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The University of Connecticut ........................................................................................................ 1

Fall 2008........................................................................................................................................ 1

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Introduction

The Vital Signs Monitor was developed with the purpose of measuring a variety of physiological signals and to teach students about these signals and how they are obtained. During this project the student will learn about and measure an electrocardiogram (ECG), body temperature, and respiration. Students will also learn the fundamental electronics required to measure and transmit these analog signals to a computer. Additionally, students will build and program their own vital signs monitoring kit.

Background

Electrocardiography

Electrocardiography is a method of monitoring and recording the electric currents generated during the alternating contractions of the atria and ventricles of the heart. The device used to monitor and record these signals is an electrocardiogram, more commonly referred to as an ECG or EKG. When using an ECG, electrodes are applied to the skin in places where the heart’s electrical signals can be measured easily. Usually, these locations are between muscles on the upper arms and lower legs. Cables connect the electrodes to the ECG, where the electrical signal is turned into a waveform on a computer or a paper plot. The results produced from this machine allow physicians to observe the performance and condition of the heart, as well as diagnose any problems they may find in the signal. A normal ECG tracing is shown in Error! Reference source not found. and the various components of the ECG are shown in Figure 2.

![Figure 1, Normal ECG signal.](image)

![Figure 2, ECG segment names.](image)
The heart’s electrical system is quite complex. Electrical rhythms that begin as impulses are emitted from the sinoatrial (SA) node, also known as the heart’s “natural pacemaker.” The impulse then travels across a specific route, or pathway, moving through the atrioventricular (AV) node and into the ventricles. Once the impulse reaches the ventricles, it serves as a set of instructions, causing the heart’s chambers to contract in a routine and consistent manner. The path of this electrical signal, called the PQRST waveform as shown in Figure 2, may be followed through the heart (Figure 3). This path constitutes a single heartbeat. The ECG breaks down each heartbeat into a set of three distinct waves: the P wave, the QRS complex and the T wave. These waves indicate behavior of the impulse at each location along its pathway. The P wave is associated with the spread of the impulse through the heart’s upper chambers (atria). The QRS complex and the T wave reflect the contraction and relaxation of the ventricles respectively.

![Heart and Valves](image)

**HEART and VALVES**

Figure 3, Cross-section of the anatomical structure of the heart. Blue indicates passages bringing blood into the heart (oxygen poor); red indicates passages through which blood exits (oxygen rich).

**What is an ECG used for?**

If this set of rhythms is interrupted, delayed or sent down the wrong path, the heartbeat may become irregular, (i.e., moving too fast or slow). These abnormal rhythms are produced if a patient has suffered a heart attack or heart disease. An ECG can be used to help detect the pathologic changes. ECGs can be used if patients experience any of the following symptoms:

- Angina (chest pain resulting from the heart not getting enough oxygen)
- Palpitations (strong, fast or otherwise irregular heartbeat)
• Arrhythmias (irregular, fast or slow heart rhythms)
• Dyspnea (shortness of breath)
• Syncope (lightheadedness or loss of consciousness)
• Pericarditis (inflammation of the pericardium - a thin, fluid-filled sac surrounding the heart)
• Long Q-T syndrome (a disorder that could lead to fainting (syncope) or sudden cardiac death)
• Myocarditis (Inflammation of the heart muscle due to viral infection)
• Certain congenital heart defects

Many people with coronary artery disease, heart valve disease or heart muscle disease will eventually have abnormal ECG readings. Because many ECGs are done while the patient is at rest, certain abnormalities that occur during periods of stress may not appear even in patients with significant disease. In fact, it has been estimated that the resting ECG is accurate only about 50% of the time. Because it is very common to see this false-negative result (i.e., the ECG does not find the damage or abnormality that is really present), a normal ECG is not enough to rule out suspected heart disease.

You will have the opportunity to create a plot of your own ECG and analyze your heart rate using a real electrocardiogram machine, called the Siemens Burdick EK10. Instructions on how to operate the ECG are located at the end of this booklet in APPENDIX A.

After creating your own ECG in this project, you will have the opportunity to apply electrodes to your arms and legs and observe your own heart’s signal on a computer screen.

**Body Temperature**

Physicians often use the body’s temperature as an indicator of infection. A normal body temperature is usually 98.6°F (37°C) when taken orally. An oral temperature greater than 100°F usually indicates a fever. Body temperature can be taken with a variety of different thermometers. The original thermometer was a glass tube filled with mercury. Modern thermometers are usually filled with alcohol which changes volume with a change in temperature. Digital thermometers use thermistors or thermocouples to take a temperature measurement. This project will use a thermistor as the body temperature sensor.

The thermistor is a special resistor that changes its resistance with a change in temperature. There are two types of thermistors, positive temperature coefficient
(PTC) and negative temperature coefficient (NTC). Positive temperature coefficient thermistors resistance increases with increasing temperature. Negative temperature coefficient thermistors decrease in resistance with increasing temperature (Figure 4). You will be using a NTC thermistor to measure body temperature in this project.

![Figure 4](image)

**Figure 4, Typical NTC thermistor output curve.**

**Respiration Rate**

Many times physicians monitor respiration rate as it can be an indicator of respiratory function or fever. There are a variety of methods of measuring respiratory rate. These methods include a stethoscope, respirometer, or by a nasal thermal sensor. The nasal thermal sensor will be used in this project.

The respiration rate is defined as the number of breaths per minute. In this project, a probe will be placed in the nostril to detect the temperature of the air. When the patient exhales, warmer air will pass over the sensor. When the patient inhales, cooler air will be drawn past the sensor into the lungs. These temperature fluctuations will create a waveform that can be processed to determine the respiration rate. Figure 5 shows the nasal respiration sensor and a typical respiration waveform.

![Figure 5](image)

**Figure 5, Nasal respiration sensor (left) and typical respiration waveform (right).**


**BASIC ELECTRONICS**

Before discussing the elements used to create a circuit, the nature of electricity should first be discussed. Current is known as the flow of electricity through a circuit. Resistance is the opposition to the flow of current. Voltage refers to the amount of electrical force that must be used to move current through the circuit.

In the case of a circuit, electricity acts much like water in a pipe. In this analogy voltage is the pressure in the pipe, current is how fast the water flows through the pipe, and resistance acts like a valve that only allows a certain amount of water to pass through the circuit. The circuit acts as the different pathways the water can take. Each of the different circuit elements acts to manipulate the “water” in different ways. To understand what is happening in the circuit, keep this analogy of water in mind as you read the following section.

**Printed Circuit Board**

A Printed Circuit Board, or PCB, is what connects all of the electrical components together to form a circuit. A normal PCB is constructed with a thin sheet of a fiberglass substrate, which is an insulator. An insulator keeps the electricity from traveling down undesired circuit paths. The fiberglass substrate has solder covered copper lines called traces that conduct electricity between components. These traces can be on one or both sides of the fiberglass substrate. Components are always mounted on the top layer of the board and soldered on the bottom layer of the board. Some special PCB’s can contain layers of traces embedded in between the top and bottom layers. These are called multilayer PCBs and are usually found in electronic devices where space and weight are a large concern (i.e., cell phones, laptop computers, airplanes, and satellites). PCBs are used in almost every electronic device.

** Resistors  

A resistor acts to resist current flow. As the strength of a resistor increases, it becomes more difficult for current to flow in the circuit. A color-coded band indicates the strength of a given resistor. The unit of resistance is the Ohm (Ω). For example, our ECG design consists of resistors with resistance values of 1k (1,000) Ω and 1M (1,000,000) Ω. The schematic symbol of a resistor is shown below in Figure 6.

---

Figure 6, Schematic symbol for a resistor.
Resistors and power

Resistors are also rated by their power capacity. Power is calculated by Ohm’s law: \( P = I \times V \) and \( I = V/R \).

Substituting for \( I \) gives us \( P = V^2/R \) and substituting for \( V \) gives \( P = I^2R \).

In these equations, \( P \) is power, \( I \) is current, and \( V \) is voltage. The power may not always be important to the theoretical operation of a circuit, but it becomes extremely important in the real world. If the power capacity of a component is less than power delivered to that component, it will get very hot and destroy the component.

For example, for the 1kΩ resistors in the ECG, the power is:

\[
P = \frac{(9\text{V})^2}{1,000 \Omega}
\]

\[
P = 0.081 \text{ W or 81 mW}
\]

Resistors are commonly sold in with power ratings of \( \frac{1}{4} \) W, \( \frac{1}{2} \) W, 1W, and 2W. In general, resistors with higher power ratings are larger and more expensive than resistors with lower power ratings. Since size and cost are both concerns for our ECG we will choose the resistor with the lowest power rating that is still above our calculated power value of 0.081 W. Since the lowest value available is \( \frac{1}{4} \) W, which is equal to 0.250 W, and 0.250 W is greater than 0.081 W, we have chosen \( \frac{1}{4} \) W resistors for our ECG.

Reading the Color Code

The code in Table 1 describes how to determine the value of a resistor as shown in Figure 7. Note that the color lines on the resistor are read in the following order: 1st digit, second digit, multiplier, tolerance and quality.

Table 1, Resistor Color Code Chart.

<table>
<thead>
<tr>
<th>Black</th>
<th>Brown</th>
<th>Red</th>
<th>Orange</th>
<th>Yellow</th>
<th>Green</th>
<th>Blue</th>
<th>Violet</th>
<th>Gray</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

To illustrate how to determine resistance, we use the resistor in Figure 7 and the color code chart in Table 1. First locate the tolerance band on the resistor: it is gold as shown in Figure 7. Starting from the other end, identify the first band (the color green). Write down the number associated with the color green from the color code chart in Table 1, Resistor Color Code Chart. (green is 5). Now read the next color,
here it is violet, so write down a “7” next to the 5. Now read the third or 'multiplier' band and write down that number of zeros. In this example it is red (2), so the resistor’s value is 5,700 \( \Omega \), or 5.7 k\( \Omega \). If the “multiplier” band is black (for zero) don't write any zeros down.

**Capacitors**

A capacitor is a circuit element that is used for storage. The capacitor itself is made of two conductor plates that are separated by an insulator (dielectric) such as air, glass, paper, plastic, or ceramic. A capacitor is “charged” when one plate of the capacitor has more electrons than the other. The unit of capacitance is the Farad (F). A diagram of a simple capacitor and its schematic symbol are shown below in Figure 8.

![Figure 8, A model of a simple capacitor and the schematic symbol for a capacitor.](image)

Capacitors can vary widely in the types of materials they are constructed from. Some of the more common types of capacitors include electrolytic, ceramic, tantalum, and polypropylene. Each type of capacitor is specialized for a particular type of application. The capacitors in the ECG circuit are electrolytic and polypropylene.

Capacitors are also rated by their voltage. They can range from just a few volts to over 10,000 V. In general, the minimum voltage rating of the capacitor you choose should be above the maximum voltage applied to that capacitor. The maximum voltage in our circuit is 9 V + 9 V or 18 V, so we have chosen values of 50 V and 25 V, both of which are above the 18 V maximum in the circuit.

**Integrated Circuit Chips**

Integrated Circuit Chips are usually called IC chips. An IC chip is a specific circuit that has been miniaturized to fit into a small package. There are thousands of different types of IC chips, each performing a different function in a circuit. One type of IC chip is an operational amplifier, which is usually referred to as an op amp. In this project, the op amp acts similarly to the volume control on your TV. It enlarges the power, current, or voltage of the circuit without physically changing the signal. In the case of the ECG, the “volume” of the heart’s impulse is being turned up so we can see it in the tracing. In Figure 9 below is a picture of what some typical IC chips
look like. There is also a diagram, called a pinout, of an op amp. In the pinout diagram, each of the legs of the chip is labeled to indicate a specific connection it has with the rest of the circuit. Some of these connections are input, output, voltage source \((V_{CC})\), and ground \((V_{CC-})\).

### Packaging

The term packaging refers to the size, shape and connection method of a component.

### Basic Digital Electronics

Digital is a system that represents if a device is on or off. Digital logic uses binary numbers to represent this. If a device is on, it is said to be a digital 1 or high. If a device is off it is said to be a digital 0 or low. When a circuit is built we use batteries or power supplies that have DC voltages. In order to switch a gate high or low we must first define what voltage the gate will interpret as high and what voltage the gate will interpret as low. For the TTL (Transistor to Transistor Logic) that we will use, a digital high has been defined as +5 VDC and a digital low have been defined as 0VDC or ground. Often digital logic is used to switch other electronics. Logic gates are used to make decisions about switching. Three basic types of logic gates are AND, OR, and NOT (also known as an inverter). Gates usually have two inputs and an output. The gate will switch the output high or low based on what the input is and what type of gate it is. The input and output for each gate is organized in what is called a truth table. By examining the AND truth table (Table 2) we can see that the output will only be high in the case that Input A and Input B are high.
Serial Communication:

Digital devices can communicate with each other using logic. This binary information is organized into groups. Each binary digit in these groups is called a bit. The larger the group is, the more information is sent at one time. Serial communication works by sending one byte of information after another through two wires, a signal and a ground.

The vital signs monitor uses a serial communication format called RS232. This is the format used by all serial ports on IBM PC’s as well as many other devices. The main difference between normal serial communication and the RS232 format is that the normal voltage range for TTL is +5 to 0 VDC; the voltage range of the RS232 format has been increased to +10 to -10 VDC. The vital signs monitor uses the MAX232 IC to convert the serial data from the microprocessor to the RS232 format. The vital signs monitor is also capable of communicating wirelessly using Bluetooth. The Bluetooth option is not included in the kit due to the high cost.

Analog to Digital Conversion

An analog signal is a voltage that changes over time. A digital signal can only be +5 VDC and 0 VDC. Our vital signs signals are analog signals. However, the computer only understands digital information. In order to get the computer to read our analog signals we must perform analog to digital (A/D) conversion.

Our A/D converter has 8 bits, and has a voltage range from 0 to +5 VDC. Since it is an 8 bit converter there are 256 different binary numbers that will represent the input voltage. The resolution of the A/D converter is 5 VDC/256 or about 19.5 mV. The A/D converter operates by periodically sampling the voltage of a signal and recording it in binary. Figure 10 shows an analog waveform y(t) being sampled at intervals of Δt. The voltage recorded at each Δt interval is then scaled based on the resolution of the converter. For example, if a voltage of 0V is read the A/D converter would output a value of 0. If the voltage was 2.5V the A/D converter would output a value of 128.
Isolation

Since the vital signs monitor has leads which create an electrical path across the heart, care must be taken to ensure that the patient is electrically isolated from any potentially harmful sources of electricity. In the case of our ECG, the patient is connected to the leads, the leads are connected to the vital signs monitor, the vital signs monitor is connected to the computer, and the computer is plugged into a 120 VAC outlet. It is very unlikely that a scenario could occur in which enough things went wrong to actually complete a circuit between the patient and the 120 VAC source, but as engineers we must plan for this event.

An isolator is a device which transmits an electrical signal without an electrical connection between the input and the output of that device. The vital signs monitor has a digital isolator between the microprocessor and the MAX232 IC.

What is a microprocessor?:

A microprocessor is a device that acts as a little computer. Many electronic devices such as MP3 players, CD players, microwaves, calculators, and cell phones contain a microprocessor. We use the microprocessor for decision making, control, and transmitting data. For the vital signs monitor we will use a Microchip PIC microprocessor number 16F870. The following is a summary of the basic commands and functions of the microprocessor.

Ports and Input/Output:

There are three I/O ports on the PIC16F870 Ports A, B, and C. They are labeled on the data sheet as RX0 through RX7 (where X is A, B, or C). Since the pins can be multifunctional there is usually more than one label associated with each pin. Each port has 8 pins and each port has an 8 bit binary variable that represents it called.
PORTX. Therefore each bit of that variable represents a pin on the microprocessor. As outputs, all of those bits default to a digital “0” (aka 0 VDC, ground or a digital low) unless there is an input at one of the pins. So if a digital “1” (AKA +5 VDC or a digital high) is placed at pin 25 of the microprocessor, then the bit that represents bit 4 of port B will be high. So the variable PORTB will have a value of B’00010000’. This is the reason values are in binary when using the microprocessor. By looking at a port’s variable we can determine which pins are high or low. Conversely by storing a value to a port variable it is possible to put a digital high at a specific pin of the microprocessor. For example if a value of B’00010000’ is stored to the variable PORTC there will be +5 VDC at pin 15 of the microprocessor. As inputs, the bits for the variables have no default value. They will randomly assign themselves a value, for this reason input pins are said to be “floating pins”. It is important to incorporate a default value into the electrical design of the microprocessor circuit.

The I/O ports on a microprocessor do not work until the program has declared them as either an input or output. This is called the direction of the port. Port B can be set up as an input and port C as an output. This is done during the program initialization. TRISX is the variable that determines the direction of the portX. Storing a digital 1 to a bit in TRISX will make a desired pin an input and a digital 0 to a bit in TRISX will make that pin an output. So to set all of Port B as inputs you would store B’11111111’ to TRISB, and to set all of Port C as outputs you would store B”00000000” to TRISC.s

Soldering Techniques

Soldering is the process in which the components are connected to the traces on the PCB. This process can be tricky because bad connections will result in problems with your circuit. Therefore, soldering requires some concentration and patience. Here are some tips for better soldering.

- Keep parts clean: grease, fingerprints, and dirt will keep solder from sticking properly.
• Keep the soldering iron clean: clean the soldering iron by wiping it on a wet sponge. Make sure the iron is not blobbed with solder.

• Keep your hands clean: solder contains lead, so it’s a good idea to wash your hands when you are done.

• Heat parts: use the soldering iron to heat the parts. Touch the solder to the parts, not the iron. The hot parts melt the solder. **Do not melt the solder with the iron directly because a blob of molten solder will not stick to your cold parts.**

• Amount of Solder: too little solder will not attach the parts, too much gets in the way and may touch other components.

• Amount of Heat: you need to heat things up enough to melt the solder, but don't overheat components - most electrical components can only take a couple of seconds of heat.

• Keep hands cool: remember, heat conducts along parts and wires...do not hold them in your hand. Use pliers, clamps, etc.

• Cooling: parts do not cool instantly. You need to hold the parts together a few seconds after removing the iron before you let go.

• Wire-to-component: For things such as switches, there is often a little tab (often with a hole in it) to solder. It is tempting to twist the wire in and around the tab-hole and then heat and solder the whole mess. This usually produces a big messy blob that often doesn't conduct properly as it is hard to heat all that metal at once. It's better to pre-tin the wire and the tab (even if you fill the hole). Then heat the tab, stick the wire a short way into the hole (the solder plugging the hole will be molten) and heat the wire as well. A tiny bit more solder will fuse it all together. Keep in mind that large components take a long time to cool.

• PCB: printed circuit boards are the easiest to solder. Push the component lead or wire through the hole. Lay the iron against both the wire and the pad for a second or two on one side and then touch the solder to the other side of the component lead or wire and pad. The solder should melt and flow all around the wire/tab and pad. Be sure to hold components such as sockets firmly down to the board. To solder an IC socket down, do the two opposite corners first.
Instructions for Soldering

1. Solder the leads in place.

2. Obtain cone-shaped soldered joints.

3. Do not apply round solder joints. This will result in a bad connection.

4. Trim the excess wires up to the level of the solder.
EQUIPMENT

Oscilloscope

An oscilloscope (right) is a machine that draws a graph of an electric signal. In most applications the graph shows how signals change over time, or time dependency. The vertical (Y) axis represents voltage and the horizontal (X) axis represents time. Figure 1 shows a sample-readout. This simple graph can tell you many things about a signal:

- Specific voltage values per time.
- Calculate the frequency of a signal.
- Determine what portion of a signal is direct current (DC) and alternating current (AC).
- Determine what portion of the signal is noise and whether the noise is time dependant.

For more information refer to APPENDIX B: Oscilloscope.

Figure 1, X, Y, and Z Components of a Displayed Waveform.
**PARTS FOR THE PROJECT**

**Checklist**

When you receive your vital signs monitor kit, go through the parts listed below and make sure your kit is complete. Record the contents of your kit by checking the box next to each part name. If you have trouble identifying a part, or a part is missing from your kit, let someone know, and they will help you.

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</tr>
<tr>
<td>2</td>
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<td>8 pin DIP socket</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>1</td>
<td>Isolator (IL712-2)</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>2</td>
<td>Voltage Regulators (L7805ACZ, 3 pins)</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>1</td>
<td>Voltage Inverter (ADM660AN)</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>1</td>
<td>Oscillator (brown ZTT 4.0MG)</td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td>8</td>
<td>1k Ω Resistor (brown black red)</td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>4</td>
<td>1M Ω Resistor (brown black green)</td>
<td><img src="image7.png" alt="Image" /></td>
</tr>
<tr>
<td>1</td>
<td>100 Ω Resistor (brown black brown)</td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>2</td>
<td>3.3k Ω Resistor (orange orange red)</td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
<tr>
<td>3</td>
<td>4.7k Ω Resistor (yellow purple red)</td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
<tr>
<td>1</td>
<td>320k Ω Resistor (orange red yellow)</td>
<td><img src="image11.png" alt="Image" /></td>
</tr>
<tr>
<td>4</td>
<td>470k Ω Resistor (yellow purple yellow)</td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
<tr>
<td>5</td>
<td>Capacitors: 0.1 µF</td>
<td><img src="image13.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>Capacitors: 0.001 µF</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Capacitors: 47 µF</th>
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</tr>
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<table>
<thead>
<tr>
<th></th>
<th>Capacitors: 3.3 µF</th>
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<table>
<thead>
<tr>
<th></th>
<th>Capacitors: 10 uF</th>
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<td>2</td>
<td></td>
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<table>
<thead>
<tr>
<th></th>
<th>Capacitor: 0.01 uF</th>
</tr>
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<td>1</td>
<td></td>
</tr>
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<table>
<thead>
<tr>
<th></th>
<th>DB9 RS232 Serial Connector (silver)</th>
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<tr>
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</tr>
</tbody>
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<table>
<thead>
<tr>
<th></th>
<th>Toggle Switch (SPDT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Toggle Switch (DPDT)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Banana Jacks: 2 Orange, 1 Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Banana Plugs: 2 Orange, 1 Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
### ASSEMBLY INSTRUCTIONS

#### Circuit Board Procedure

1. Begin the circuit board assembly by inserting and soldering the DIP sockets one at a time into the circuit board. Insert the 8 pin sockets at slots U1, U2, U3, U4, U8, and U10. Insert the 16 pin socket at U7, and insert the 28 pin socket at U9. **Make sure the notch at the end of the socket is on the same side as the square pad.** Be sure the socket is fully inserted into the PCB and all of the pins of each socket are in each hole and none have folded underneath the socket. Once a socket has been soldered it is extremely difficult to remove!! To avoid damaging the IC chips do not insert them into the socket now, the heat
from the soldering iron could damage the chip. Be sure to solder each pin of the sockets.

2. Insert a 1 MΩ resistor into slot R3. To make insertion easier, bend the leads straight down on both sides of the resistor, and place the leads in the holes. Solder and clip. The direction in which the resistors are inserted is not important though it may look more organized if all the gold stripes are on the same side. Put 1 MΩ resistors into R4, R5, and R6, solder and clip.

3. Put a 100 Ω resistor into R21 solder and clip.

4. Put a 3.3k Ω resistor into R7 and R12 solder and clip.

5. Put a 4.7k Ω resistor into R13, R14, and R16 solder and clip.

6. Put a 320k Ω resistor into R20 solder and clip.

7. Put a 470k Ω resistor into R15, R17, R18, and R19 solder and clip.

8. Insert the oscillator into the three pin holes labeled X1. The oscillator is the light blue piece with the letters ZTT written on it. The direction is not important because the part is symmetrical.

9. Place a 0.1 μF capacitor into slots C6, C7, C8, C9, and C10. These are the small black and gray cylindrical capacitors. The positive lead of the capacitor should be placed in the square hole and the negative lead (white stripe) should be in the other hole.

10. Place the 0.001 μF capacitor into the C15 slot. This is the two pinned part with 102G written on it. The letter after the 102 could be different. This capacitor does not have any polarity so it can be soldered in any direction.

11. Place the 47 μF capacitors into slots C11 and C12. Solder and cut.

12. Place the 3.3 μF capacitor into the C13 slot.

13. Place the 0.01 μF capacitor into the C3 slot.

14. Place the 10 μF capacitor into the C1 and C2 slots.

15. Insert two 5 V regulators into the two three pin positions labeled U5 and U6 on the board with the lettering (flat side) on the regulator facing the bottom of the PCB. The regulators are the 3 pinned black pieces with a rounded side and a flat side.

16. Cut your wires, then strip both ends of all wires with the strippers and tin them. To tin the wires, heat the wire with the soldering iron, and then touch the solder to the wire. The solder will melt and soak into the wire. You should
put on enough solder to coat the stripped portion of the wire. Too much solder will make blobs of solder on the wire and the wire will not fit into the hole on the PCB. Make sure you read through the directions and look at the schematic before cutting your wires. Some wires may need to be longer than others!

17. Insert one end of one of the short black wires into the terminal of J1 labeled Gnd.

18. Take a short green wire and insert one end into the J1 hole labeled Tx.

19. Insert the short orange wires into the two holes labeled Arm, and the black wire into the hole labeled Leg. Solder and clip.

20. Insert 6 red wires into the holes labeled SW and SW. Solder and clip.

21. Insert 2 black wires into the negative terminals of V1 and V2. Solder and clip. Solder the black wires to the negative terminals of the battery holder.

22. Insert 2 red wires into the positive terminals of V1 and V2. Solder the red wires to the positive terminal of the battery holder making sure to keep the V1 and V2 wires on the same battery. (V1 should be on one battery, V2 on the other.)

23. Insert the other red wires from the S1 and S2 positions on to the DPDT switch as follows:

![Diagram]

Before soldering, cut 4 pieces of heat shrink tubing and slip over wires. Solder wires to switch. Use a heat gun to shrink the heat shrink over the switch terminals.

24. Eight holes will need to be drilled into your box; 3 for the ECG inputs, 1 each for the body temperature and respiration, two for the switches, and one larger
one for the serial connector. Think before you drill! Make sure your pieces will fit where you plan to drill the holes!

25. Insert one red wire into the SW Pwr hole solder and clip. Slip heat shrink tubing over the red wire and solder to the middle pin of the SPDT switch. Repeat this step for the Resp and Temp wire holes with a different color wire. This completes the mode switch.

26. Insert the black female banana jack into one of the three holes you made for the ECG inputs and tighten it. Slip heat shrink over the short black wire and insert into the hole on the jack, solder and clip. Repeat for the two orange jacks, inserting them into the other holes using the two short orange wires from the Arm inputs.

27. Insert and screw the RS 232 serial connector onto the box. Insert the black wire from the negative output terminal into the hole labeled 5 on the serial connector. Insert the green wire from the positive terminal of the output into the hole labeled 2 on the serial connector. Solder and clip.

28. Insert and solder short black wire into pin 1 of J2 on the PCB for the respiration thermocouple. Connect the other end of the short black wire to the top pin of the respiration jack. Repeat with a different wire for pin 2 of J2 and attach to the bottom pin on the jack. Insert the jack into the side of the box and secure with a nut.

29. Repeat the previous step for the body temperature sensor (J3). This time insert the black wire into J3 pin 2 on the board and solder. Use a short red wire for J3 pin 1. Connect the short red wire to the bottom pin of the jack and the short black wire to the top pin and solder. Insert the jack into the side of the box and secure with a nut.

30. The microprocessor now needs to be programmed. Appendix F shows some sample code for programming a microprocessor, however, you will be provided with a pre-programmed one. After it has been programmed, it must
be carefully placed into the 28 pin DIP socket. The notch on the chip should line up with the notch on the socket.

31. Now insert the remaining IC Chips into their DIP sockets. The IL712, TL072, LM358, and ADM660AN all have 8 pin sockets, and the ADM3202 has 16 pins.

IT IS VERY IMPORTANT THAT ALL OF THE ICS ARE FACING THE CORRECT WAY! YOU COULD PERMANENTLY DAMAGE THE CHIPS IF THEY ARE INSERTED THE WRONG WAY!

ECG Lead Procedure

1. Cut the gray cable into two equal pieces. These wires will be the arm leads for your ECG. Cut and strip another wire to the same length as the gray cables. This third wire will serve as the leg lead.

2. Strip 2-3" of gray insulation from cable. Use a sharp knife to lightly cut through the insulation making sure not to cut the metal shield underneath.

3. Push the shield together with both fingers as shown in figure below. This will cause the shield to loosen around the wire.
4. Use the knife to pry a hole in the shield. This will allow you to pull the wire through the shield. Make sure the hole is close to the gray insulation.

5. Pull the wire through the hole in the shield so the shield is now hollow.
6. Repeat steps 1-5 for the second cable.

7. Twist the two shield wires together along with the leg lead wire. Slip black plastic banana plug cover over the wires. Carefully solder the shield and wire to the banana plug.

**TIP:** For best results, put plug in the metal vice (not the ones with the plastic on the clamp. Put a blob of solder on the soldering iron and touch it to the plug. Let the plug heat up so it is hot enough to melt the solder. Push the wires into the plug and fill the hole with solder.

8. Solder the orange banana plugs to the white arm lead wires.

9. Strip the other end of the wires removing the insulation and the shield.

10. Solder the alligator clips to the white wire. Be careful not to solder the shield to the clip as it will cause a short circuit.
Respiration Thermocouple Wiring Procedure

1. Slip the black plastic strain relief piece onto the thermocouple wire first.

2. Solder the white wire to the pin in the center of the plug. This pin is for the tip of the plug.

3. Solder the red wire to the long metal tab with the hole. This tab is for the barrel of the plug.

Figure 13, Vital Signs Monitor PCB
Figure 14, Schematic page 1.

Figure 15, Schematic page 2.
LabView™ SOFTWARE

When viewing the vital signs signals, software must be used to convert the electrical impulse into a visual representation that we can see and understand. LabView is a unique software package that provides just that.

Introduction to LabView™

LabView™ (Laboratory Virtual Instrument Engineering Workbench) is a software package developed to build programs with symbols (icons) rather than writing out lines and lines of programming text. It uses symbols, terminology and formats that are familiar to technicians, scientists, and engineers. LabView™ is programmed to act as an interface, helping pieces of hardware “communicate” with each other. Moreover, LabVIEW™ offers built-in libraries that allow the user to work over the internet and use different programming formats and systems.

LabView™ Applications

The applications to LabView™ are endless. In the past, multiple instruments were necessary to obtain the data a researcher wanted. In the case of the vital signs monitor, several oscilloscopes would be needed to view more than one heartbeat from an individual simultaneously. Instead, LabView™ has virtual instruments (VIs). These are programs that are built into LabView™ and perform the same...
function as another piece of equipment such as an oscilloscope. In our case we can view as many heartbeats from many individuals as we want. We just need to specify how many channels we will need rather than use multiple oscilloscopes.

LabView’s™ virtual instruments may be modified for each specific application. This means that the user can manually add functions to their VI at any time. Furthermore, LabView™ can be “plugged” into the internet, so progress can be controlled from remote locations. In other words, someone in the U.S. could monitor and control the heat in their house in Russia!

Of course, LabView™ would be one component in an entire system. In our system, we have a circuit board, a power source (the batteries), a data acquisition board that collects the data, LabView™, and a computer. These components can be categorized into one of the following groups that comprise the entire system.

- Computer
- The acquisition board
- The supervised system itself

An example of another system is shown in the following figure.

![Figure 17, A typical virtual system using LabView™.](image)

From a functional standpoint, LabView™ has two different screens: front screen and back screen. The front screen is the user screen (or Front Panel). It is the location of the user-interface that has the capacity to look like the front of an instrument. There are controls, (such as buttons, meters, gauges and whatever else the user needs to monitor the data), and indicators the user needs to handle their data. The back screen
(diagram) is the graphical programming code. This is where all the icons are arranged and programmed. This screen is the control center for LabView™ applications. It is here where changes can be made to the function of the VI.

The two screens have two subpanels known as palettes. These palettes are used to build the VI and negotiate objects. The tools palette changes the function of the mouse. An arrow can be used to select different controls and place them on the screen. A finger might be used to press the buttons and turn the dials on the front screen. The cursor allows labels to be added to the program so it is better organized and clear to follow. The front panel has a control palette where different knobs, switches and monitors may be selected. The back panel has a functions palette that allows one to choose icons that make the VI work specifically. Figure 18 and Figure 19 show the front and back screens respectively.
Figure 18, Front panel with tool and control palettes shown.

Figure 19, Back panel with tools and functions palettes.
Figure 20 shows an example of a constructed front panel. This VI is a converter from Celsius to Fahrenheit temperature scales. The “Numeric” palette is one of the options within the control palette. To construct the instrument, simply drag the components from the palettes to the desired location.

In order to convert temperature from Celsius to Fahrenheit, we know that the following mathematical conversation must be used

\[ \text{DegF} = (\text{DegC})(1.8) + 32 \]

Therefore, this mathematical operation must be constructed in the back screen. Figure 21 shows the addition and product operations and constants taken from the numeric sub palette and constructed on the back screen to build this conversion.
This is only a small example of the plethora of capabilities that LabVIEW™ can offer. A more complex application will be used for the visualization of your vital signs monitor project. The application involves composite levels of programming such as for loops, do loops, and charts for the drawing of the signal on the computer screen.

**Designing Your LabView™ Interface**

The vital signs monitor system that you will develop is for the continuous acquisition and chart recording of single or multi-input channels. This will allow you to record and save buffered analog data from one or more individuals, which is continuously acquired into a circular buffer at the same time that data previously retrieved from the buffer is plotted. The virtual instrument (VI) that you are about to design will also allow you to plot multiple points from multiple channels on a single chart.

The buffer size is the number of scans that will be held in the internal memory buffer, and is limited by the amount of memory the computer has available. In order to avoid potential computer freezes, it is recommended that you stick with the default buffer provided for you.

You will want to add more functions to the diagram to customize this VI for the vital signs monitor application. A common reason to read data while the acquisition is in progress is to process and display the data in pseudo-real time. The acquisition rate you can achieve depends on how much processing and display the VI must do. Add whatever filter processing you need to this subVI, or replace it with one of your own. Note that the amount of the data returned will change depending...
on the scan backlog. Use the "number read" output from the AI Read VI to determine how many scans are returned.

**Introduction to Virtual Instrument (VI) Icons for ECG Design**

Below is a list of the icons you will use for data acquisition and processing of ECG signals.

<table>
<thead>
<tr>
<th>ICON SYMBOL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="AI Config" /></td>
<td><strong>AI Config.</strong> Configures an analog input operation for a specified set of channels.</td>
</tr>
<tr>
<td><img src="image" alt="AI Start" /></td>
<td><strong>AI Start.</strong> Starts a buffered analog input operation.</td>
</tr>
<tr>
<td><img src="image" alt="AI Read" /></td>
<td><strong>AI Read.</strong> Reads data from a buffered data acquisition</td>
</tr>
<tr>
<td><img src="image" alt="Butterworth Filter" /></td>
<td><strong>Butterworth Filter.</strong> Generates a digital filter using the sampling frequency, low cutoff frequency, high cutoff frequency, order, and filter type.</td>
</tr>
<tr>
<td><img src="image" alt="Peak Detector" /></td>
<td><strong>Peak Detector.</strong> Finds the location, amplitude, and second derivative of peaks or valleys in the input array.</td>
</tr>
<tr>
<td><img src="image" alt="Write To Spreadsheet File" /></td>
<td><strong>Write To Spreadsheet File.</strong></td>
</tr>
<tr>
<td><img src="image" alt="Max &amp; Min" /></td>
<td><strong>Max &amp; Min.</strong> Compares x and y and returns the larger value at the top output terminal and the smaller value at the bottom output terminal.</td>
</tr>
<tr>
<td><img src="image" alt="Beep" /></td>
<td><strong>Beep.</strong> Causes the system to issue an audible tone.</td>
</tr>
<tr>
<td><img src="image" alt="AI Clear" /></td>
<td><strong>AI Clear.</strong> Clears the analog input task associated with taskID in.</td>
</tr>
<tr>
<td><img src="image" alt="General Error Handler" /></td>
<td><strong>General Error Handler.</strong> Determines whether an error has occurred. If an error has occurred, this VI creates a description of the error and optionally displays a dialog box.</td>
</tr>
<tr>
<td><img src="image" alt="Index Array" /></td>
<td><strong>Index Array.</strong> Returns the element or sub-array or your input signal (array) at the provided index.</td>
</tr>
<tr>
<td><img src="image" alt="Do-While Loop" /></td>
<td><strong>Do-While Loop.</strong> The While Loop executes the subdiagram until the conditional terminal, an input terminal, receives a specific Boolean value (i.e., stop command).</td>
</tr>
<tr>
<td><img src="image" alt="Case Structure" /></td>
<td><strong>Case Structure.</strong> Has one or more subdiagrams, or cases, exactly one of which executes when the structure executes. Whether it executes depends on the value of the Boolean, string, or numeric scalar you wire to the external side of the terminal or selector.</td>
</tr>
</tbody>
</table>
INSTRUCTIONS FOR LABVIEW™ INTERFACE DEVELOPMENT

Phase I - Retrieving Input Signal

The code diagram in Figure 14 provides the computer a means for receiving your ECG analog signal. The smaller labeled boxes that are attached to the VI icons are controls and constants. You can create them using the RIGHT mouse button options. You will notice that the wiring for these boxes is unique (i.e., color, thickness, design). Use the “Show Context Help” under HELP options to guide you in making the appropriate wire connections.

![Code Diagram for receiving waveform signal.](image)

Phase II - Buffering Input Signal

To the right of the previous code, implement a While Loop and apply one shift registry as explained in the text box below. Be sure to give yourself plenty of room within the While loop box to avoid cluttering up your program.
Word to the wise: It becomes very difficult to track errors when the graphical code looks like spaghetti.

Figure 23, While Loop used to repeat waveform recording operation

**Phase III – Digital Signal Processing**

It is here where you will perform the necessary data processing to display real-time waveform recordings. The illustration in Figure 24 provides you with a detailed map of the VI icons and wiring. These connections will take the raw signal buffer it, display it, and digitally filter it. It is very important that you use the “Context Help” to ensure that your connections are being made properly. Remember…the smaller boxes that lead into the VI icons are controls and constants and can be obtained by using the RIGHT mouse button options. (It will be described later as to how you may change the appearance of the controls in the Front Panel.)
Phase IV – Threshold and Peak Indicators

Here you will continue with more detailed digital signal processing. You are going to develop the necessary signal processing to display filtered real-time waveform recordings. The illustration in Figure 25 provides you with a detailed map of the necessary VI icons and attachments. It is here that the filtered ECG signals are displayed, and threshold & peak indicators are implemented. The purpose of these indicators is to provide some feedback to the user (i.e., physician) regarding the patient’s average heart rate. It is very important that you use the “Context Help” to ensure that your connections are being made properly. Remember...the smaller boxes that lead out of the VI icons are indicators and can be obtained by using the RIGHT mouse button options as was done for constants and controls. (It will be described later as to how you may change the appearance of these indicators.)
**Phase V – Write Data to Spreadsheet File for Exporting**

This VI opens or creates the file before writing to it and closes it afterwards. You can use this VI to create a text file readable by most spreadsheet applications (i.e., MS Excel). This VI calls the Array to Spreadsheet String function to convert the data. You can optionally transpose the data (as in the illustration Figure 22).

![Diagram](image)

**Figure 25**, Detailed map of the necessary VI icons and attachments.

![Diagram](image)

**Figure 26**, VI calls the Array to Spreadsheet String function.
Decorating Your ECG Front Panel

Use decorations controls and indicators, located on the Controls»Decorations palette, to add graphics to customize front panels. These objects are for decoration only and do not display data. A final ECG front panel may look something like the pictures shown in Figure 27.

Figure 27, Completed example front panel for vital signs monitor.

Tools Palette: Gives color to your front panel.
**ECG Setup Protocol**

- Place a limb sensor, (sticky pad) on the right wrist that has been wiped clean with alcohol.
- Repeat step 1 for left wrist.
- Place the ground pad on the inside of your right calf between your bone and muscle that has been wiped clean with alcohol.
- Make sure mode switch is in ECG mode and the vital signs monitor is turned on.

To begin running the vital signs monitor program, simply press the arrow button located in the top left hand side of the screen. The monitor will provide you with a raw printout, filtered printout, and heart rate value. If you applied audio feedback successfully it should let the users know when ECG values are too low (i.e., leads not connected properly or patient is having cardiac problems). To end the program, simply press the stop button located on the right hand side of the top printout screen.
APPENDIX A

Using the “SIEMENS Burdick EK10” ECG Machine

ELECTROCARDIOGRAM BASICS

The electrical activity of the heart can be recorded at the surface of the body using an electrocardiogram. The electrocardiogram (ECG) is simply a voltmeter that uses up to 12 different leads (electrodes) placed on designated areas of the body.

Why is an Electrocardiogram Done?

This test will help the doctor evaluate the patient's cardiac condition related to:

- If a heart attack has occurred
- What part of the heart was damaged
- If there are any irregular heart beats or rhythm
- If there is a decreased supply of blood and oxygen to the heart

What do the Waves and Intervals mean?

![Diagram of heart cycles and waves](image)
<table>
<thead>
<tr>
<th>P-Wave</th>
<th>QRS.</th>
<th>T-Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>If it is longer than .20 seconds, it may indicate first-degree heart block. SA Node fires. Atrial Depolarization Sinus initiated rhythm.</td>
<td>Depolarization of the ventricles. Ventricular Contraction. Atrial Repolarization. (Can't always be seen on ECG)</td>
<td>Ventricle Repolarization. May be affected by changes in serum K levels.</td>
</tr>
</tbody>
</table>

- The P wave is caused by atrial depolarization. The P wave is usually smooth and positive. The P wave duration is normally less than 0.12 s.

- The PR interval is the portion of the ECG wave from the beginning of the P wave (onset of atrial depolarization) to the beginning of the QRS complex (onset of ventricular depolarization). It is normally 0.12 - 0.20 s.

- The PR segment is the portion on the ECG wave from the end of the P wave to the beginning of the QRS complex. The PR segment corresponds to the time between the end of atrial depolarization to the onset of ventricular depolarization. It is an isoelectric segment, during which the impulse travels from the AV node through the conducting tissue (bundle branches and Purkinje fibers) toward the ventricles.

- The QRS complex represents the time it takes for depolarization of the ventricles due to ventricular depolarization. The normal QRS interval range is from 0.04 s - 0.12 s measured from the first deflection to the end of the QRS complex.

- The ST Segment represents the period of ventricular muscle contraction before repolarization. The ST segment is normally isoelectric (no electrical activity is recorded). However, the ventricles are contracting.

- The QT interval begins at the onset of the QRS complex and to the end of the T wave. It represents the time of ventricular depolarization until ventricular repolarization.

- The T wave is formed due to ventricular repolarization. The wave is normally rounded and positive.

**ECG Procedure:**

- Remove one limb sensor, (sticky pad) and place it on your right bicep, between your bone and muscle.
• Repeat step 1 for left arm.
• Remove a limb sensor and place it on the inside of your right calf between your bone and muscle.
• Repeat step 3 for left leg.
• Attach lead LA to the tab of the limb sensor on your left arm.
• Attach lead RA to the tab of the limb sensor on your right arm.
• Attach lead RL to the tab of the limb sensor on your right leg.
• Attach lead LL to the tab of the limb sensor on your left leg.
• Press auto button.
• Press 1 or 2, and use the ECG that looks most like the model ECG.
• Press the stop button when satisfied with your reading.

Calculating Heart Rate
You can measure your heart rate from your ECG print out.

• Take a ruler and measure in centimeters from the peak of a QRS complex to the peak of an adjacent QRS complex of to adjacent waves.
• Convert centimeters to millimeters by multiplying this number by ten.
• Divide that number by 50 mm/s.

Figure A-1: Model ECG format, showing P wave, QRS complex, and T wave.
• Multiply this number by 60. That will give you your heart rate in beats per minute.

• Fill out the back of the ECG paper with your general information. The number you calculated above can be placed as “Rhythm.”

• On the reverse side of the given paper, peel off the stickers and place your four best ECG readings on it.
Oscilloscope Operation

Electronic equipment can be divided into two types: analog and digital. Analog equipment works with continuously variable voltages, while digital equipment works with discrete binary numbers that may represent voltage samples. For example, a conventional phonograph turntable is an analog device; a compact disc player is a digital device. The oscilloscope we will be using is capable of both analog and digital signals.

The generic term for a pattern that repeats over time is a wave - sound waves, brain waves, ocean waves, and voltage waves are all repeating patterns. An oscilloscope measures voltage waves. One cycle of a wave is the portion of the wave that repeats. A waveform is a graphic representation of a wave. A voltage waveform shows time on the horizontal axis and voltage on the vertical axis.

You can classify most waves into these types:

- Sine waves
- Square and rectangular waves
- Triangle and saw tooth waves
- Step and pulse shapes
For our purposes, we will be using sine waves and square waves. The sine wave is the fundamental wave shape for several reasons. It has harmonious mathematical properties - it is the same sine shape you may have studied in high school trigonometry class. Test signals produced by the oscillator circuit of a signal generator are often sine waves. The square wave is another common wave shape. Basically, a square wave is a voltage that turns on and off (or goes high and low) at regular intervals. It is a standard wave for testing amplifiers - good amplifiers increase the amplitude of a square wave with minimum distortion. Television, radio, and computer circuitry often use square waves for timing signals.

If a signal repeats, it has a frequency. The frequency is measured in Hertz (Hz) and equals the number of times the signal repeats itself in one second (the cycles per second). A repeating signal also has a period - this is the amount of time it takes the signal to complete one cycle. Period and frequency are reciprocals of each other, so that 1/period equals the frequency and 1/frequency equals the period. So, for example, the sine wave in Figure B-2 has a frequency of 3 Hz and a period of 1/3 s.
Voltage is the amount of electric potential (a kind of signal strength) between two points in a circuit. Usually one of these points is ground (zero volts) but not always - you may want to measure the voltage from the maximum peak to the minimum peak of a waveform, referred to at the peak-to-peak voltage. The word amplitude commonly refers to the maximum voltage of a signal measured from ground or zero volts.

The volts per division (usually written volts/div) setting varies the size of the waveform on the screen. A good general purpose oscilloscope can accurately display signal levels from about 4 mV to 40 V. The volts/div setting is a scale factor. For example, if the volts/div setting is 5 V, then each of the eight vertical divisions represents 5 V and the entire screen can show 40 V from bottom to top (assuming a graticule with eight major divisions). If the setting is 0.5 V/div, the screen can display 4 V from bottom to top, and so on. The maximum voltage you can display on the screen is the volts/div setting times the number of vertical divisions.

**Setting the Oscilloscope Controls**

Some oscilloscopes have an AUTOSET or PRESET button that sets up the controls in one step to accommodate a signal. If your oscilloscope does not have this feature, it is helpful to set the controls to their standard positions before taking measurements.

Standard positions include the following:

- Set the oscilloscope to display channel 1
- Set the volts/division scale to a mid-range position
- Turn off the variable volts/division
- Turn off all magnification settings
- Set the channel 1 input coupling to DC
• Set the trigger mode to auto
• Set the trigger source to channel 1
• Turn trigger hold to minimum or off
• Set the intensity control to a nominal viewing level
• Adjust the focus control for a sharp display
• Turn the three red knobs all the way to the right
APPENDIX C

Debugging Your LabVIEW™ Code

Correcting Broken VIs

If a VI does not run, it is a broken or non-executable VI. The Run button often appears broken when you create or edit a VI. If it is still broken when you finish wiring the block diagram, the VI is broken and will not run.

Common Causes of Broken VIs

Complete the following steps to check for the most common reasons why a VI is broken while you edit it.

1. Confirm that your block diagram has no broken wires.
2. Confirm that you wired all block diagram terminals.
3. Determine if a subVI is broken by selecting Windows»Show Error List and checking all the entries in the VI List section for errors. You break a subVI if you edit its connector pane after you place its icon on the block diagram of the VI.

Debugging Techniques

If a VI is not broken, but you get unexpected data, you can use the following techniques to identify and correct problems with the VI or the block diagram data flow:

- Wire the error in and error out parameters at the bottom of most built-in VIs and functions. These parameters detect errors encountered in each node on the block diagram and indicate if and where an error occurred. You also can use these parameters in the VIs you build.
- Use execution highlighting to watch the data move through the block diagram.
- Single-step through the VI to view each action of the VI on the block diagram.
- Use the Probe tool to check intermediate values as a VI runs.
- Use breakpoints to pause execution, so you can single-step or insert probes.
- Suspend the execution of a subVI to edit values of controls and indicators, to control the number of times it runs, or to go back to the beginning of the execution of the subVI.
• Comment out a section of the block diagram to determine if the VI performs better without it.

Refer to Activity 5 in the LabVIEW™ Tutorial for an example of how to debug VIs.

**Execution Highlighting**

Use execution highlighting to view an animation of the execution of the block diagram. Execution highlighting shows the movement of data on the block diagram from one node to another, using bubbles that move along the wires. Use execution highlighting in conjunction with single-stepping to see how data move from node to node through a VI.

*Note: Execution highlighting greatly reduces the speed at which the VI runs.*

Complete the following steps to use execution highlighting.

1. Open the block diagram of any VI.

2. Click the Highlight Execution button on the block diagram toolbar to enable execution highlighting.

3. Run the VI and view the block diagram as the VI runs. Notice that with execution highlighting, bubbles move along the wires to mark the movement of data from one node to another and the values at each terminal are displayed.

4. Stop the VI.

5. Click the Highlight Execution button again at any time to disable execution highlighting.

***When all else fails, check the hardware setup…***

***Chances are there may be a problem with the instrument***
APPENDIX D

Circuit Analysis

This Appendix explains the analysis of an electrocardiogram circuit. It takes two inputs, \( V_1 \) and \( V_2 \), and determines output \( V_o \). The circuit is analyzed using three node equations according to Kirchhoff’s Current and Voltage Laws. To see a complete drawing of the circuit refer to Figure 1 in Appendix E.

The ultimate goal of the node equations are to eliminate the two unknowns, \( V_a \) and \( V_3 \), and create equations in terms of the two inputs, \( V_1 \) and \( V_2 \), and the output, \( V_o \).

To begin, the circuit is converted to the Laplace Domain to aid in forming the node equations. In this new notation the capacitors can be treated as resistors and the rules for series and parallel resistors can be used. The capacitor values are converted to the following equation:

\[
C = \frac{1}{sC}
\]

Initial conditions:

\[
V_a = V_p = V_{in}
\]
\[
V_b = 0
\]

**Kirchhoff’s Current Law at Node A:**

\[
\frac{V_a - V_1}{sC_3 + R_3} + \frac{V_a - V_3}{R_6} + i_c = 0 \quad (A)
\]

substitute \( i_c = 0 \)

\[
\frac{sC_1(V_a - V_1)}{1 + sC_3R_3} + \frac{V_a - V_3}{R_6} = 0
\]

\[
\frac{sC_3(V_a - V_1)}{1 + sC_3R_3} + \frac{(1 + sC_3R_3)(V_a - V_3)}{R_6} = 0
\]

\[
V_a[s(C_3 + \frac{C_3R_3}{R_6}) + \frac{1}{R_6}] - V_3[s(\frac{C_3R_3}{R_6}) + \frac{1}{R_6}] = sC_3V_1 \quad (1)
\]

**Kirchhoff’s Current Law at Node B:**
\[ \frac{V_b - V_3}{sC_1} + \frac{V_b - V_o}{1 + \frac{1}{R_1}} + i_b = 0 \quad (B) \]

\[ i_b = 0 \text{ because } V_b = 0 \]

The denominator of the second term is determined by putting the capacitor and resistor in parallel using the following equation for two resistors in parallel:

\[ R_{eq} = \frac{1}{\frac{1}{R_x} + \frac{1}{R_y}} \]

Solve for \( V_3 \):

\[ \frac{sC_1(V_b - V_3)}{1 + sC_1R_1} + (sC_2 + \frac{1}{R_2})(V_b - V_o) = 0 \]

\[ sC_1(V_b - V_3) + (1 + sC_1R_1)(sC_2 + \frac{1}{R_2})(V_b - V_o) = 0 \]

\[ sC_1(-V_3) + [s^2C_2C_1R_1 + s(C_2 + \frac{C_1R_1}{R_2}) + \frac{1}{R_2}](V_o - V_b) = 0 \]

\[ V_3(sC_1) = -V_o[s^2C_2C_1R_1 + s(C_2 + \frac{C_1R_1}{R_2}) + \frac{1}{R_2}] \]

\[ \frac{V_o}{V_3} = \frac{sC_1}{s^2C_2C_1R_1 + s(C_2 + \frac{C_1R_1}{R_2}) + \frac{1}{R_2}} \]

\[ V_3 = \frac{-V_o[s^2C_2C_1R_1 + s(C_2 + \frac{C_1R_1}{R_2}) + \frac{1}{R_2}]}{sC_1} \quad (2) \]

**Kirchhoff’s Current Law at Node C:**

\[ \frac{V_a - V_2}{sC_4} + \frac{V_a}{1 + \frac{1}{R_4}} = 0 \quad (C) \]

Solve for \( V_a \):

\[ \frac{sC_4(V_a - V_2)}{1 + sC_4R_5} + \frac{V_a}{R_4} = 0 \]

\[ sC_4(V_a - V_2)(1 + sC_4R_5) = 0 \]
Kirchhoff’s Voltage Law at $V_{in}$:
\[-V_2 - V_{in} + V_1 = 0 \quad (D)\]

Kirchhoff’s Voltage Law at Node A:
\[-V_a + i_b R_6 + V_3 = 0 \quad (E)\]

\[\text{substitute } i_b = \frac{V_a - V_1}{\frac{1}{sC_3} + R_3}\]

\[-V_a + R_6 \left[ \frac{V_a - V_1}{\frac{1}{sC_3} + R_3} \right] + V_3 = 0\]

\[-V_a + \frac{R_6(sC_3)(V_a - V_1)}{1 + sC_3 R_3} + V_3 = 0\]

Manipulation leads to equation (1) found by KCL at Node A.

To get the final equation in terms of only the inputs and output, substitute equations (3) and (2) into equation (1) for the values of $V_a$ and $V_5$, respectively, and solve.
\[
\begin{align*}
V_0 &= \left( sC_1 \right) \left( sC_3V_1 - \left[ \frac{V_2(sC_4)}{s(C_4 + \frac{C_4R_3}{R_4}) + \frac{1}{R_4}} \right] \left[ s(C_3 + \frac{C_3R_3}{R_6}) + \frac{1}{R_6} \right] \right)
\end{align*}
\]

\[
V_0 = \left( \frac{C_1C_4C_3V_1 + \frac{C_2C_4C_3V_1R_2}{R_4} - C_1C_4C_3V_2}{R_6} \right) + s^2 \left( \frac{C_2C_4C_3V_1R_2}{R_6} \right) + s^3 \left( \frac{C_2C_4C_3V_1R_2}{R_6} \right) + s\left( \frac{C_2C_4C_3V_1R_2}{R_6} \right) + \frac{1}{R_2R_6}
\]
APPENDIX E

Multisim

This tutorial walks through the creation and simulation of an ECG using Multisim. To make this easier, a schematic of the finished circuit is shown below in Fig. 1. Construction of the circuit may be easier if the parts are placed in roughly the same area as they appear in the schematic in Fig. E-1 below.

![Figure E-1: ECG Schematic.](image)

From the START menu,

Click “All programs”

Click “Cadence PSD 14.2”

Click “Schematic”

To begin drawing your ECG schematic you must place your components. To do this, select **get new part** from the draw menu. You may also use Ctrl G, or click on the get new part icon. The part can be found in the part list or you can type in the part name. Below is a list of common parts and the names for their symbols that you will need to remember in order to build your circuit.

**Some common Components are:**
Procedure:
1. Begin by adding the six resistors. You can rotate a part by selecting it and pressing “ctrl r” on the keyboard. The part name can be edited to match the schematic by double clicking it. Pspice calls the part name the reference designator. Change the value of the resistors by double clicking the value label next to each resistor. Type the value and click ok.

Set the Resistor values as follows:
R1=1k
R2=1k
R3=1Meg
R4=1Meg
R5=1Meg
R6=1Meg

2. Add the four capacitors. Change the value of the capacitors by double clicking the value label next to each capacitor. Type the value and click ok.

Set the Capacitor values as follows:
C1=47u
C2=47u
C3=3.3u
C4=1n

3. Place 4 op-amps by using the part number TL072, the part will appear on the list as TL072/301/TI. The TL072 IC is an 8 pin IC chip. Each IC chip contains two individual op-amps. In Pspice the op-amps are designated as “Gate A” or “Gate B” Edit the attributes of the op-amp by double clicking on the reference designator not the TL072/301/TI part number. The op-amp has a unit label which in usually similar to U2A, where U2 is a particular IC chip and A is the “gate”. Changing the gate will automatically change the pin numbers on the schematic. Change the U numbers to IC1 and IC2 and the gate letters to A and B as they appear in the schematic.

4. Add two DC voltage sources (V1 and V2). Be sure to rotate the source so that the + end is on the left. To set the voltage of the two sources double click on the value and change the value to 9V (V must be upper case). Click OK to continue. Repeat this for the other voltage source.

5. To make connections between components, use the draw wire tool, which is located to the right of the zoom tools. Click one end of a component to start a wire, clicking again will make a corner. Right clicking or clicking on the end of a component will terminate the wire. In Pspice a connection between two lines is a dot. If two wires cross and there is no dot, there is no electrical connection.

Note: Do not draw the wires through the parts. Draw a line from each connection point to the next.

6. To simulate the output of this circuit there must be an input. We will use a sine wave for the input. The inputs of this circuit are at pin 3 of IC2A and at pin 5 of IC1B. Add a sine wave generator to each input. Connect one end of the sine wave generator to each input as shown in the schematic. To edit the attributes of the sine wave generators V3 and V4 double click the part. Be sure to press Save Attr after changing each attribute. Press OK only when you have changed all attributes.

7. Set the sine wave generator attributes as follows:

   V3:
   DC=.1
   AC=.1
   VOFF=.1
   VAMPL=.1
   FREQ=227

   V4:
   DC=0
   AC=.1
   VOFF=0
   VAMPL=.1
   FREQ=277
8. To examine the output there must be what is called a load resistor connected to the output of the circuit which is pin 7 of IC2B. Place a resistor by pin 7 of IC2B. Set the value of the resistor to 10k. Connect one end of the resistor to the output.

9. Next add four analog grounds. It is necessary to indicate the point at which the output voltage is going to be measured. This is done by using a voltage marker. To add a voltage marker, choose Mark Voltage/Level from the Markers menu, or click the icon. Place the voltage marker on pin 7 of IC2B.

10. To setup the type of analysis that will be performed choose setup from the analysis menu. The bias point detail and AC sweep boxes should be checked. Click the AC sweep button to set the AC Sweep and Noise Analysis parameters of the AC sweep. Use the following settings.

**AC sweep and Noise Analysis parameters:**

AC Sweep Type = Octave
Pts/Octave: 101
Start Freq.: 0.01
End Freq.: 1.00k
Noise Analysis Disabled (Not Checked)

Click OK to close the AC Sweep and Noise Analysis Window. Clicking Close on the Analysis Setup window will save these settings. Begin simulation by choosing Simulate from the Analysis menu.