Laboratory 1
Basic Electric Components/Measurements
and Traditional Instruments

1 Objectives

- Familiarization with resistive electric components such as resistors and potentiometers.
- Familiarization with traditional instrumentation equipment such as the multimeter, function generator, and oscilloscope.
- Use of instruments to perform basic DC and AC measurements.

2 Background

Most instrumentation systems contain electric circuits; hence, as engineers, it is crucial that we know how to build, design, and analyze systems containing electric components. The experimental analysis of electric circuits requires the generation and measurement of signals (e.g., voltages and currents) via special purpose instruments. In the following, the various components and instruments to be used in this laboratory will be briefly described. More detailed information about the subjects covered in this laboratory can be found in references [1, 2, 3] and equipment manuals (the laboratory TA is responsible for having the manuals available if requested).

2.1 Electric Components

Resistor: A resistor is a dissipative element that converts electric energy into heat. The voltage-current relationship of an ideal resistor is given by

\[ V = RI \]  

where \( I \) is the current flowing through the resistor of resistance \( R \) when a voltage \( V \) is applied across its terminals. A resistor is conventionally drawn as shown in Figure 1. The unit of resistance is the Ohm (\( \Omega \)).

The most common resistor is made of carbon and manufactured as a cylinder with axial wire leads. Four colored bands painted around the cylinder body identify the resistance value
Figure 1: Schematic Representation of a Resistor

\[ R = AB \times 10^C \pm D \% \]

For example, if the color bands from left to right on a resistor are red, violet, orange, and gold, then the resistance is

\[ R = (27 \times 10^3 \pm 5 \%) \Omega \]
\[ = (27,000 \pm 1,350) \Omega \]

The resistor power rating measures the amount of voltage or current the resistor can handle without being destroyed. Carbon resistors are supplied in \( \frac{1}{6}, \frac{1}{4}, \frac{1}{2}, 1, \text{ and } 2 \) Watt sizes, and are identified by the dimension of their cylindrical body as illustrated in Figure 3. The maximum allowable voltage \( V_{\text{max}} \) under which a resistor can operate without damage is another important parameter to consider in the component selection process. For the available resistors in our laboratory \( V_{\text{max}} = 30 \) Volts.

\textbf{Potentiometer:} A potentiometer is a resistor whose value can be continuously adjusted. It consists of a carbon or wirewound resistor with a moving tap which can be positioned by either rotating a shaft or sliding a contact rule as shown in Figure 4. Potentiometers are characterized as either finite or infinite turn. The inherent characteristic of an infinite turn potentiometer is that its resistance varies periodically depending on the amount of rotation (typically one full rotation corresponds to the maximum resistance span). In the finite turn potentiometers, the amount of rotations required to expand the full scale of resistance limits
Table 1: Resistor Color Code

<table>
<thead>
<tr>
<th></th>
<th>A, B, C bands</th>
<th>D band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0 Gold (C only)</td>
<td>-1 Gold</td>
</tr>
<tr>
<td>Brown</td>
<td>1 Silver (C only)</td>
<td>-2 Silver</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
<td>±10%</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
<td>No band</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
<td>±20%</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Violet</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Gray</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Carbon Resistor Dimensions and Power

the amount of revolutions of the shaft. Potentiometers are schematically represented by the one of the symbols shown in Figure 4.

Figure 4: Circular and Sliding Potentiometers

**Breadboard:** Throughout your experiments whenever electric circuits have to be built, "breadboards" will be used for component mounting and creating artificial wired connections. A breadboard is comprised of a grid of small, contact squares which are internally connected (i.e., short circuited) within a column or row (see Figure 5). Specifically, all contacts in the individual rows \( r_1, r_2, r_3, \) and \( r_4 \) are short circuited. In a similar manner, all contacts in the individual columns \( c_1^{top} \) through \( c_{29}^{top} \) and \( c_1^{bot} \) through \( c_{29}^{bot} \) are short circuited. The terminals of various components (resistors, capacitors, op-amps, etc.) are attached to the contacts through a plug-in procedure. For example, Figure 5 shows a resistor that has been connected in cascade with a capacitor. Although the resistor and capacitor terminals are not
in direct contact, they share contacts within the same column \( c_{11}^{col} \). This implies that there is a wired junction between their terminals.

### 2.2 Kirchhoff’s Laws

Kirchhoff’s laws are the basis for the analysis of electric circuits. They allow you to calculate voltages and currents anywhere in a circuit.

**Current Law:** Kirchhoff’s current law states that the algebraic sum of all currents entering and leaving a node is zero. For example, at node A of Figure 6

\[
I_1 + I_2 - I_3 = 0, \quad (4)
\]

which can be rewritten as

\[
I_3 = I_1 + I_2. \quad (5)
\]
**Voltage Law:** Kirchhoff’s voltage law states that the algebraic sum of voltages around a closed loop is zero. For example, in the loop of Figure 7

\[ V_1 - V_2 - V_3 - V_4 = 0 \]  

where it is assumed that the voltage drops across each passive element in the direction of the current flow.

### 2.3 Instruments

**Multimeter:** A multimeter is an instrument that can selectively measure multiple electrical quantities, such as for example, voltage (voltmeter), current (ammeter), and resistance (ohmmeter), upon the proper adjustment of its dials and buttons. In digital multimeters (to be used in this laboratory), the numerical value of the quantity being measured is directly shown in the instrument’s display. The resolution of these devices is usually specified through the number of displayed digits (e.g., 3½ or 4½ digits). When a multimeter is characterized as having a resolution of \( X \frac{1}{2} \), it implies that it can provide an accurate measurement for the first \( X \) displayed digits within an individual scale. As an example, consider the case of a 3½ digital volt meter with a scale of 0 to 0.1 Volts, and display measurement presentation of \( \underline{XXX} \). For this scale, the voltmeter is accurate within 0.0005 Volts. Note that this is not the voltmeter’s resolution when the scale is different than the aforementioned.

Most of the meters used for measuring electric signals employ current detection as their basic indicating mode. An ammeter measures the current flowing between two terminals sharing the same voltage potential within an electric circuit. The ammeter is connected in between (i.e., in series with) the two terminals as shown in Figure 8(a). This measurement can be achieved only if the current can flow through the ammeter. Therefore, the ideal ammeter should act as a short circuit (i.e., \( R_{in} = 0 \) where \( R_{in} \) is the internal resistance of the meter) since it should not modify the circuit characteristics. The voltmeter measures the potential difference between a pair of nodes of an electric circuit. The voltmeter is connected in parallel with the portion of the circuit between the pair of nodes as illustrated in Figure 8(b). This
measurement can be achieved only if no current flows through the voltmeter. Therefore, the ideal voltmeter should respond as an open circuit to the node pair ($R_{\text{in}} = \infty$). An ohmmeter is usually embedded within a voltmeter; hence, it is connected in parallel with the resistance to be measured.

The resistance $R$ between two nodes can be calculated if the current flowing through the resistance and the applied voltage are known; i.e., using (1), we have that $R = \frac{V}{I}$. An ohmmeter (usually embedded within a voltmeter) applies a known, reference voltage $V_{\text{ref}}$ to the nodes and measures the current to then obtain the resistance by $R = \frac{V_{\text{ref}}}{I}$. To avoid damage to the multimeter, no other voltage should be applied to the nodes at the same time. The typical resistance range is 1 Ω to 32 MΩ for most multimeters.

**Power Supply:** A power supply is an electric device that provides a known DC voltage in place of a battery. A power supply is plugged into a wall outlet, and can typically deliver voltages ranging from 0 to 30 Volts. In addition, many power supplies provide separate, fixed ±12 Volts and/or ±5 Volts output terminals since these voltages are commonly used to power active electric components such as op-amps and digital integrated circuits.

**Function Generator:** Whereas power supplies are used to provide DC voltages to a circuit, a function generator provides periodic AC voltages. This equipment allows you to vary not only the amplitude of the periodic AC signal, but also its waveform. Typically, sinusoidal, square, and triangular waveforms are included in most commercially available function generators.

**Oscilloscope:** Oscilloscopes are used for detailed monitoring of AC and DC electric signals in measurement systems. Whereas digital multimeters display the numerical value of a voltage or current signal, an oscilloscope displays signals as waveforms on a screen with high accuracy and precision. Dials or buttons on the equipment’s front panel allow the modification of the amplitude and time scales of the signal being displayed. Typical oscilloscopes have two to
Figure 9: Physical Effects of Electric Shocks

four channels for signal monitoring. Signals are accessed via probes or clamps connected to oscilloscope channels.

3 Laboratory Practices

3.1 Safety Rules

While working in a laboratory environment, particular attention should be paid in the avoidance of electric shocks. Several important safety considerations must be observed while constructing the experiments.

The real measure of a shock’s intensity is measured by the amount of current forced through the body. This implies that a voltage of 10 Volts can be as deadly as 5000 Volts. Any current amount over 10 mA can cause a painful shock. The lethal current range is between 100 to 200 mA, where ventricular fibrillation of the heart occurs. Above this range, the resulting muscular contractions are so severe that the ventricular fibrillation is prevented as shown in Figure 9. If an electric shock occurs, turn the power off and/or remove the victim as quickly as possible without endangering yourself. The resistance of the victim decreases with time and the fatal current may be reached if action is delayed. If the victim has stopped breathing or is unconscious, start artificial respiration and call a medical authority.

Note that this figure is just a rough guideline of the effects of electric shocks in terms of the amount of current.
3.2 Circuit Construction Rules

While laying out the circuits for testing, the following rules should be observed. First, maintain the same “ground” for all devices. Ground is considered to be the zero-Volts, voltage reference potential. In the laboratory, several instruments are tied to the Earth’s potential for additional security. Power panels in the laboratory have terminals which are interconnected and tied to the Earth’s ground. Instruments (power supplies, function generators, oscilloscopes, etc.) may connect to the AC line with a three-terminal plug. The round non current-carrying contact is normally connected to the instrument chassis (see Figure 10). According to this, all instruments have their individual chassis interconnected through the grounding system of the power line. The individual instrument grounds should be wired appropriately, otherwise short circuits may occur. To avoid short circuits, several circuits have their terminals floating; i.e., neither terminal is connected to the ground. This is mostly common in power supplies, where two terminals provide the appropriate output and the third one is connected to the instrument chassis. In this way, either terminal can be grounded, or both left floating as depicted in Figure 11.

Secondly, neatness should be among the primary considerations when laying out your circuits. Avoid using very short or very long leads. Use the same colored wire for connecting the instruments’ ground. Avoid having any loose wires in your setup and refrain from insecure connections. Use shielded wires for low-level signals. To eliminate the effects of magnetic fields induced by the 60-Hz power line and the high frequency signals from the computers, you may want to provide a magnetic shield (e.g., aluminum foil enclosure) to your components.

4 Laboratory Procedure

4.1 Equipment List

- Four known resistors (\(\frac{1}{4}\) Watts, 5% uncertainty) \(R_k = 10\ \Omega, 100\ \Omega, 1\ \text{K}\Omega,\) and \(1\ \text{M}\Omega\).
- Four unknown resistors \(R_{ui}, i = 1, \ldots, 4\) (\(\frac{1}{4}\) Watts, 5% uncertainty).
- One circular potentiometer (\(\frac{1}{10}\) Watts, 20% uncertainty).
• Breadboard and a set of leads.
• Power supply, function generator, and oscilloscope.
• Set of BNC cables and function generator/oscilloscope probes.

4.2 Multimeter Measurements

1. Using the breadboard and multimeter, measure the value of the unknown resistances \( R_{ui} \). Comment about the accuracy of your measurements. Do you expect to obtain more accurate measurements for high, medium, or low resistances? Compare the measured values with nominal values from the color code.

2. Connect any two of the known resistors in series using the breadboard. What is the expected resistance of your series connection? Measure the series resistance with the multimeter and compare it with the expected value. Repeat the same procedure with the two resistors connected in parallel.

3. Select a resistor \( R_{ui} \) and a resistor \( R_k \) of approximately the same order as the chosen \( R_{ui} \). Connect the resistors in series and apply an appropriate voltage\(^2\) to the series connection using the power supply. A schematic representation of this circuit is shown in Figure 12. Before proceeding, you must request the laboratory TA to approve your electrical connections. By using the multimeter as a voltmeter, devise a way of calculating the unknown resistance \( R_{ui} \) from some voltage measurement in the circuit. Call this new measurement of the unknown resistance, \( R_{ui}^v \). Now, by using the multimeter as an ammeter, devise a way of calculating the unknown resistance \( R_{ui} \) from the current measurement. Call this new measurement of the unknown resistance, \( R_{ui}^a \). Repeat the above procedures for two other resistors \( R_{ui} \).

4. Comment on your measurements \( R_{ui} \), \( R_{ui}^v \), and \( R_{ui}^a \) obtained in the above experiments. Which method provided the most (least) accurate measure of the nominal resistance? Justify your answer.

\(^2\)Be careful not to choose a large voltage. Take into consideration the power ratings of the resistors.
4.3 Oscilloscope Measurements

1. Using a BNC cable, connect the output of the function generator to one of the oscilloscope channels. **Before proceeding, you must request the laboratory TA to approve your electrical connections.** Generate the sinusoidal signal shown in Figure 13 from the function generator for the following four cases $T = 10^{-3}$, $10^{-4}$, $10^{-5}$, and $10^{-6}$ sec, and view them on the oscilloscope. The amplitude scale, time scale, and trigger of the oscilloscope may have to be adjusted to properly view each case. **The TA should verify that the proper signal has been generated.** Adjust the oscilloscope so you only view the AC component of the signal. Now, adjust the oscilloscope so you view both the DC and AC components of the signal. What are the DC and AC amplitudes of the signal?

2. Repeat the above procedure for the periodic signal shown in Figure 14.

3. Connect any two of the resistors $R_k$ in series and apply the above sinusoidal voltage signal to the series connection using the function generator (i.e., in the circuit of Figure 12, replace the voltage supply with the function generator). **Before proceeding, you must request the laboratory TA to approve your electrical connections.** What voltage do you expect to see across each resistor? Using the oscilloscope probes, connect one channel to the applied voltage and the other channel across the bottom resistor (i.e., the one that is now in place of $R_u$ in Figure 12). Make sure the ground connectors of the probes are connected to the circuit ground. Setup the oscilloscope so that both the input and output voltages are seen simultaneously on the screen. Describe what you see. Do your theoretical and experimental results agree? Explain any discrepancies.

4. Repeat the above procedure for the periodic square voltage signal.

5. Assemble the circuit shown in Figure 15 on the breadboard. Make $V_i = 10 \sin (2\pi \times 10^{3} t)$ Volts and adjust the potentiometer such that $V_o = \frac{5}{6} V_i$. What do you expect the potentiometer resistance $R_p$ to be? Measure $R_p$ using the multimeter (in doing so, don’t forget to first turn off the function generator), and compare the measured resistance with the expected value. Explain any discrepancies.
Figure 13: Sinusoidal Waveform

Figure 14: Periodic Square Waveform
References

