Physics 120 (2019) Lab 3 - Harmonic Analysis and Diode Circuits

We return to filters and consider the special case of resonance, where the fulter attenuates signals above and below a preferred frequency. This is one form of band-pass filter. We next move tot he case of nonlinear electronic devices, for which the semiconductor diode is an important and fundamental example.

3-1. LC resonant circuit

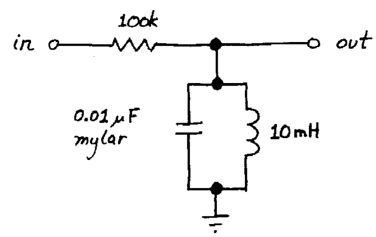

Figure 3.1: LC parallel resonant circuit.

Construct the parallel resonant circuit shown in Figure 3.1. Drive it with a sine wave, varying the frequency through a range that includes what you calculate to be the circuit's *resonant frequency*, which for ideal components is $f_o = 1/(2\pi\sqrt{LC})$. Compare the resonant frequency that you observe with the one you calculated (**1 pt**); the circuit attenuates the signal considerably, even at its resonant frequency because the inductors includes some series resistance. Thus start with a 10 V signal. Illustrate resonance with a series of **SCREENSHOT**s or a **SCREENSHOT** with swept frequency (**2 pts**).

Finding Fourier Components of a Square Wave

This resonant circuit can serve as a "Fourier Analyzer" the circuit's response measures the amount of 16 kHz (approximately) present in an input waveform.

Try driving the circuit with a square wave at the resonant frequency. Note the amplitude of the (sine wave) response relative to the drive with a **SCREENSHOT** (**1 pt**). Now gradually lower the driving frequency until you get another peak response at 1/3 the resonant frequency and check the amplitude; it should be 1/3 the amplitude of the fundamental response. With some care you can verify the amplitude and frequency of the first three nonzero harmonics ($3f_o$, $5f_o$, and $7f_o$) of the Fourier series. Report your results and illustrate them with three **SCREENSHOT**s (**3 pts**).

Here is a reminder of the Fourier series for a square wave:

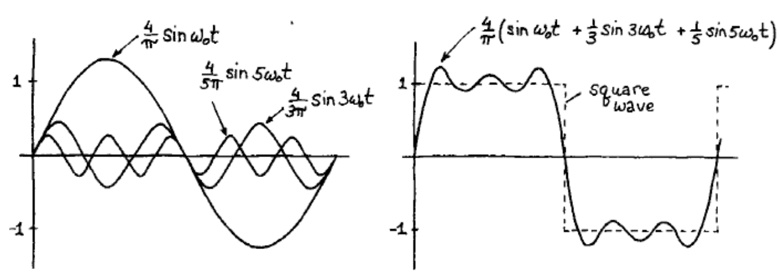

Figure 3.2: Fourier series for square wave.

"Ringing"

Now try driving the circuit with a low-frequency square wave: try 20 Hz. You should see a brief output in response to each edge of the input square wave. If you look closely at this output, you can see that it is a decaying sine wave.

What is the frequency of this sine wave (No surprise here!)? Why does the signal decay (**1 pt**)? Does it appear to decay exponentially? Document your claim with a **SCREENSHOT** (**1 pt**).

3-2. The diode

Here is another device that does not obey Ohm's law and does not even conduct in a symmetric fashion; the diode. Use a 1N914. We need to include a current-limiting resistor in the test setup because you can't just apply a voltage across a diode without a big pop(!). You'll see why after you've measured the diode's **V** versus **I**. Do this by wiring up the circuit shown in Figure 3.3.

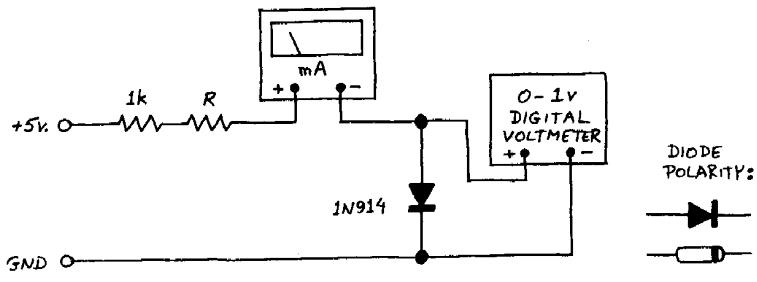

Figure 3.3. Diode **VI** measuring circuit

In this circuit you are applying a current, and noting the resultant voltage drop across the diode. The 1 kΩ resistor limits the current to safe values. Vary **R** with a resistor substitution box and measure **I** versus **V**. First, get an impression of the shape of the linear plot; just four or five points should define the shape of the curve. Then draw the same points on a semi-log plot, which compresses one of the axes. Prepare final plots in two forms: linear (**1 pt**) and "semi-log." (log_{10} **I** versus **V**) (**1 pt**).

What happens if you reverse the direction of the diode? Note the behavior on the linear plot (**1 pt**). How would you summarize the **V** versus **I** behavior of a diode (**1 pt**)?

Now explain what would happen if you were to put +5 V directly across the diode (**Please don't try it!**) (**1 pt**)? Does it depend on the orientation of the diode (**1 pt**)? Look at a diode data sheet. What parameter corresponds to "boom" (**1 pt**)?

3-3. Half-wave rectifier.

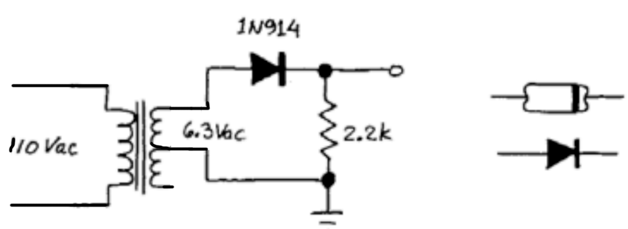

Figure 3.4: Half-wave rectifier

Construct a half-wave rectifier circuit with a 6.3 VAC (RMS) transformer and a 1N914 diode (Figure 3.4). Connect a 2.2 kΩ load, look at the input as well as the output on the oscilloscope and take a **SCREENSHOT** (**1 pt**). Comment on the shape and the polarity of the signal (**1 pt**). What happens if you reverse the direction of the diode (**1 pt**)? *Don't be troubled if* $|V_{peak}|$ *is a bit more than* $6.3\sqrt{2}\ V$ *; the transformer designers want to make sure that the output meets specifications under a load.*

3-4. Full-wave bridge rectifier

Construct a full-wave bridge circuit (Figure 3.5) with the output of the transformer "floating". *Pay attention to the location of the ground, i.e., do not ground either end of the output of the* *transformer - or poof!* Pay attention to the orientation of the diodes or you may find yourself burning out diodes.

Look at the output waveform and take a **SCREENSHOT** (**1 pt**). *Please do not attempt to look at the floating input - yet.*

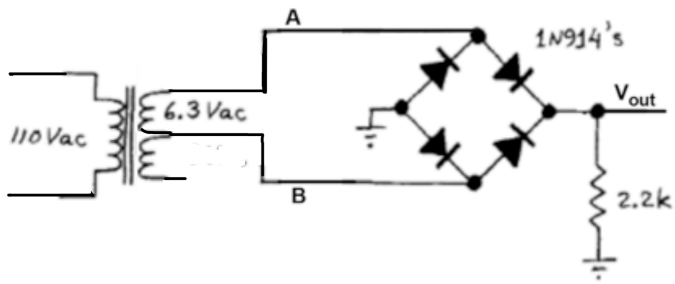

Figure 3.5: Full-wave bridge.

Look at the region of the output waveform that is near zero volts. Why are there flat regions (**1 pt**)? Measure their duration, document it in your report with a **SCREENSHOT** and an explanation (**1 pt**).

What would happen if you reversed any one of the four diodes (**1 pt**)? Just answer this - please do not try it! Explain why diodes in this circuit usually fail in pairs (**1 pt**).

Differential measurements with a single-ended amplifier, as on the oscilloscope.

Use a pair of scope probes to measure the output of the transformer in a differential manner. Connect one channel (say Ch3) to one output lead (A in Figure 3.4), the second channel (say Ch4) to the other lead (B in Fig. 3.4), and connect the probe grounds to Common. Make sure both channels have the same gain and are DC coupled. Use a MATH function to take the difference Ch3 - Ch4. Take a **SCREENSHOT** of the three signals and explain what do you see for Ch3, Ch4, and their difference (**2 pts**).

3-5. Ripple

Connect a 15 μF electrolytic capacitor in parallel with the 2.2KΩ output resistor in the circuit of Figure 3.5. *Observe the polarity of the capacitor or it too can go poof!* Qualitatively, why does the added capacitor change the output? Explain and document the effect with a **SCREENSHOT** (**1 pt**).

Estimate what the "ripple" amplitude (**1 pt**). *You can do this exactly by the convolution integral of the full-wave rectified sine with a low-pass filter. Or, you can estimate the "ripple" amplitude from the nearly linear discharge of the waveform. Use the cursors on the oscilloscope to estimate the discharge time and recall that the initial decay of an RC circuit has a slope proportional to -1/RC.* Measure the "ripple" amplitude; do your estimate and measurement agree (**1 pt**)?

Now put a 470 μF capacitor in parallel with the output resistor and see if the ripple is reduced to the value you predict. Explain and document the effect with a **SCREENSHOT** (**1 pt**). This circuit is now a respectable voltage source for loads that draw low current.

3-6. Signal diodes

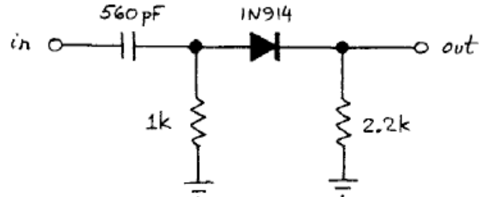

Figure 3.6: Rectified differentiator.

Use a diode to make a rectified differentiator (Figure 3.6). Drive it with a square wave at 10 kHz or so at 1 Volt amplitude, or more. Look at input and output, take a **SCREENSHOT**, and explain the shape of the output waveform (**1 pt**).

What does the 2.2 kΩ load resistor do (**1 pt**)? *Hint*: *You should see what appears to be RC discharge curves with the 2.2 kΩ to ground in place and with the 2.2 kΩ removed. The challenge here is to figure out what determines the R and C that you are watching*.

3-7. Diode clamp

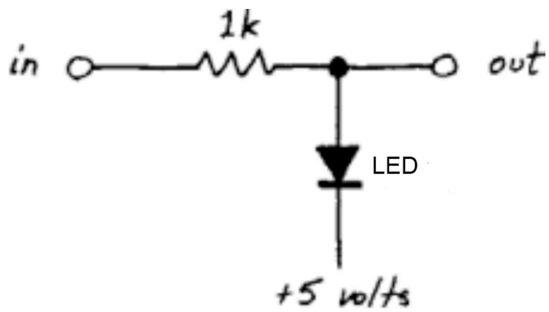

Figure 3.7: Diode clamp

Construct a simple diode clamp circuit (Figure 3.7) using an LED as the diode. Drive it with a sine wave from your function generator, at a 10 V amplitude and a frequency of 10 Hz or less, and observe the output and document it with a **SCREENSHOT** (**1 pt**). Document when the LED is lit (**1 pt**). Is the clamped voltage is not quite constant? *Hint: is the resistance of the diode zero really zero when it conducts?* Document your conclusion (**1 pt**).

3-8. Diode limiter

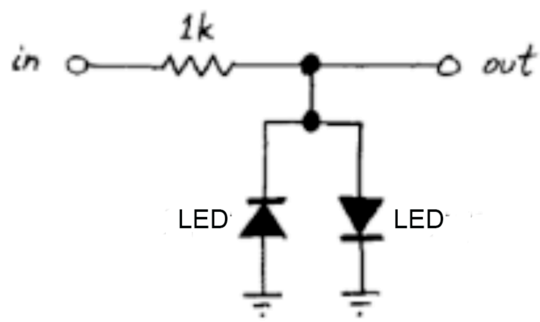

Figure 3.8: Diode limiter.

Build the simple diode limiter shown in Figure 3.8 using an LED as the diode. Drive it with sine waves, triangle waves, and square waves of various amplitudes and document your results with **SCREENSHOT**s (**2 pts**). Describe what the circuit does, and why (**1 pt**). Can both LEDs be on at the same time (**1 pt**)? This is a popular circuit for the input of many measurement instruments - why (**1 pt**)?

40 point total