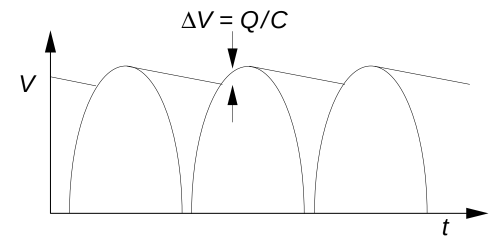
Physics 338 LAB 2 Spring 2016

Mostly Diode Circuits
New Scope Modes

Part I: Rectification

0. (See H&H p.33)



The peak-to-peak ripple depends on the capacitance C of the storage capacitor, the current draw I of the load, and the period T that the capacitor must alone power the load:

$$\Delta V = \frac{Q}{C} = \frac{IT}{C}$$

The rms ripple voltage can be estimated from relationship between the amplitude (in volts) of a saw-tooth wave (A) and the resulting rms voltage $V_{\rm rms}$:

$$V_{\rm rms} = \frac{A}{\sqrt{3}}$$

where $A = \frac{1}{2}\Delta V$ (i.e., ΔV is peak-to-peak). The result is Eq. (1) below.

The dc droop (reduction in output dc voltage due to current draw) should be about $\frac{1}{2}\Delta V$. If we assume (contrary to fact) that there is no resistance in the circuit, the result is Eq. (2) below. Note that the term $T/2C$ has the unit of ohms, and is equivalent to the "internal resistance" of a battery or the Thévenin resistance (output impedance) of a general circuit. A common power supply specification is "load regulation": the maximum amount of dc droop typically expressed as a percentage of the zero-current output voltage V_0. (Clearly the maximum dc droop depends on the maximum designed output current. For the below lab, assume the design maximum current is 0.25 A.)

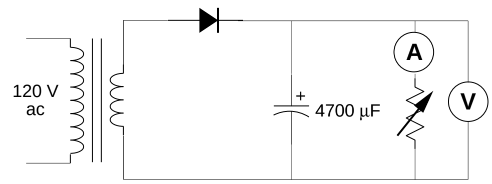
1. Half-wave Rectifier

Construct a half-wave rectifier shown, using a ~ 7 $\rm V_{rms}$ transformer and a 1 A diode. Use various power resistors (10, 20, 50, 100, 200 Ω) for the load — keep the current below about $\frac{1}{2}$A. For the $R = 20\ \Omega$ and $R = 200\ \Omega$ loads, sketch the output waveform as seen on the scope with and without the capacitor in place. For each of the above power resistors, measure (DM-97 DMM) the dc voltage out ($V_{\rm dc}$) and the rms ac ripple ($V_{\rm ripple}$) for the resulting the dc current I (measured with M3900 DMM).Plot and fit $V_{\rm dc}$ vs. I and $V_{\rm ripple}$ vs. I. (If Thévenin applied: $V_{\rm dc} = V_{Th} - R_{Th} \cdot I$ would be exact, but diodes are non-linear devices, so WAPP to a quadratic curve for this almost linear relationship.) Extract the effective capacitance from the fit to Eq. (1) by relating the linear coefficient of I to that derived from the above theory. Use your fits to calculate the ripple and load regulation at $I = 0.25$ A.

$$V_{\rm ripple} = \frac{A}{\sqrt{3}} = \frac{\Delta V}{2\sqrt{3}} = \frac{T}{2\sqrt{3}C}\, I \tag{1}$$

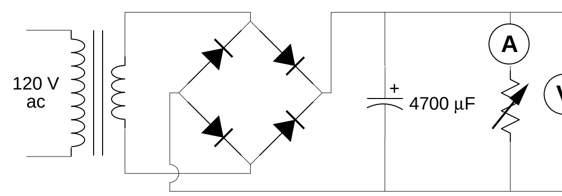
$$V_{\rm dc} = V_0 - \frac{\Delta V}{2} = V_0 - \frac{T}{2C}\, I \tag{2}$$

According to Eq. (1) doubling the capacitance should halve the ac ripple. With the 50Ω power resistor in place, double your capacitance by adding another capacitor (parallel or series?) and note the effect.



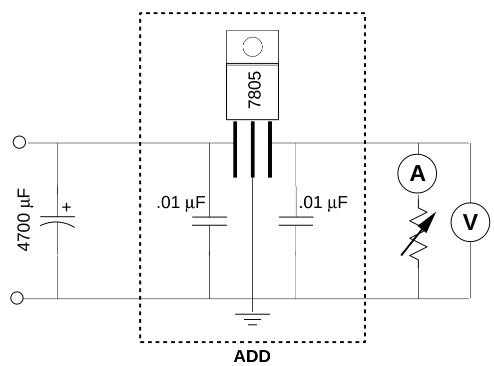
2. Full-wave Rectifier

   Construct either a full-wave bridge rectifier or a full-wave center-tapped rectifier. Repeat the measurements, plots and fits of the previous part. Compare the full-wave rectifier's ripple and regulation to the half-wave rectifier's ripple and regulation. According to the theory, both should have improved by a factor of 2 (since the only change is a factor-of-two reduction in T). In this case I would not bet on theory! Don't destroy this circuit as next you're just going to insert a regulator between the capacitor and the load.



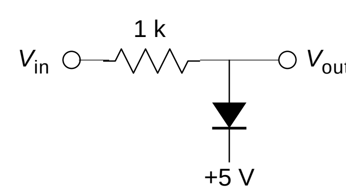
3. Regulated Power Supply

   In your full-wave rectifier circuit, insert the 7805 IC regulator between the capacitor and the load as shown. Again measure ripple and regulation (this time don't exceed $\frac{1}{4}$A) and compare these values with those of the unregulated circuit. Check with a scope to make sure your circuit isn't oscillating. You should find $V_{\text{dc}} \approx 5.0$ V and $V_{\text{ripple}} < 1$ mV for all I, so plots and fits are not needed.



4. Diode Clamp

   Construct the diode clamp circuit and drive it with a large amplitude ($\sim$ 10 V) sine wave ($\sim$ 1 kHz) from the function generator. Observe and discuss the output. Construct a voltage divider from 1k and 2k resistors and divide the +15 V supply to make a different +5 V source. Compare the diode clamp's V_{out} when connected to this new +5 V supply with that obtained when connected to the protoboard's +5 V supply. (Sketch the V_{in} & V_{out} waveforms produced with each +5 V power supply.) Why is the signal less well clamped with the new +5 V source? What is the input impedance (think Thévenin) of each of the +5 V sources? Fix up the divider by adding a 6.8μF capacitor from the divider point to ground. This is acting as a bypass capacitor. Discuss its operation.



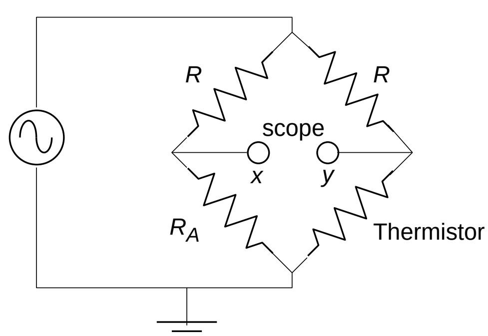
Extra Credit: The Thévenin equivalent circuit for the voltage divider circuit is a perfect voltage source in series with R_T. Construct this equivalent circuit (using the protoboard's +5 V supply as the perfect voltage source) and show that it responds to the diode clamp exactly as the voltage divider did. Note that you are seeing the reverse of 'voltage droop': here current goes in and as a result the voltage goes up.

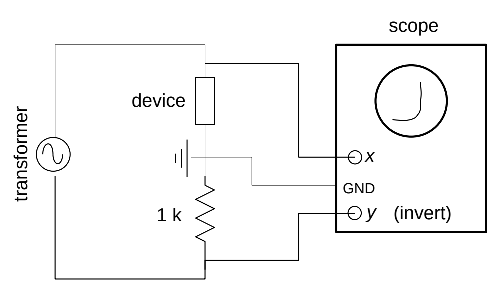
Part II: New Scope Modes

0. Most commonly an oscilloscope is used to display voltage relative to ground as a function of time, however it also has other useful modes. You can measure the voltage across a component not at ground ("floating") using the "x minus y" mode. You can make voltage vs. voltage plots (as opposed to voltage vs. time) using "xy" mode (which confusingly may be labeled "$x - y$" on some scopes).

1. Wheatstone Bridge: "x minus y" mode (a.k.a.: differential mode)

   Construct an ac bridge circuit as shown (below left) to measure the resistance of a thermistor. The R resistors are fixed 10k resistors and R_A is a variable resistance box. For the null detector, connect scope channels 1 & 2 to x & y and have the scope display "x minus y" (i.e., in the MATH MENU Operation▶ −). (Both channels should be set to the same scale (VOLTS/DIV). When the MATH MENU is selected the scale for the MATH trace is set by the multipurpose knob; the selected value is displayed as the bottom option in the MATH MENU.) Use a 100 Hz sine wave to power the bridge. Adjust R_A for a "null" (i.e., nearly zero voltage difference between x and y) and find the thermistor resistance from R_A. Note that, once nulled, changing the thermistor's temperature (e.g., by pinching the thermistor between thumb and forefinger) results in a dramatic change in the displayed differential voltage (e.g., a doubling of the previously near-zero signal). Measure the thermistor's resistance with an ohmmeter and compare to the bridge result. Note particularly that while "x minus y" mode allows you to make a differential voltage measurement with a scope, the limited resolution of the scope's ADC results in odd results when V_x is nearly equal to V_y. Remark: if your aim really was to measure $V_x - V_y$ an alternative solution (as in #2 below) would be drive the bridge with a transformer (freeing up ground in the secondary (bridge) circuit), establish ground at one side of the bridge, and then use a single probe to look for a good "null". However, when diagnosing complex circuits, switching ground is usually not an option, so commonly the only way to view the voltage drop across a component is this differential mode. (Hence this pedagogical exercise.)





2. Diode Curve Tracer: "xy" mode

   Construct the circuit shown (above right), which plots (on the scope) the current through a component (y) vs. the voltage across it (x). The scope must be in xy mode (in the DISPLAY menu: Format▶XY). We'll use a 60 Hz sine wave from our transformer to drive the circuit. . . thus we can set ground to be in the middle of things. x (CH1) will be the voltage drop across the device; y (CH2) will be negative for a positive current, but otherwise proportional to the current (1 V = 1 mA). We can display y-values that are positive for positive currents by inverting y: Using the CH2 MENU, select Invert▶On. Observe the I–V characteristics of a 100 Ω resistor, a Si diode, a Ge diode and a Si Zener diode. Sketch the curves obtained (be sure to include scope settings!) and explain each element's behavior. What is the "turn-on" voltage for the Si diode? the Ge diode? What's the Zener (breakdown) voltage for the Zener?