight line.

(b) It is always good to check the "Absolute Maximum Ratings" section of the datasheet before you use any unfamiliar component. Open the datasheet for the 1N4148 diode (look it up!) and check what currents and voltages you should avoid subjecting the diode to. We are unable to make any voltages greater than 15 V at the moment, so voltages won't be a danger here. However, your power supply can put out considerable current (at least an ampere). So, to avoid violating the "Forward continuous current" limit in that scary table.

What is the smallest possible resistor we should have in series with our diodes, if we want to be protected up to our power supply's 15 V limit?

The max forward continuous current I_F of the 1N4148 is 300 mA. In order to limit the current through the diode to 300 mA or less when it is connected to a 15 V power supply, we need a series resistor of

$$\frac{15\,\mathrm{V}}{300\,\mathrm{mA}} = 50\,\Omega.$$

(We could be a little more precise and say that if current is flowing, there is 0.6 V across the diode and the resistor drops only 14.4 V, but we would get a very similar answer.)

(c) Small diodes (i.e., those intended for low currents) are known as "signal diodes," and do tasks like eliminating one polarity from a signal that goes both plus and minus. Look at the circuit of Figure **??** (ignoring the dashed capacitor for now) and predict what it will do to an incoming signal.

Then wire it up and drive it with a 1 kHz, 6 Vpp (peak-to-peak) sine wave.

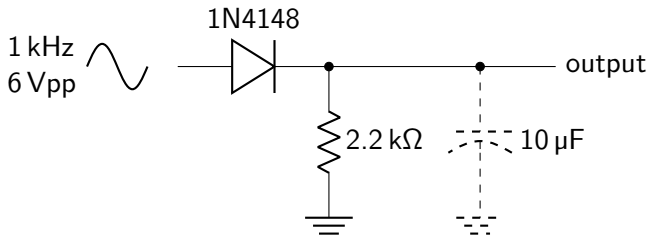
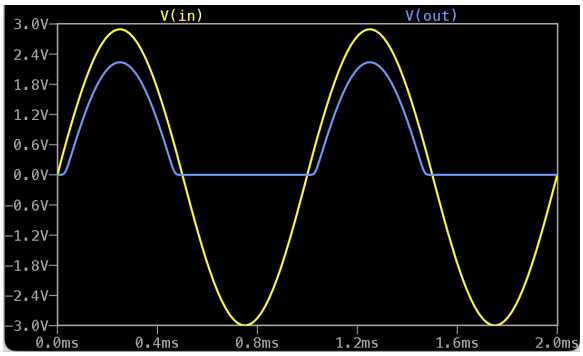


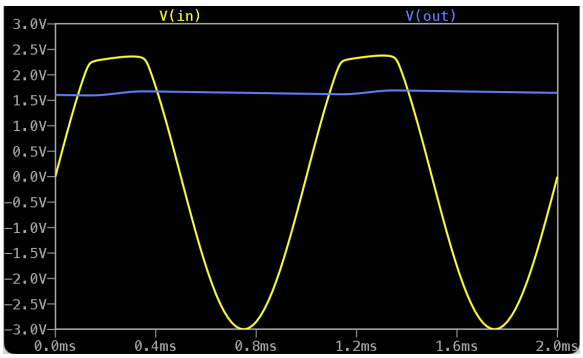
Figure 1: Half-wave rectifier circuit. The dashed capacitor will be added in part (d) below.

Observe the input and output (use CH1 and CH2) on the 'scope, and sketch the waveforms. Does the output match your prediction?



The diode only conducts if the input waveform is above one diode drop (0.6 V). Otherwise, no current flows and the output is at ground (there is no current through the resistor). When current is flowing, the output is always one diode drop lower than the input.

(d) Now add a 10 µF electrolytic capacitor in parallel with the 2.2 kΩ resistor. **Careful:** this component is polarized; make sure you connect it with the side marked "+" at the higher voltage. Sketch the output waveform below, and explain why it changed from what you saw above.



Adding the capacitor created an integrator (aka low-pass filter), so our output is now the average of the curve we saw in the previous part. The input waveform changed as well: the peaks got flatter. This is because current is flowing through the diode to charge the capacitor when the input is above 0.6 V; because this is happening quickly (at a high frequency) and the capacitance is large, the reactance of the capacitor is very small (remember $X_C = 1/(\omega C)$). It draws lots of current from the supply, enough that the function generator's 50 Ohm output impedance causes appreciable "droop" in the output.

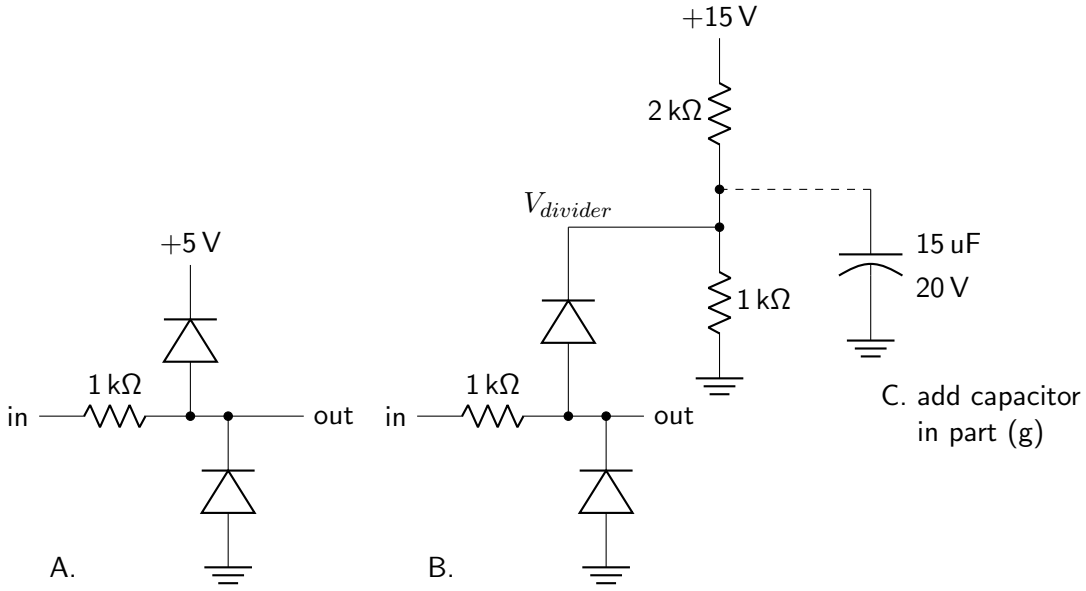


Figure 2: Signal clamp circuits. Be sure to observe the polarity of the capacitor in circuit C.

(e) Diodes are often used in protection circuits to limit or "clamp" voltages within certain values, to protect later stages of a circuit from unwanted voltage levels. Build the circuit of Figure **??**A. What limits does this circuit place on the output voltage? Predict below, then drive the circuit with a large amplitude sine wave from the Siglent function generator to check its performance.

If the voltage at the output exceeds 5.6 V, then the upper diode has one diode drop of voltage across it, and begins to conduct more or less like a wire. As current flows, any voltage in excess of 5.6 V is dropped across the resistor. The lower diode will conduct if the output voltage is less than -0.6 V. So, the limits on the output voltage are $-0.6\ \mathrm{V} < V_{out} < 5.6\ \mathrm{V}$.

(f) Modify your circuit to the configuration of Figure **??**B (omit the 15 µF capacitor for now). Should it work the same, given that the voltage divider is configured to generate +5 V? Try it out (and expect to be surprised). Explain what's happening.[1]

The voltage divider outputs 5 V only if no current is flowing in or out. But when the upper diode begins conducting, that extra current must flow through the 1k resistor. Changing the current through the resistor changes the voltage across it, and the limiting voltage is no longer 5 V!
In terms of input and output impedance, we note that the divider has output impedance of 1k||2k=666 Ω, and the impedance of the clamp circuit is about 1k when the diode conducts (the diode has negligible resistance while conducting, since its I-V curve is nearly vertical in that range). That is far from our rule of thumb for cascading circuits, where $R_{in} > 10R_{out}$. So we expect loading to affect the source considerably, which is what we see: the threshold voltage is not a steady 5 V, but changes as we inject current into the divider.
This makes the waveform look curved instead of neatly clipped at the top, since injecting more current into the divider raises the clamp's threshold voltage.

(g) Now add the 15 µF capacitor (Figure **??**C) and test it again. explain what's happening now, perhaps invoking the concept of reactance.

Now the current injected into the divider can either flow through the 1k resistor, or through the capacitor. If the signal is a reasonably high frequency (the current is only momentary, not a steady current), then the reactance of the capacitor is much lower than the resistance of the resistor, and most of the extra current flows in the capacitor instead (the lower-impedance path). This allows the voltage out of the divider to stay much more steady at 5 V. The capacitor was chosen to have a high capacitance value because $I = C\frac{dV}{dt}$, so even quite high currents will not change the voltage across the capacitor very quickly.

[1] Hint: Input and output impedance!