The Oscilloscope, AC Signals, & the Electrocardiogram

In this lab you will explore the operation of the oscilloscope. It will then be used to observe some time-dependent voltage signals. Finally, a computer oscilloscope is used to view your electrocardiogram (EKG).

I. Theory

The oscilloscope (frequently referred to as the “scope”) is an extremely useful instrument for measuring voltages that vary with time. It works on much the same principles as your television set. A beam of electrons is generated by heating a cathode at the rear of the tube. This beam is accelerated along the length of the tube by applying a potential difference between the screen and the cathode. (See figure 1.) Question: Which end must be at the higher potential?

Along the way, the electron beam passes between parallel plates charged so as to deflect the beam vertically. A time-varying voltage to be measured is connected across these plates. Another set of plates is placed so as to deflect the beam horizontally. An increasing voltage is applied to these plates to “sweep” the beam across the screen of the scope. This produces a “graph” of the input voltage versus time on the screen.

The EKG (electrocardiogram) sensor measures cardiac electrical potential waveforms (voltages) produced by the heart as its chambers contract. Heart muscle cells are polarized at rest. This means the cells have a very small potential difference (voltage) from one side to the other of their cell membranes.

The cells of the heart can depolarize without an outside stimulus; that is, they will depolarize spontaneously. The group of cells that depolarize the fastest is called the pacemaker (also known as the sinoatrial or SA node). These cells are located in the right atrium. All the cells of both atria depolarize and contract almost simultaneously.

The atria and the ventricles are isolated from each other electrically. Therefore, the depolarization of the atria does not directly affect the ventricles. Another group of cells in the right atria, called the atrioventricular or AV node, send electrical signals from the atria down a special bundle of conducting fibers (called the Bundle of His) to the ventricles. In the muscle wall of the ventricles are the Purkinje fibers, which are a special system of muscle fibers that bring depolarization to all parts of the ventricles almost simultaneously. This process causes a small time delay and so there is a short pause after the atria contract before the ventricles contract.

Figure 1. Oscilloscope tube.
contract. Because the cells of the heart muscle are interconnected, this wave of depolarization, contraction and repolarization spreads across all the connected muscle of the heart.

When a portion of the heart is polarized and the adjacent portion is depolarized this creates an electrical current that moves through the body. The changes in these currents can be measured, amplified, and plotted over time. The EKG is the graphical representation of the measured electrical currents.

**The Electrocardiogram**

One part of a typical EKG (electrocardiogram) is a ‘flat line’ or trace indicating no detectable electrical activity. This line is called the **Isoelectric line**. Deviation from this line indicates electrical activity of the heart muscles. The first deviation from the Isoelectric line in a typical EKG is an upward pulse following by a return to the Isoelectric line. This is called the **P wave** and it lasts about 0.04 seconds. This wave is caused by the depolarization of the atria and is associated with the contraction of the atria.

After a return to the Isoelectric line there is a short delay while the heart’s **AV node** depolarizes and sends a signal along the atrioventricular bundle of conducting fibers (**Bundle of His**) to the **Purkinje fibers**, which bring depolarization to all parts of the ventricles almost simultaneously. After the AV node depolarizes there is a downward pulse called the **Q wave**. Shortly after the Q wave there is a rapid upswing of the line called the **R wave** followed by a strong downswing of the line called the **S wave** and then a return to the Isoelectric line. These three waves together are called the **QRS complex**. This complex is caused by the depolarization of the ventricles and is associated the with the contraction of the ventricles.

After a short period of time the chemical ions that have been involved in the contraction migrate back to their original locations. The movement of these ions generates an upward wave that then returns to the Isoelectric line. This upward pulse is called the **T wave** and indicates repolarization of the ventricles.

The sequence from P wave to T wave represents one heart cycle. The number of such cycles in a minute is called the **heart rate** and is typically 70-80 cycles (beats) per minute at rest. Some typical times for portions of the EKG are given below.

- P-R interval… 120-200 milliseconds (0.120 to 0.200 seconds)
- QRS interval... under 100 milliseconds (under 0.100 seconds)
- Q-T interval... under 380 milliseconds (under 0.380 seconds)

If your EKG does not correspond to the above numbers, DO NOT BE ALARMED! These numbers represent typical averages and many healthy hearts have data that fall outside of these parameters. To read an EKG effectively takes considerable training and skill. This sensor is NOT intended for medical diagnoses.
II. Experimental Procedure

A. Setting up the Oscilloscope

There are five regions of knobs on the front of the oscilloscope. They are all outlined in blue, except for the power region, which is outlined in red.

- CRT: this region adjusts the intensity and focus of the trace you see on the screen.
- Trigger: this region allows us to tell the scope how to properly display the input to either channel one (CH1) or channel two (CH2).
- Power: this region contains the power button and the power indicator light.
- Vertical: the buttons in this region adjust the vertical (voltage) scale of the scope. Notice we can use two inputs into this region; in other words, we can look at two voltage versus time signals at once.
- Horizontal: the knob in this region adjusts the horizontal (time) scale.

Plug in the scope, and turn it on.

Calibrate the scope by turning the three calibration knobs all the way clockwise. Two are found in the vertical region; they are the small knobs on each of the VOLTS/DIV knobs. The other is the VARIABLE SWEEP knob in the horizontal region. All three are labeled “CAL’D”. You will never need to adjust these again.

In the trigger region, turn the HOLD OFF knob all the way counterclockwise to the minimum position. You will never need to adjust this knob again.

Point the following knobs upward: the INTENSITY and FOCUS knobs in the CRT region, the TRIGGER LEVEL and POSITION knob in the Trigger region, and the two POSITION knobs in the Vertical region.

Make sure all pull knobs (there are 7) are in their normal, pushed in position. However, the square XY button in the Trigger region should be out.

In the Trigger region, the COUPLING switch should always be on AUTO. The SOURCE switch should be on the channel we are using, in this case, CH1. In the center of the vertical
region, the VERT MODE switch should also be on the channel we are using, in this case, CH1. In the Vertical region, both channels (1 and 2) have a switch; these should be set to AC.

If you do not have a horizontal green line on your screen, turn the CH1 POSITION knob until the line appears on the screen. Now, adjust the INTENSITY and FOCUS knobs to get the finest line possible.

B. Checking the Calibration of the Oscilloscope

At the bottom of the Vertical region, there is a metal tab which provides a signal for calibrating the scope, labeled CAL. The signal is a square wave with a frequency of 1000 Hz and a peak-to-peak amplitude of 2.0 V, as shown in Figure 2. We would like to take that signal and feed it into the scope through channel 1, so that we can see how accurately the scope reads the signal. **NOTE:** the actual amplitude and frequency may be somewhat different from these nominal values. If you make a careful enough measurement, you may determine the accuracy of the calibration signal.

First, let’s look at the screen. The screen is made up of a grid of 8 large divisions in the vertical direction and 10 in the horizontal direction. The scales on the scope refer to these large divisions. Each large division is broken up into 5 subdivisions. On this grid, the horizontal direction represents time and the vertical direction represents voltage. The scale of our “graph,” that is, the amount of voltage or time represented by one division, can be adjusted to fit the signal we wish to measure.

Since we will be using channel 1, the voltage (vertical) scale is set by the large knob marked “CH 1 VOLTS/DIV” in the Vertical region. The time (horizontal) scale is set by the “TIME/DIV” knob in the Horizontal region. So, the number next to the pointer on each knob indicates how much voltage one vertical division represents or how much time one horizontal division represents.

**NOTE:** The readings of voltage and time should be made precisely by interpolating between sub-divisions on the scope screen, to a resolution of 0.1 main divisions. Do not round off to the nearest division.

**Viewing the calibration signal:**

Attach the BNC end of a BNC-to-banana cable to the CH1 input.

There are two banana plugs on the end of the cable. The red plug is connected to the central wire, and the black plug is connected to a cylindrical braided outer shield. Using an alligator clip, connect the red plug (central conductor) to the CALibration terminal, found at the bottom of the Vertical region. Connect the black plug to the GND (ground) terminal.
Set the vertical and horizontal scale by adjusting the CH1 VOLTS/DIV and TIME/DIV knobs until you have at least one full cycle on your screen. Choose settings for the VOLTS/DIV and TIME/DIV knobs that best display your signal (by “best”, we mean you should have the largest picture possible and still see at least one full cycle). Use the CH1 vertical position knob and the horizontal position knob to help you center the graph. Turn the TRIGger LEVEL knob and note how it effects the stability of the signal; then adjust it until you get a clear, stationary signal.

When you are satisfied with the settings, sketch what you see on the screen, in your lab book. Be sure to label the axes, including the scales you chose. (You must always record the scale settings when taking any measurements.)

To find the peak-to-peak voltage $V$ of the signal, count the number of divisions from the top of the signal to the bottom. Read this number precisely; you should get at least one decimal precision. Now multiply the number of divisions by the scale factor (i.e., the setting of the VOLTS/DIV knob). Then, $V$ is given by

$$V = \text{(number of div) \times (scale factor)} = \text{(number of div) \times (number of volts/div)} = \text{amplitude (V)}$$

The period $T$ is determined similarly by precisely counting the number of horizontal divisions:

$$T = \text{(number of div) \times (scale factor)} = \text{(number of div) \times (number of ms/div)} = \text{period (ms)}$$

Show these measurements on your sketch of the scope screen. Calculate the frequency of the signal from your measurement of the period, recalling that $T = 1/f$.

Q1. Compare $V$, $T$, and $f$ with what is expected. NOTE: Anytime you are asked to compare a measurement with a theoretical value, show the % discrepancy and discuss the sources of error.

C. Signals from the Function Generator

The function generator is an adjustable AC power supply that provides a voltage that varies periodically with time. With the function generator we may generate sinusoidal waves or other periodic shapes. Here we will measure these signals.

It is important to understand that changing the settings on the oscilloscope merely amounts to zooming in and out of the graph, much like changing the magnification of a microscope. However, changing the settings on the function generator actually changes the signal itself.

Turn on the function generator. Connect a BNC-to-BNC cable from the function generator 50 Ω OUTPUT (not TTL) to the CH 1 input of the scope. Briefly sketch the whole arrangement in your lab book.

On the scope, set the CH1 VOLTS/DIV knob to 2 V/div and the TIME/DIV to 1 ms/div.

On the function generator:
1. Set the AMPLitude knob to 10 o‘clock.
2. Set the frequency RANGE pushbutton to 100.
3. Adjust the FREQ. (coarse) knob to get a displayed frequency of about 125 Hz.
4. Set the FUNCTION button to a sine wave.
5. Record the frequency that you set on the function generator in your lab book.
If you do not have a sine-wave signal on your scope, adjust the appropriate knobs on the scope, i.e. TRIGger LEVEL, CH1 POSITION, VOLTS/DIV, etc., until the signal appears clearly on the screen.

Choose settings for the VOLTS/DIV and TIME/DIV knobs that best display your signal (by “best”, I mean you should have the largest picture possible and still see at least one full cycle).

Draw a picture of what you see on the screen to scale, in your lab book. From the scope, determine $V$ (peak-to-peak), $T$, and $f$; be sure to show your work in finding $V$ and $T$ from their numbers of divisions on the screen and the corresponding scale factors. Does your value for $f$ agree with the function generator’s value for $f$?

Now vary the CH1 VOLTS/DIV setting to a different scale. Measure the peak-to-peak voltage $V$ of the signal using this scale setting.

Q2. What happened to the picture on the screen when you changed the VOLTS/DIV knob? Did the signal being sent to the scope change (if so, what changed?) or its representation on the screen?

Now, vary the TIME/DIV setting on the time base to a different scale. Measure the period using this new scale setting.

Q3. What happened to the picture on the screen when you changed the TIME/DIV knob? Did the signal being sent to the scope change (if so, what changed?) or its representation on the screen?

Set the VOLTS/DIV and TIME/DIV knobs to the scale you chose to be the “best”. Now change the RANGE button on the function generator to 1K. Roughly sketch what you see in your lab book. Choose the new best scales and roughly measure $V$, $T$, and $f$.

Q4. What happened to the picture on the screen when you changed the scale on the function generator? Did the signal being sent to the scope change (if so, what changed?) or its representation on the screen?

On the function generator, turn the AMPLitude knob to 8 o’clock. Again, sketch what you see in your lab book. Choose the best scales and roughly measure $V$, $T$, and $f$.

Q5. What happened to the picture on the screen when you changed the amplitude knob? Did the signal being sent to the scope change (if so, what changed?) or its representation on the screen?

On the scope, adjust the three CAL’D knobs, the TRIG LEVEL knob, the CH1 AC-GND-DC switch to see what these knobs do.

Finally, play around a bit with the different settings of the FUNCTION and FREQUENCY knobs on the function generator and report on what you see.

D. The Electrocardiogram (EKG)

This experiment section will use the Science Workshop interface system to read and display the electrocardiogram on a computer-based oscilloscope. The purpose of this laboratory activity is to demonstrate a method for measuring the electrical activity of the heart muscle – the electrocardiogram.

In this activity, the EKG sensor will measure the electrical current associated with the polarization and depolarization of heart muscle tissue during the heart’s contractions. The
Science Workshop program records and displays the electrocardiogram (heart voltage signal). The Science Workshop program automatically calculates heart rate based on the peaks and valleys in the EKG trace.

1. **Computer Setup**
   a) Connect the EKG sensor’s DIN plug into Analog Channel A on the interface.
   b) Log onto the computer and open *Science Workshop*. From the File menu, click Open and open the file: (your section number is n)

   C:\labs\122\secn\oscillo\B13_ekgd.sws.

   The document will open with a Graph display of “EKG Voltage (mV)” versus “Time (sec)” on one plot, and “Heart Rate (bpm)” versus “Time (sec)” on the second plot.

   **Note**: For quick reference, see the Experiment Notes window. To bring a display to the top, click on its window or select the name of the display from the list at the end of the Display menu. Change the Experiment Setup window by clicking on the “Zoom” box or the Restore button in the upper right hand corner of that window.
   c) The “Sampling Options…” should be set as follows: Periodic Samples = Fast at 100 Hz (100 samples per second).

2. **Sensor Calibration and Equipment Setup**
   **About the EKG Sensor**
   The sensor consists of the electronics box with a cable for connecting to the *Science Workshop*. Three electrode leads enter the electronics box on the side opposite the cable that attaches to the interface. The circuitry isolates the user from the possibility of electrical shock in two ways. The sensor signal is transmitted through an opto-isolation circuit. Power for the sensor is transferred through a transformer. The circuitry protects against accidental over-voltages of up to 4,000 Volts.

   The sensor is designed to produce a signal between 0 and five volts with 1 volt being the Isoelectric line. Deviation from the Isoelectric line indicates electrical activity. The shape and periodicity of the signal is of primary importance, so the sensor does not need to be calibrated.

   **Equipment Setup: Connecting the EKG Sensor to a Person**
   Use three electrode patches per subject. The electrodes can be reused but they tend to absorb moisture (they are very hygroscopic), and therefore, reuse is not recommended. The electrodes should be kept in an air-tight, clean, dry container for storage.

   Because the electrical signal produced by the heart and detected at the body’s surface is so small, it is very important that the electrode patch makes good contact with the skin. Scrub the areas of skin where the patches will be attached with a paper towel to remove dead skin and oil.
a) Peel three electrode patches from the backing paper. Firmly place the first electrode on the right wrist. Place a second electrode on the right upper arm. Place the third electrode on the left upper arm. (This is one of several possible arrangements for EKG electrodes on the body.)

Place each electrode so it is on the inside part of the arm (closer to the body) and the tab on the edge of the electrode patch points down, so the wire of the sensor can hang freely without twisting the edge of the electrode patch.

b) Connect the micro alligator clips from the sensor to the tabs on the edges of the electrode patches. There are several different ways to connect the EKG sensor. This simple arrangement is appropriate for the classroom.
   i) Connect the black (or "reference") alligator clip to the wrist electrode patch. This is the reference point for the “Isoelectric” line (baseline).
   ii) Connect the green (or negative) alligator clip to the right upper arm electrode patch.
iv) Connect the red (or positive) alligator clip to the left upper arm electrode patch.

3. Resting EKG
   a) Click the “REC” button to begin recording data. The person whose EKG is being measured should remain calm and relaxed. Encourage the person to breathe normally. The values of data will be recorded in the Graph display.
   b) Click the “STOP” button to end data recording after about fifteen seconds. “Run #1” will appear in the Data list in the Experiment Setup window.

Data Table: Interval Analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P wave peak</td>
<td>sec</td>
</tr>
<tr>
<td>Q wave dip</td>
<td>sec</td>
</tr>
<tr>
<td>R wave peak</td>
<td>sec</td>
</tr>
<tr>
<td>S wave dip</td>
<td>sec</td>
</tr>
<tr>
<td>T wave peak</td>
<td>sec</td>
</tr>
<tr>
<td>next R wave (R') peak</td>
<td>sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Time</th>
<th>Typical Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-R interval</td>
<td>sec</td>
<td>0.120 to 0.200 sec</td>
</tr>
<tr>
<td>QRS interval</td>
<td>sec</td>
<td>under 0.100 sec</td>
</tr>
<tr>
<td>Q-T interval</td>
<td>sec</td>
<td>under 0.380 sec</td>
</tr>
<tr>
<td>R-R' interval</td>
<td>sec</td>
<td>0.5 to 1.2 sec</td>
</tr>
</tbody>
</table>

Analyzing the Data – Record all your answers in a table in your lab book.
   a) Click the Graph to make it active. Click the “Magnifier” button. The cursor changes to a magnifying glass shape when it is in the graph display area.
   b) In the plot of EKG Voltage, use the Magnifier-cursor to click and draw a rectangle around a region of the data that includes four or five complete heart cycles. The graph will rescale to show the region you selected.
   c) Click the “Smart Cursor” button. The cursor changes to a cross-hair shape when it is in the Graph display area. The Y-coordinate of the cursor is displayed near the Y-axis label. The X-coordinate of the cursor is displayed near the X-axis label.
   d) Move the cursor/cross-hair into the plot of EKG Voltage. Place the cursor at a point that corresponds to the peak of a P wave. Record the time (displayed as the X-coordinate near the X-axis label).
   e) Move the cursor/cross-hair to the point that corresponds to the peak of the Q wave. Record the time. Move the cursor/cross-hair to the point that corresponds to the peak of the R wave. Record the time.
   f) Calculate the P-R interval and record the time.
   g) Move the cursor/cross-hair to the point that corresponds to the peak of the S wave. Record the time.
   h) Calculate the Q-R-S interval and record the time.
i) Move the cursor/cross-hair to the point that corresponds to the peak of the T wave. Record the time.

j) Calculate the overall Q-T interval and record the time.

k) Calculate the R-R' interval between two successive heartbeats. The inverse of this time is the heart rate, in beats per second.

l) Click the “Autoscale” button to rescale the graph to fit the data.

m) Click the “Statistics” button to open the Statistics area. Click the “Statistics Menu” button in the plot of Heart Rate (bpm).

n) Select “All of the Above” from the Statistics Menu. The Statistics area in the plot of Heart Rate will show count, minimum x and minimum y, maximum x and maximum y, mean for x and y, and Standard Deviation for x and y.

o) Record the minimum y, maximum y, and mean of y as the heart rate in a table.

Data Table: Heart Rate Analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
</tr>
</tbody>
</table>

Q6. Compare your values for the P-R, Q-R-S, and Q-T intervals to the typical times given. What could explain the differences?

Q7. How does the heart rate measured by the EKG compare to your heart rate as determined by direct measurement of the pulse at the wrist or neck? What could explain the difference? Compare with the value as determined from the R-R' interval.

III. Equipment

Oscilloscope (B+K 2120B)
Function generator (Instek GFG-8020H)
1 - BNC-to-banana cable
1 - red crocodile clip
1 - BNC-to-BNC cable
Science Workshop Interface System and computer
EKG Sensor
EKG electrodes
Paper towels