Chapter 1 - Introduction:

Safety

Most of the electronics that will be practiced in this manual are no more dangerous than those one may encounter using typical electronic devices such as cell phones.Many electronics textbooks do not even discuss safety hazards. Probably, the primary hazard in following this manual is mechanical rather than electrical, for example, dropping an instrument or computer on your foot. However, care and safety are always important, and one should avoid exceeding tolerances on all devices. Resistors can get very hot, very fast and can lead to skin burns if touched. Transistors are famous for "popping" when improperly wired. The minor explosion from one could damge the eye. Soldering will not be a significant component of this manual, but solder contains harmful heavy metals and caution should be exercised to protect eyes, hands, and lungs.

It is important not to take electronics lightly. In many lab settings, you'll encounter high voltages that can be dangerous — a current of just a few milliamperes through the heart can be life-threatening. When working with high voltage, it's wise to ground your arm to prevent current from passing through your body if contact is made.

Even when high voltage is not involved, using grounding straps is a good habit—not for your safety, but to protect sensitive electronic components from static discharge, which can easily damage semiconductors. While we don't have enough grounding straps for

Just a small error.

Chapter 2:

compare the electric potential at one point **relative to another**.

How?

- Place the **multimeter probes across** (in parallel with) the component.
- This allows the meter to measure the drop in electric potential **through** that component.

Example:

To measure the voltage across a resistor, you touch:

- One probe to the resistor's current input side.
- The other to the current output side.
- See

💡 Think of it like checking the **pressure difference across a valve** in a water pipe.

⚡ Current is Measured in Series

Why in series? ¶

Current is the **flow of electric charge** through a circuit. To measure it, the current must pass **through the multimeter** so it can count how much is flowing.

How?

- Break the circuit and insert the multimeter **in line** with the component (in series).

Is this supposed to just say "see"?

Chapter 3:

Part 2 - Signal Generator Output Impedance

Measurements

Use at least 10 different load resistors between 10 and 100 000 Ω to measure V_L. For such a large range, it is useful to use a logarithmic scaling like Table 1. Figure 3 and show the circuit you will be analyzing. The output impedance (resistance) of the signal generator is fixed by the signal generator. All instruments have such an impedance, and it may be important to know its value depending on the electronics work you are doing. It is difficult to characterize a single resistance in a circuit, and therefore, we will rely on the voltage divider circuit discussed in Part 4 - Application: Voltage Divider to Measure Temperature.

Table 1: Resistor values separated logarithmically over five decades.

decade	R_L values
10	10, 20, 50
100	100, 200, 500
1000	1000, 2000, 5000
10 000	10 000, 20 000, 50 000
100 000	100 000

I added this because I don't really understand how to use and read this table. I have never heard of it for decades.

Chapter 4:

Time

Figure 1: A (a) sine wave, (b) square wave, and (c) triangle wave form. The rms voltages are $V_{rms} = V/\sqrt{2} = V_{pp}/2\sqrt{2}$ for the sine waveform, $V_{rms} = V = V_{pp}/2$ for the square waveform, and $V_{rms} = V/\sqrt{3} = V_{pp}/2\sqrt{3}$ for the triangle waveform.

Part 2 of this lab is to measure the response or output of series resistor and capacitor (RC) circuits when given DC or AC input.

Experiment

Part 1 Theory of RMS Voltage

Periodic voltages without DC voltage contribution such as sine-, square- or triangular-wave voltages, see Fig. 2, are characterized by the period T, frequency f = 1/T, amplitude V, peak-to-peak value Vpp = 2V, and rms value Vrms. The rms value corresponds to the value of a DC voltage which – at a given electrical resistance – leads to the same dissipated power as the AC voltage. The rms voltage can be calculated by averaging the square of the AC voltage, V(t):

$$V_{rms} = \sqrt{\langle V^2 \rangle} = \sqrt{\frac{1}{T}\int_0^T (V(t))^2\,dt} \qquad (1)$$

where $\langle V^2 \rangle$ is the average of the voltage squared. Evaluation of this integral leads to different effective values for the voltage-time characteristics as shown in Figure 1.

Are you wanting to link to the figure here?

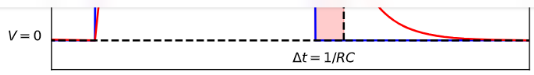

Figure 3: A close-up image of the charging and discharging capacitor circuit with a series resistor.

Exercise 2

- Explain your process for finding $\tau = RC$ and its uncertainty.
- What are your oscilloscope settings. Explain how your oscillosope settings make sense.

Part 2b - Theory of AC Impedances

A single capacitor circuit with a sinusoidal input voltage will have a time-dependent voltage across the capacitor that is ideally

$$V_C(t) = V_o \cos(t) \tag{7}$$

The current can be calculated by using the capacitor charge $Q = V/C$ and $I = dQ/dt$ to obtain

$$I_C(t) = CV_o \sin(t) = CV_o \cos(t + \pi/2), \tag{8}$$

Should be a question mark.

Here's a few more places where there's an issue in the code, a degree appears to be an o(?), and there is a mention of a figure and it doesn't link to it. I am not sure if you want to always link to the figure when you mention them or not.

indicating a phase shift $\theta = \pi/2$ rad between the voltage and current on the capacitor. The maximum current is $I_{max} = \omega C V_o$, which comes from the amplitude of the derivative to find the time-dependent current. Similar to resistance in Ohm's Law, there is a **capacitive reactance**, X_C, for the maximum current and voltage

$$X_C = \frac{V_o}{I_{max}} = \frac{1}{\omega C} \tag{9}$$

Capacitive reactance is a resistance to voltage changes rather than resistance to current changes as observed in a resistor. Because it is a type of resistance, it can be added to resistor resistance as a **total impedance**, Z, of an RC circuit. The equation above is only a relationship for the maximum values of voltage and current due to the phase difference between the time-dependent values. Using the idea that the two impedance values are 90 ^\circ} out of phase means they can be treated like orthogonal vectors (phasors) - see Figure 4. We can compute the total impedance using something analogous to the Pythagorean Theorem.

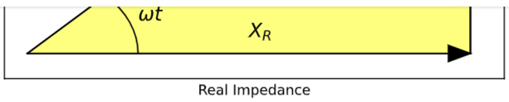

Figure 4: A diagram of impedance phasors.

The voltage is a sum of the voltages on the resistor and capacitor (circuit loop rule 1). In a simple resistor circuit the voltage and current would follow one another as $V_o \cos(t)$. As noted above the voltage and current for a capacitor are 9 ^\circ} out of phase.

$$V(t) = V_o \left(\cos(\omega t) + i \sin(\omega t)\right) = V_o e^{-i\omega t} \tag{10}$$

where the imaginary i indicates an independent vector (phasor) direction that is due to the frequency dependence of the capacitor impedance. For a series circuit, we can describe the total impedance by

$$Z_{total}^2 = X_R^2 + X_C^2 \tag{11}$$

The magnitude of each impedance determines the phase angle between input voltage and the voltage across the resistor in the circuit. The current in the circuit can be measured by the voltage drop in the resistor because there is no phase added by the resistor. Using Figure 4 one can find a relationship between the impedances

From this, we can define a crossover frequency when ω = 1/RC, θ = 45o. This is where the

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resistor voltage equals the capacitor voltage (see Fig. 6). The phase will be between 0 and 90o depending on ω, R, and C, and you will see something like Fig. 5 on your oscilloscope.

Chapter 5:

```
plt.xlabel(r'log($\omega$)')
plt.show()
```

Part 2 - Theory of RLC Circuits

Inductors are a circuit component you likely have not encountered. It is essentially a coil of wire with a magnetic core to enhance its strength. See .

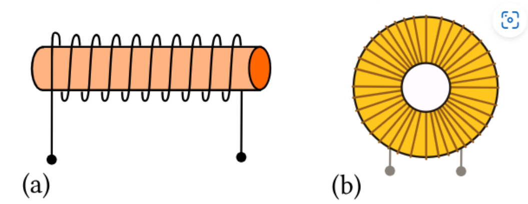

Figure 4: The makeup of an inductor includes a wire coil wrapped around a core material. (a) A solenoidal type inductor. (b) A toroidal type inductor.

A voltage applied across an inductor creates a magnetic field along the inductor. The strength of the field or magnetic flux is related to the voltage, cross-sectional area, length, and number of turns.

We define inductance, L, as

$$L = \frac{\Phi}{I} = \frac{\mu N^2 \pi R^2}{\ell} \tag{13}$$

Something appears to be missing.

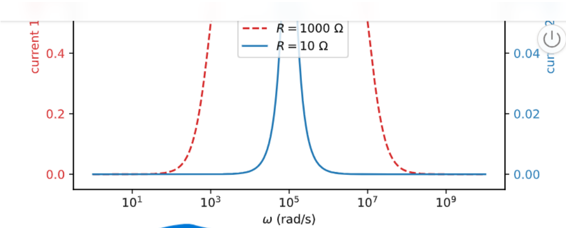

Figure 9: Plot of the current flowing through the RLC circuit as a function of input frequency Parameters are defined in and $V_o = 10$ V. The resistance is changed for comparison of quality factor from 1000 Ω to 10 Ω.

A graphical way to think about the quality factor is the frequency of the resonance divided by the width of the resonance.

$$\boxed{Q = \frac{\omega_o}{\Delta\omega}} \tag{30}$$

An example of estimating this from a graph would be to observe that the center resonance of the $R = 1000\ \Omega$ circuit is at $\omega_o = 10^5$ rad/s The width of the resonance, which is calculated at $I_{max}/2 = 0.707 \times 10^{-5}$ A. Therefore, $\Delta\omega = 0.65 \times 10^7 - 1.5 \times 10^5 = 6.35 \times 10^6$ rad/s. See Figure 10 where the width $\Delta\omega$ is shown by a horizontal arrow at the appropriate height on the graph.

These sentences sound a little odd to read. I think there is an error in at least one of them.

Exercise 6

Show the instructor your damped oscillations on the oscilloscope.

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#code for exercise 5
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Exercise 7

Challenge: The RLC circuit is sometimes called a “notch filter” because it only allows a specific frequency range to transmit with efficiency. Create a circuit that would transmit a frequency of 10 kHz with the highest Q you can achieve. Consult the instructor before you power your circuit.

Is this supposed to be there?