

Lab 6: Filter applications and Power Supply Design

Prelab

Read section 3.8.1 (Transformer Basic Operations) and the beginning of chapter 11 through section 11.6 (Voltage regulators and Power Supplies).

- Use EveryCircuit to help you design the high pass and the low pass filters for use in part II. (Note the design guides in that section.)

Be ready to show the simulations at the beginning of class.

Connect a single AC signal source to your filter circuit and click the ‘f’ yellow arrow to begin a frequency sweep. Select the output voltage node (wire) and click the ‘eye’ to see a Bode plot showing both attenuation and phase. You can adjust the values of your components and watch as the Bode plot changes.

Note that the following real world values are available to you:

- Resistors: 2.2, 2.7, 3.9, 4.7, 6.8, 8.2, 10, 18, 22, 33, 47, 51, 68, 82, 100, 120, 150, 180, 220, 240, 270, 330, 390, 430, 470, 510, 560, 620, 680, 750, 820, 910, 1k, 1.2k, 1.5k, 1.8k, 2.2k, 2.4k, 2.7k, 3.3k, 3.9k, 4.3k, 4.7k, 5.1k, 5.6k, 6.2k, 6.8k, 7.5k, 8.2k, 9.1k, 10k, 12k, 15k, 18k, 22k, 24k, 27k, 33k, 39k, 43k, 47k, 51k, 56k, 62k, etc. . .
- Capacitors: 22pF, 100pF, 1nF, 10nF, 22nF, 33nF, 47nF, 100nF, 220nF, 330nF, 470nF, 560nF, 680nF, 1 μ F, 2.2 μ F, 4.7 μ F
- Inductors: 100 μ H, 510 μ H, 1mH, 10mH, 100mH

Supplies

- Multimeter
- Function Generator (x2)
- Oscilloscope (and probes)
- Breadboard
- Minigrabber probes w/ adapters
- Wall Transformer
- 330 Ω , 510 Ω , 1.2k Ω , 4.7k Ω , 10 k Ω resistors
- 1 μ F, 10 μ F, 100 μ F capacitors
- Small signal, Schottky and Zener diodes
- LM317 linear regulator
- 10k Ω potentiometer

Part I: Transformers

Check with your instructor before plugging in the transformer!

Construct the circuit shown in figure 1. The transformer has a center tapped secondary coil so there are three wires connected to the secondary side. Two output voltage levels are achievable this way. Connect the two outermost wires to obtain the largest output voltage. Connecting one outer wire and the center wire will result in half the output voltage.

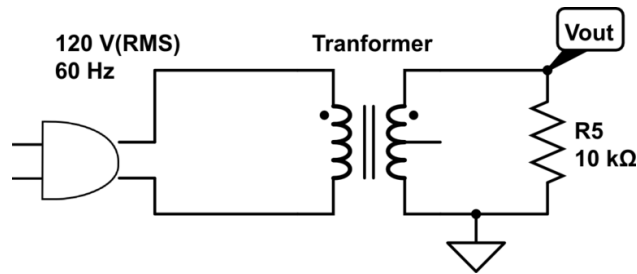


Figure 1: Transformer connected to a load

- Q. What is the secondary coil voltage specification for this transformer? (Look in the datasheet) From this V_{rms} value, calculate what you expect the peak-to-peak measurement to be.
- Q. Use your oscilloscope to measure the peak-to-peak voltage. Does this agree with what you predicted? If not, why not? (Hint: Look at the load specification in the datasheet.)
- Unplug the transformer and connect the center tap wire and ONE of the others wires up to the same circuit.
- Q. What do you measure as the peak-to-peak voltage? How does this compare to what you would expect?
- Q. Is the output voltage directly or inversely proportional to the number of windings on the secondary coil? What must the winding ratio (N_P/N_S) be for this transformer?
- Q. Is the current in each coil directly or inversely proportional to the number of turns in that coil?

Part II: Filter application

In the past few labs you have characterized the frequency response of filters over a wide range of frequencies. Often, we are interested in extracting a specific signal or deleting a specific signal.

In this section you will use the transformer along with both function generators to create a composite signal from three sine waves of widely varying frequencies. Then, you will design and implement three filters, each should extract out only one of the input signals.

- First, **without any of the filter sections**, construct the circuit shown in figure 2.
 - Refer to figure 3 for how to properly layout your breadboard.
 - **Check with your instructor before plugging in the transformer.**
 - Set the output level of each function generator to about half max.
- Reset the scope using DEFAULT SETUP and then enable x10 mode. Set the scope trigger source to 'AC Line', this will force it to trigger off the 60 Hz transformer signal only.
- Q. On your scope examine the combined output (V_{all}). Explain what you see. **Check that your output is correct with your instructor before moving on.**

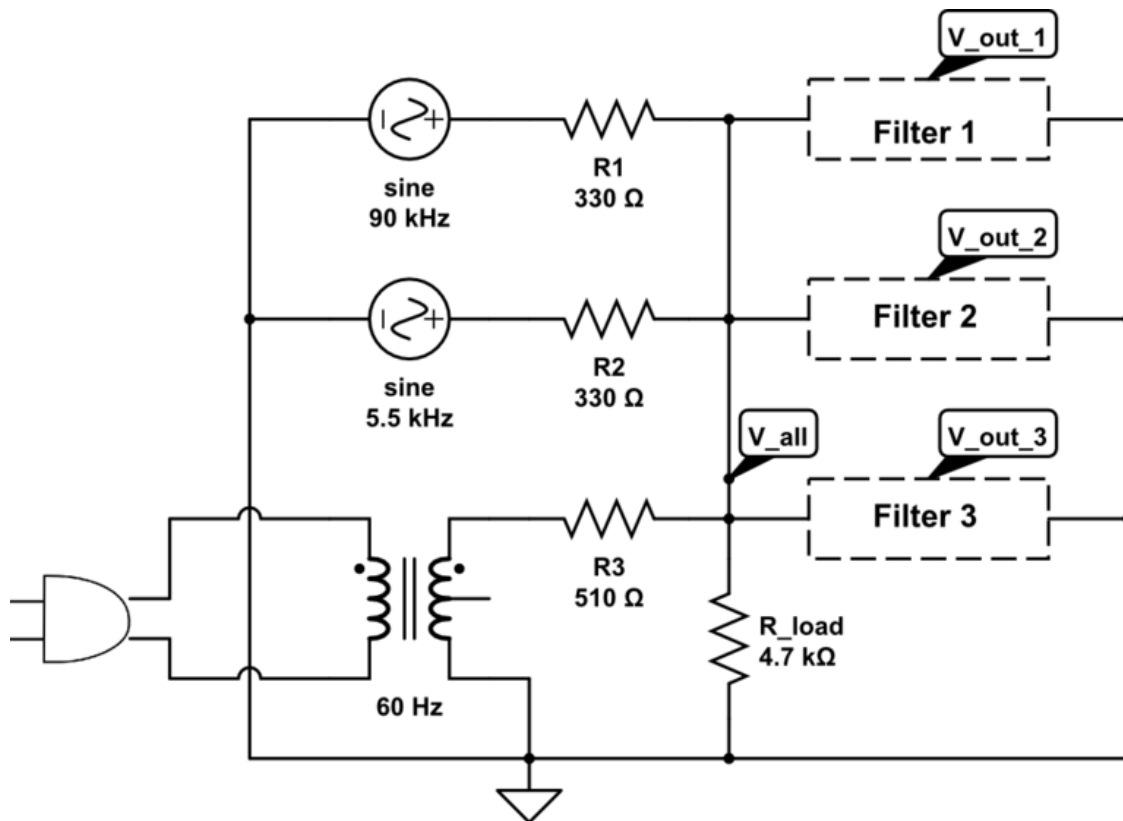


Figure 2: Merging and separating signals

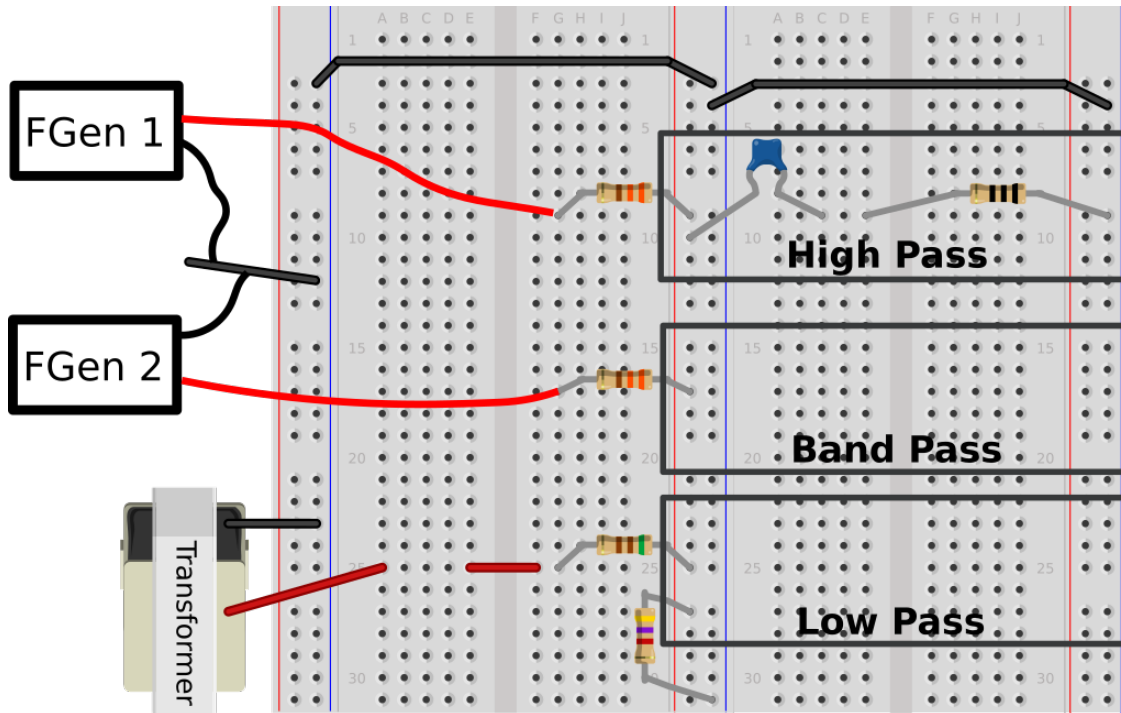


Figure 3: Proper breadboard layout, an example high pass filter is shown

Using the knowledge you have gained in the last few labs, design three types of filters and construct them in parallel.

- Filter 1 (high pass) should extract only the 90 kHz signal
- Filter 2 (band pass) should extract only the 5.5 kHz signal
- Filter 3 (low pass) should extract only the 60 Hz signal

A few reminders and tips

- Don't use electrolytic capacitors
- Avoid resistors less than 500 Ω or more than 100 k Ω
- The cutoff frequency of an RC filter is $f_c = 1/(2\pi RC)$
- The central frequency of an LC notch or bandpass filter is $f_0 = 1/(2\pi\sqrt{LC})$
- Keep averaging turned off

Q. Include diagrams of the circuits you design with all relevant information.

Q. Propagate uncertainty through the cutoff/central frequency for each filter.

Q. Include pictures of the scope output for each filter showing the MEASURE menu set to measure frequency.

Part III: Diodes and DC Power Supplies

3.1 Diode Types

Obtain a 1N5819 Schottky diode and a 1N4002 silicon diode.

The Schottky diodes have an extra low forward voltage drop and are good for both high power uses (since they won't heat up as much as standard diodes) and for low power (since less power is lost to the diode). They also have higher switching speeds and so can be preferred for high frequency applications. On the downside, they cost more and have a higher reverse leakage current which can cause problems in some circuits.

- Q. Use your multimeter to measure the forward voltage drop for each diode. Compare the values you find to the values in the data sheets (find the data sheets online).

3.2 AC Rectification

Creating a DC power supply first requires “rectification” of the AC signal. That is, removing the negative half of the sine wave so that the electrons always are moving in the same direction.

3.2.1 Half Wave Rectification

Half wave rectification is the simplest method of turning an AC signal into a DC signal.

- Connect channel 1 of your scope to measure the output of the function generator, and channel 2 to measure at V1 as shown in figure 4.
- Set the input peak-to-peak voltage to about 4 volts and the frequency to around 1 kHz.
- Measure the max voltage of the input and the max voltage of the output (V1).

Q. Take a picture and explain what you see.

Q. What is the difference in voltage between the input max and output max? Where did this difference come from?

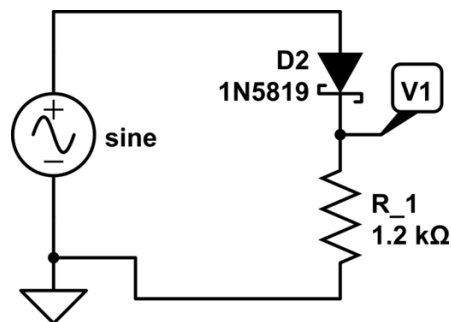


Figure 4: Half wave rectification

Half wave rectification removes the negative half of the wave, but also wastes half the power. A better method is “full wave” rectification. Full wave rectification uses four diodes to effectively flip the negative half of the wave and make it positive.

3.2.2 Full Wave Rectification

One downside of full wave rectification is that the “ground” of the AC input and the “ground” of the DC output are no longer at the same potential. Since we would like to measure with the scope across the load, and the scope and the function generator are connected to the same ground wire in the wall, we need to “float” the AC part of the circuit we don’t short two different potentials during the measuring process.

This is accomplished by using the transformer as the AC source instead of the function generator. **Once again, have your instructor check before plugging in the transformer.**

- Construct the circuit in figure 5 and take a picture of the voltage across the load resistor.
- Q. Explain what you see and how this circuit works.

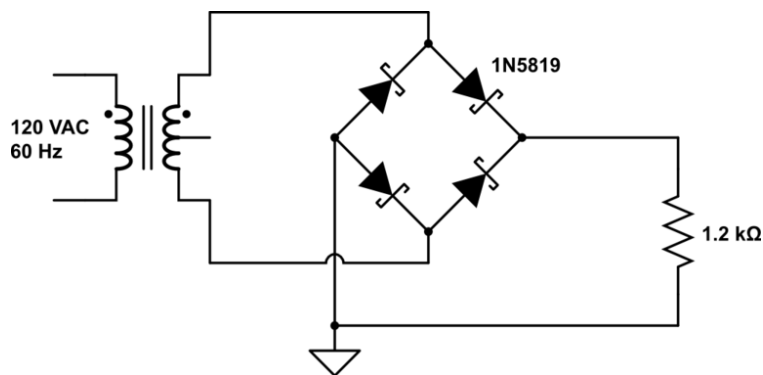


Figure 5: Full wave rectification using a bridge rectifier circuit

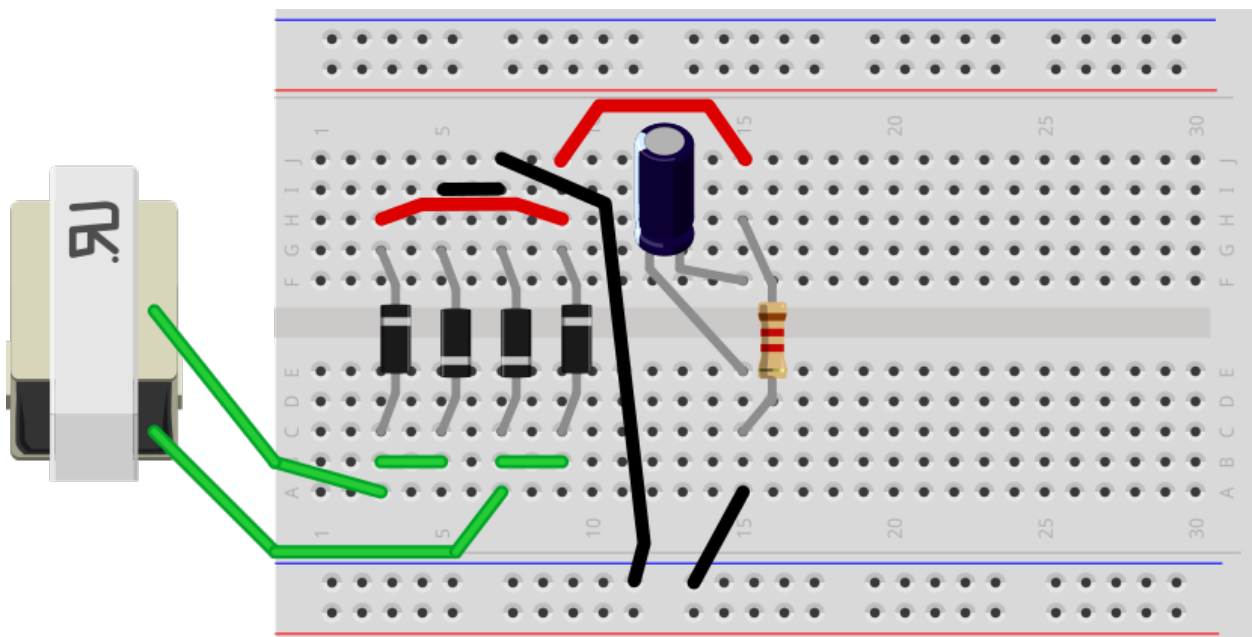


Figure 6: Proper breadboard layout (including section 3.3)

3.3 Smoothing

You now have a very bumpy DC signal. To make this useful as a power supply this signal must be smoothed out.

- Add a $10\mu\text{F}$ capacitor in parallel with the load. **This is an electrolytic capacitor so you must pay attention to polarity!**
 - If not done already, switch the trigger source to AC Line.
- Q. Measure the mean voltage and the ripple (peak-to-peak) voltage of the resulting signal.
- To obtain a smaller ripple voltage, replace the $10\mu\text{F}$ capacitor with a $100\mu\text{F}$ capacitor.
- Q. Once again, measure the mean and the ripple. **You will use this mean value in section 3.4.** *Tip: To obtain a more accurate ripple measurement, switch the channel to AC coupling and then zoom in to the signal which now has the DC component stripped off.*

You now have a basic DC power supply, however if you change the load, the mean voltage and the ripple will change. Hence why this is called an unregulated power supply.

3.4 Regulation

The final step is to add a voltage regulator. We are going to use the ubiquitous LM317 linear regulator integrated circuit, shown in figure 7. The output voltage is set using a voltage divider, which can be made variable through the use of a potentiometer.

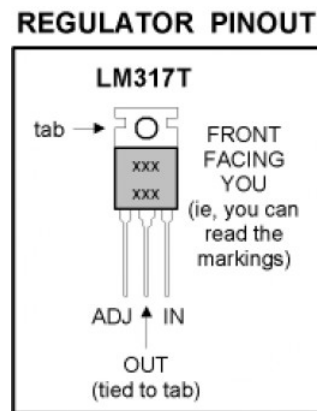


Figure 7: LM317 adjustable voltage regulator pinout

The LM317 uses a combination of transistors and an internal reference voltage $V_{ref} = 1.25$ volts to maintain a steady output voltage. However, it must have an input at least 1.25 volts higher than the output for it to function. It effectively works by burning off excess power as heat, dropping varying amounts of voltage across itself to keep the same voltage across the load

The output voltage is given by the equation $V_{out} = V_{ref}(1 + R_2/R_1)$ (where R_2 is the variable resistance of the potentiometer). When R_2 is a potentiometer wired as a variable resistor (that is, only using the center wire and one outer wire), its resistance varies from zero to $10\text{ k}\Omega$.

When R2 is at zero Ohms, the LM317 outputs it's minimum value of 1.25 volts. When R2 is at its max of approximately 10kΩ, the output will be maximized. This max can be set using R1.

Think of changing the potentiometer (R2) resistance value as “asking” the regulator to output different voltages. The regulator has a limited range it is capable of outputting, so you are going to design the circuit such that it is impossible to ask the regulator to output a voltage it can't output. The lower voltage limit is $V_{ref} = 1.25V$. The upper limit depends on the load and the input voltage. For our purposes we are going to set the R1 value such that the regulator is never asked to output a value greater than $(V_{in} - 2V)$.

- Take the average voltage you obtained with the 100 μF capacitor connected and subtract off 2 volts. Call this V_{max} . You are going to choose R1 such that the voltage regulator will never try to output a voltage higher than this.
 - Rearranging the output voltage equation for R1 gives $R1 = R2 / (V_{out} / V_{ref} - 1)$. Use V_{max} as V_{out} , the max resistance of your potentiometer as R2, and $V_{ref} = 1.25V$.
- Q. What should the value of R1 be?
- Using the value you determined for R1, construct the circuit shown in figure 8.
- Q. Use the potentiometer to vary the voltage, what range did you achieve? (Use DC coupling)
- Q. Measure any remaining ripple. (Use AC coupling)

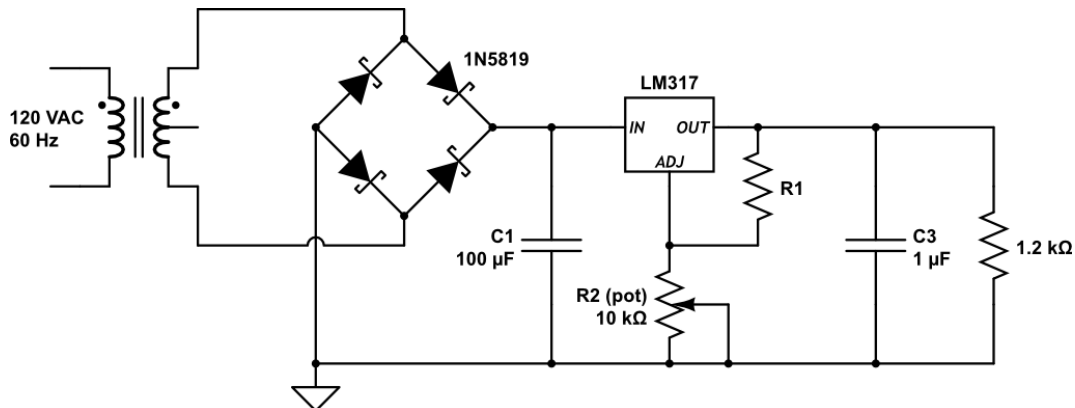


Figure 8: Adjustable regulated DC power supply

3.5 An Example

The circuit you just built is very close to the circuit used in your breadboard power supply box. Take a look at the open unit on the front table as well as the circuit diagram in the manual.

- Q. What three voltage regulator chips are used (Look for part numbers starting with “LM”)?
- Q. What voltages do these chips output? (Look up their datasheets.)
- Q. Two are black and one is larger and silver. Why is the silver one larger and metal? (Think about heat and the current rating noted on the front side of the box.)