Physics 120 (2018) Lab 3 - Harmonic Analysis and Diode Circuits

We return to filters and consider the special case of resonance, where the filter attenuates signals above and below a preferred frequency. This is one form of band-pass filter. We next move to the 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.](image)

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 \( f_0 = 1/\sqrt{LC} \). 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 SCREENSHOTs 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 (3\( f_0 \), 5\( f_0 \), and 7\( f_0 \)) of the Fourier series. Report your results and illustrate them with three SCREENSHOTs (3 pts).

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

![Figure 3.2: Fourier series for square wave.](image)

“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. Half-wave rectifier.

![Half-wave rectifier circuit](image)

**Figure 3.3**: Half-wave rectifier

Construct a half-wave rectifier circuit with a 6.3 VAC (RMS) transformer and a 1N914 diode (Figure 3.3). Connect a 2.2 kΩ load, look at the input as well as the output on the oscilloscope and take a SCREENSHOT and explain (2 pts). 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.

3-3. Full-wave bridge rectifier

Construct a full-wave bridge circuit (Figure 3.4) 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.*

![Full-wave bridge circuit](image)

**Figure 3.4**: 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).
3-4. Ripple

Connect a 15 \( \mu \)F electrolytic capacitor in parallel with the output resistor. *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, as in the class notes. 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 of \(-1/RC\). Measure the “ripple” amplitude - do your estimate and measurement agree (1 pt)?

Now put a 470 \( \mu \)F 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.

3-5. Signal diodes

![Figure 3.5: Rectified differentiator.](image)

Use a diode to make a rectified differentiator (Figure 3.5). 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 k\( \Omega \) load resistor do (1 pt)? Removing it and note what happens (1 pt). *Hint: You should see what appears to be RC discharge curves in both cases – with and without the 2.2 k\( \Omega \) to ground. The challenge here is to figure out what determines the R and C that you are watching.*

3-6. Diode clamp

![Figure 3.6: Diode clamp](image)

Construct a simple diode clamp circuit (Figure 3.6). Drive it with a sine wave from your function generator, at a 10 V amplitude, and observe the output and document it with a SCREENSHOT (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).

3-7. Diode limiter

![Figure 3.7: Diode limiter.](image)
Build the simple diode limiter shown in Figure 3.7. Drive it with sine waves, triangle waves, and square waves of various amplitudes and document your results with SCREENSHOTs (2 pts). Describe what the circuit does, and why (1 pt). Can you think of a use for this circuit (1 pt)?

33 points total