

Lab 2: Linear and Nonlinear Circuit Elements and Networks

Objectives:

Learn how to use:

- Function of an oscilloscope probe.
- Characterization of capacitors and inductors (measure reactance, X_L and X_C).
- RLC resonant circuit.
- Simple RC high-pass and low-pass filters.
- Diode properties and applications.

Reading Assignments:

- “LCR/Impedance Measurement Basics”
 - Pay attention to pages 2, 3, 12, and 13
- “ABCs of Probes”
 - Pay attention to Chapter 3.

PreLab Questions:

- [PL1] What is capacitive reactance X_C and how does it vary with frequency? (Include formula and units)
- [PL2] What is inductive reactance X_L and how does it vary with frequency? (Include formula and units)
- [PL3] Think about what happens to a 1V pk-pk (bipolar) sine wave when it is passed through a diode. Estimate the waveform and sketch it.
- [PL4] Write down the equation for the resonant frequency of a series RLC circuit.
- [PL5] Calculate the cut-off frequency for the filter (See Figure 2).
(Use the values given in the handout: $C = 0.1\mu\text{F}$ and $R = 15.55\text{ k}\Omega$)

Lab Exercises:

A. The Oscilloscope Probe and its use (30min: estimated amount of time)

In the following steps, to print the waveform shown on the oscilloscope screen:

Run the LabVIEW program “TDS1002” to display the waveform on the computer screen. The values within each box on the LabVIEW “front panel” are set manually—make sure these values match the settings on the oscilloscope itself. Right-click within the “front panel” and choose the <Copy Data> button. <Paste> this scope trace into a blank Word document. Print out the waveforms from this Word document.

A1. Set the function generator for a frequency of 10kHz and an output of 5V peak-to-peak with a sine wave function. Set CH 1 to be AC-coupled. Turn off the DC offset (push the OFFSET button in).

A2. Plug a BNC cable directly from the output of the function generator into the oscilloscope CH 1 input. Set the function generator to produce a sine wave.

[Q1] Print the waveform and tape it into your notebook.

A3. Set the function generator to produce a square wave.

[Q2] Print the waveform and tape it into your notebook.

A4. Replace the BNC cable with the scope probe set to 1X. Set the function generator to produce a sine wave.

[Q3] Print the waveform and tape it into your notebook.

A5. Set the function generator to produce a square wave.

[Q4] Print the waveform and tape it into your notebook.

A6. Set the scope probe set to 10X. Set the function generator to produce a sine wave.

[Q5] Print the waveform and tape it into your notebook.

A7. Set the function generator to produce a square wave.

[Q6] Print the waveform and tape it into your notebook.

A8. *Change the frequency to 3 MHz.*

Repeat all of the steps above: [**~5 min.**]

A9. Plug a BNC cable directly from the output of the function generator into the oscilloscope CH 1 input. Set the function generator to produce a sine wave.

[Q7] Print the waveform and tape it into your notebook.

A10. Set the function generator to produce a square wave.

[Q8] Print the waveform and tape it into your notebook.

A11. Replace the BNC cable with the scope probe set to 1X. Set the function generator to produce a sine wave.

[Q9] Print the waveform and tape it into your notebook.

A12. Set the function generator to produce a square wave.

[Q10] Print the waveform and tape it into your notebook.

A13. Set the scope probe set to 10X. Set the function generator to produce a sine wave.

[Q11] Print the waveform and tape it into your notebook.

A14. Set the function generator to produce a square wave.

[Q12] Print the waveform and tape it into your notebook.

B. Linear Components and Simple Filters

Impedance and Capacitance of a Capacitor (20-30min: estimated amount of time):

B1. Verify the capacitance of a 0.1μF Mylar capacitor via an AC RMS current measurement. The circuit is to consist of a resistor and a capacitor in series with the output of the function generator. Choose values of 1kohm for the resistor, and 0.1 μF for the capacitor. Adjust the frequency generator to output a 1kHz sine wave, with the amplitude set to maximum.

B2. Measure the AC (RMS) voltage across the resistor V_r .

[Q13] Calculate the AC (RMS) current flowing through this circuit.

B3. Measure the AC (RMS) voltage across the capacitor. Then measure the total voltage across the system (across the resistor and capacitor).

[Q14] Why don't the voltage values add up the way that they normally do?

[Q15] Calculate the Reactance X_C of the capacitor (in ohms) with the values you measured for the RMS voltages and the RMS current:

$$V_{tot}^{RMS} = I^{RMS} \sqrt{R^2 + X_C^2} = \frac{V_r^{RMS}}{R} \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2} \quad (2.1)$$

[Q16] Calculate the impedance of the capacitor (in ohms) with the voltage measured across the capacitor:

$$|V_C^{RMS}| = |I^{RMS}| |Z| = |I^{RMS}| \sqrt{R_C^2 + X_C^2} = |I^{RMS}| \sqrt{0 + X_C^2} = |I^{RMS}| \times |X_C| \quad (2.2)$$

[Q17] From the impedance and frequency calculate the capacitance. Remember to convert frequency (Hz) to radian frequency (rad/s). Calculate the capacitance using $|X| = \frac{1}{\omega C}$.

[Q18] Compare your calculated value for the capacitance to the listed value.

B4. Use the digital multimeter to measure the capacitance directly.

[Q19] Compare with the result you calculated based on your measurements.

Low-Pass and High-Pass RC Filter (30min: estimated amount of time):

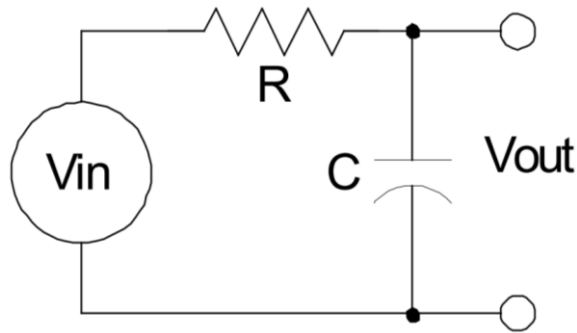


Figure 2. Filter Schematic Diagram

- B5. Build a low-pass RC filter, shown Figure 2, using the $0.1\mu\text{F}$ capacitor, and a $15.55\text{k}\Omega$ resistance (use a $10\text{k}\Omega$ and a $5.5\text{k}\Omega$ resistor in series).
- B6. *Measure the output voltage across the **capacitor (Low Pass Filter)**.* With a $1V_{p-p}$ input sine wave, measure the AC (RMS) output voltage for the following input frequencies: 5Hz, 10Hz, 15Hz, 20Hz, 50Hz, 100Hz, 200Hz, 500Hz, and 1kHz.
- [Q20] Plot the normalized output vs frequency (as a linear-linear plot).
- [Q21] Plot the normalized output vs frequency (as a log-log plot).
- [Q22] What is the cut-off frequency for this filter, as determined from the plot? Indicate this point on each plot.
- B7. Build a high-pass RC filter, as seen in Figure 2, using the $0.1\mu\text{F}$ capacitor, and $15.55\text{k}\Omega$ resistance.
- B8. *Measure the output voltage across the **resistor (High Pass Filter)**.* With a $1V_{p-p}$ input sine wave, measure the AC (RMS) output voltage for the following input frequencies: 5Hz, 10Hz, 15Hz, 20Hz, 50Hz, 100Hz, 200Hz, 500Hz, and 1kHz.
- [Q23] Plot the normalized output vs frequency (as a linear-linear plot).
- [Q24] Plot the normalized output vs frequency (as a log-log plot).
- [Q25] What is the cut-on frequency for this filter, as determined from the plot? Indicate this point on each plot.

C. The Diode (p-n junction)

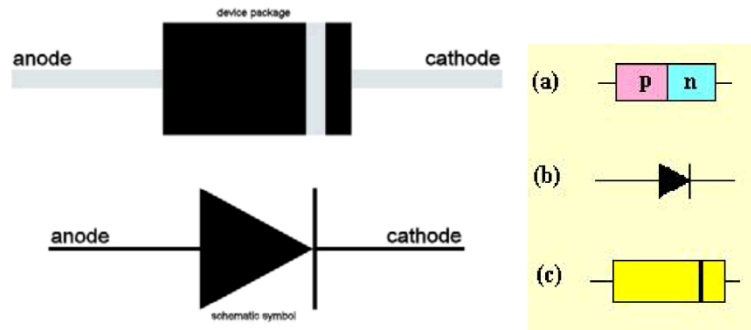


Figure 4. Diode Component Reference

The flow of current through a diode as a function of voltage across its terminals is highly nonlinear, and is given by Equation 2.3.

$$I = I_o \left(e^{\frac{qV}{kT}} - 1 \right) \quad (2.3)$$

Where:

I_o is the reverse saturation current, or leakage current (the very small amount of current that flows through the diode when the voltage across the terminals V is negative. When V is negative, the diode is said to be reverse-biased.

q is the charge of an electron

k is the Boltzman's constant

T is the temperature of the p-n junction

$\frac{kT}{q} = V_T \approx 26mV$ at room temperature, also called the thermal voltage

When V is positive, the diode is said to be forward biased, and large currents can flow (for the 1N914 small-signal diode, not for long before it burns out.)

A (generic) plot of the I-V curve for a diode is shown in Figure 5.

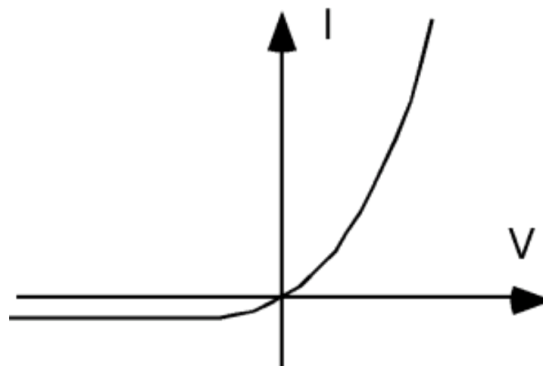


Figure 5. Generic I-V Curve

In other words, current will flow through the diode when the junction is forward-biased, but (theoretically) no current will flow when it is reverse-biased.

If too much voltage is applied in reverse-bias, the junction will also break down and destroy itself, as seen in Figure 6.

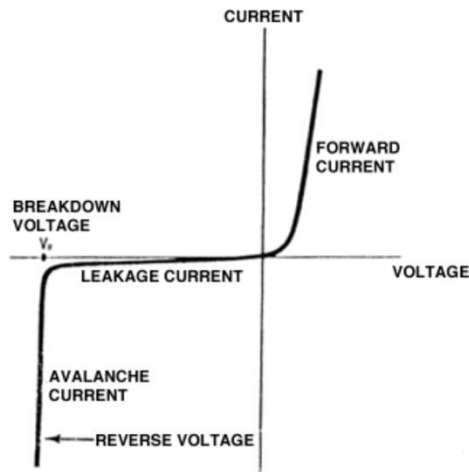


Figure 6. Breakdown of a Diode

1. Forward and Reverse Voltage Drop (at 10mA) (30min: estimated amount of time):

- C1. Wire up a $1k\Omega$ resistor in series with a 1N914 silicon diode. Place the Agilent power supply across this series combination, such that as the voltage is increased, the diode will be forward-biased. Place the hand-held DMM in parallel with the resistor, and the Agilent DMM in parallel with the diode.
- C2. Adjust the output voltage of the power supply until the voltage drop across the resistor is 10V.
- [Q26]** How much DC current is flowing through the circuit? Show your calculations. Note that this is also the current through the diode.
- C3. Measure the voltage across the diode. This is the forward voltage drop across the diode (at 10mA).
- C4. Replace the $1k\Omega$ resistor with a $1M\Omega$ resistor. Place the Agilent power supply across this series combination, such that as the voltage is increased, the diode will be reverse-biased. As before, place one of the DMMs in parallel with the resistor, and the other DMM in parallel with the diode.
- C5. Adjust the output voltage of the power supply until the voltage drop across the resistor is 10V.
- [Q27]** How much DC current is flowing through the circuit? Show your calculations. Note that this is also the reverse-saturation current through the diode.
- C6. Use the previous two circuits to measure the full I-V curve of the 1N914 diode. Use small (20mV) voltage steps of the power supply in the forward direction. Stay between -10V in the reverse direction, and 10mA in the forward direction. This is done to keep the diode from burning out. The voltage across the resistor/diode series combination is the voltage applied across the diode, and use the voltage measured across the resistor to calculate the current.
- [Q28]** Plot the I-V curve.

D. Standard Linear Power Supply (30min: estimated amount of time)

- D1. Wire up the circuit (Figure 7), to include just the transformer and the bridge rectifier. Look at the output of the just the bridge rectifier with the scope (referenced to the ground side of the bridge).

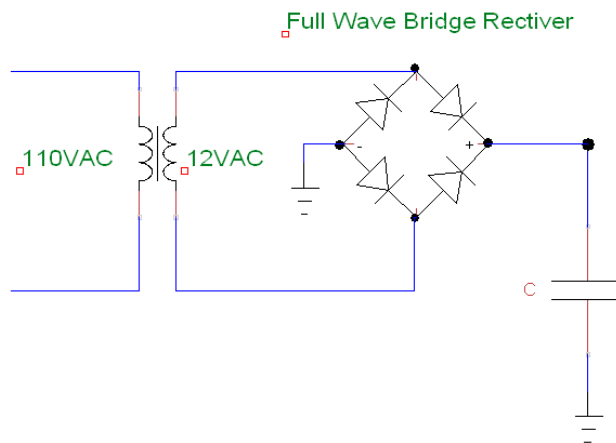


Figure 7. Standard Linear Power Supply

- [Q29] Sketch the output voltage vs. time.
Check to see if there is any residual resistance in this system.
- D2. Connect a $10\mu\text{F}$ electrolytic capacitor from the voltage regulator input to ground (in parallel).
Be aware this capacitor is polarized.
- [Q30] What is the peak to peak voltage ripple (measured across the capacitor)?