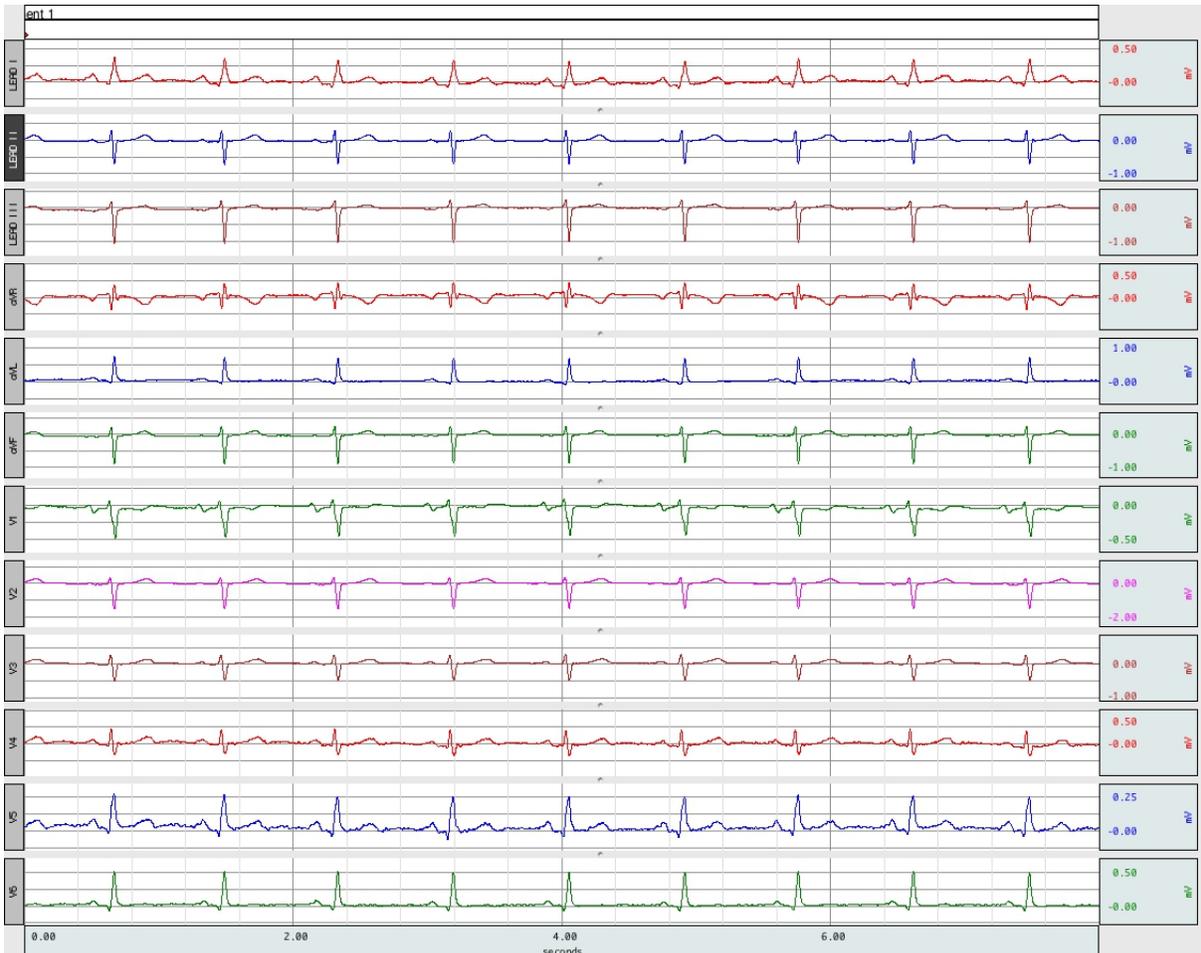


## Application Note 109 1-, 3-, 6- and 12-Lead ECG

This application note details how to acquire 1, 3, 6 and 12-Lead ECG recordings using BIOPAC equipment. It is intended for use with AcqKnowledge software versions 4 and higher using MP160 or MP150 data acquisition hardware. Contact [BIOPAC](http://www.biopac.com) for information about earlier hardware or software versions.



12-Lead ECG Recording

### Overview

An *electrocardiogram (ECG)* is a graphic recording of the changes occurring in the electrical potentials between different sites on the skin (leads) as a result of cardiac activity. *Depolarization* of the cardiac cells is the central electrical event of the heart. This occurs when the cardiac cells, which are electrically polarized, lose their internal negativity. Depolarization is propagated from cell to cell, producing a wave of depolarization that can be transmitted across the entire heart. This wave represents a flow of electricity and it can be detected using electrodes placed on the surface of the body. Once depolarization is complete, the cardiac cells are able to restore their resting polarity through a process called *repolarization*. Similarly, this flow of electricity can also be sensed using the same recording electrodes.

Obtaining accurate data from an electrocardiogram depends partially on the specific electrode placement and site preparation. One of the most important considerations in site preparation is reducing the amount of impedance between the electrode and the skin surface. *Impedance* is the measure of restriction to the applied current in an electrical circuit.

Mathematically Expressed:  $Impedance = Voltage/Current$

High electrode/skin impedance can be caused by dry skin, hair, calluses, scar tissue, and insufficient electrode gel or skin preparation. High electrode/skin impedance can have the detrimental effect of adding noise to the biopotential signal of interest. There are four types of added noises associated with high electrode/skin impedance:

- 1) Thermal noise, from real part of electrode/skin impedance
- 2) Amplifier current noise multiplied by electrode/skin impedance
- 3) Interference, imbalance in differential source impedances reduces amplifier common mode rejection ratio
- 4) Baseline drift, inconsistent ion transfer at electrode/skin junction influences half cell potentials

These potential noise sources can all be simultaneously reduced by adequate preparation of the skin electrode site. Proper skin preparation will result in a low amount of skin/electrode impedance and optimal skin/electrode contact is obtained.

- Use BIOPAC's [ELPAD](#) to lightly abrade the skin site to remove the top layer of dead skin cells. This layer is highly resistive. Then employ BIOPAC's [ELPREP](#) for rubbing the electrode placement area on the skin in order to increase the conductivity between skin and electrode. Remove excess ELPREP gel and clean and dry the skin site. Then apply the required disposable or reusable electrode to the skin site. Make certain that the electrode gel cavity (or holding sponge) has sufficient, moist, electrode gel in the application area. If sufficient gel is not present, additional electrode gel ([GEL100](#)) can be added to the cavity or sponge.

Once electrodes are placed on the skin, an impedance check (also called a “resistance” check) should be made to determine the resistance between all the applied electrodes. Resistance checking, with BIOPAC's [ELCHECK](#), should be performed between Vin+ and GND, Vin- and GND and Vin+ to Vin-. For best electrode-based measurement performance, resistance levels should be 5 Kohms or less.

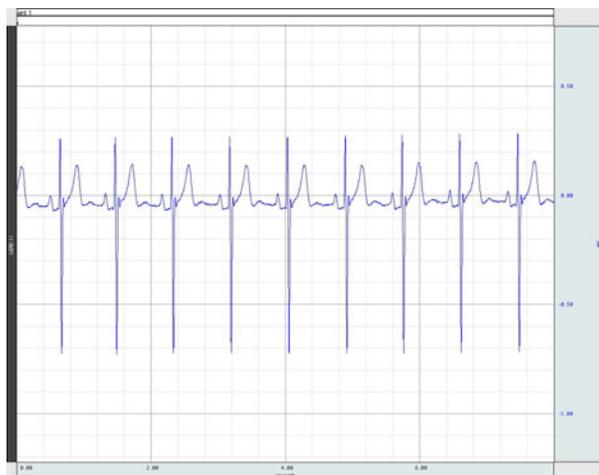
**Note:** Impedance levels will improve over time as the electrode conductivity gel fully migrates between the skin surface layers and surface electrode.

One common placement of the electrodes is based on *Einthoven's triangle*, which is an imaginary triangle drawn around the volume of the heart. Each apex of the triangle represents where the body's composition, around the heart, connects electrically with the limbs. *Einthoven's law* states that if the values for any two points of the triangle are known, the third can be computed.

Mathematically Expressed: ***LEAD II - LEAD I = LEAD III***

### **1-Lead ECG**

For a single channel, one Lead ECG, Lead II is the most commonly collected vector. Lead II is collected from the electrode attachment points of Left Leg (LL) to Right Arm (RA). The LL electrode site is considered positive and the RA electrode site is considered negative. For this measurement, just a single ECG amplifier module is required. An electrode is placed on the RA and is connected with a lead to the ECG100C module's Vin- input. Another electrode is placed on the LL and is connected to the ECG100C module's Vin+ input.



**1-Lead ECG Recording (LEAD II)**

For the 3, 6 and 12 ECG Lead options, data is collected from Leads II and I, with the difference of these two channels being equal to Lead III. Lead III can be calculated either on-line using a **Calculation > Math** channel or, after the data has been acquired, using the **Transform > Waveform Math** option. Either method will generate a standard Lead III ECG:

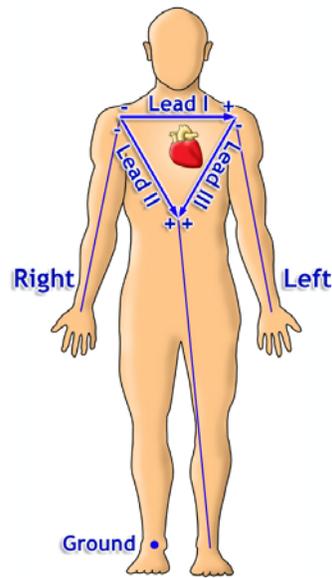
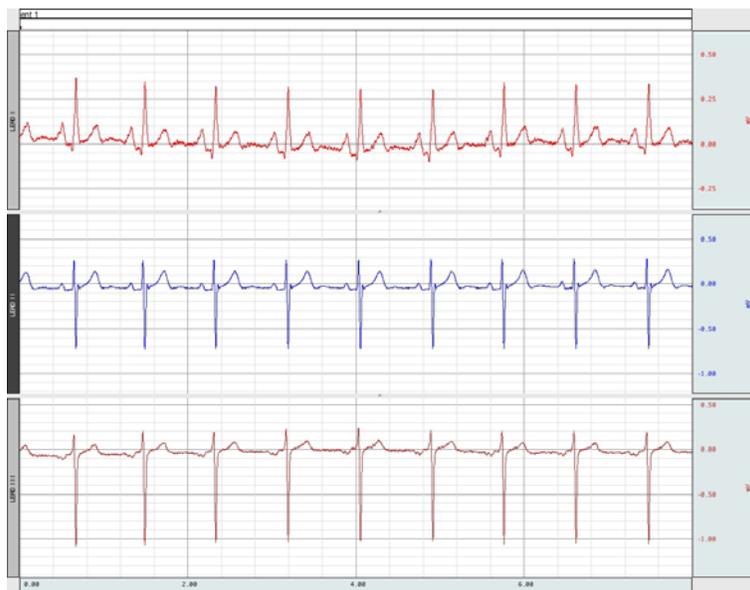


Figure 1: Einthoven Triangle LEAD Connections (Note Polarity)

### 3-Lead ECG

To obtain an accurate 3-Lead ECG with the MP160 (or earlier MP150) data acquisition system, set all of the hardware and software parameters as follows. These settings are optimal for ECG measurement, although all settings can be customized to account for individual testing preferences. For a 3-Lead ECG, just two ECG100C amplifier modules are required, as the third lead (LEAD III) can be calculated in real-time.



3-Lead ECG Recording

## 6-Lead ECG

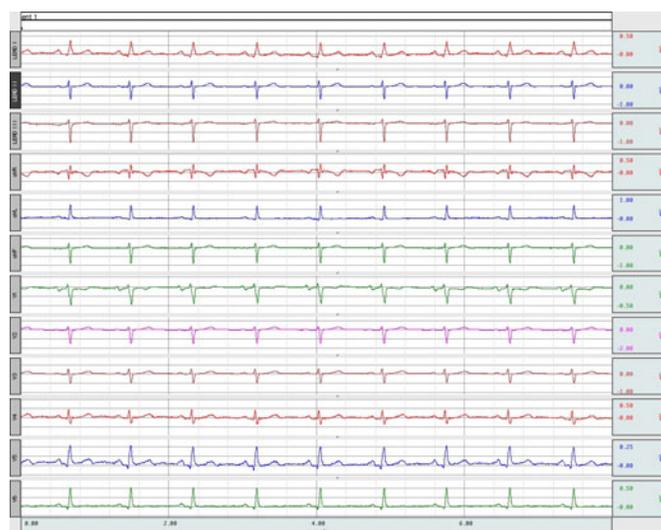
To obtain a 6-lead ECG, the three augmented leads (*also called Goldberger leads*) need to be calculated, in addition to Leads I, II and III. The augmented leads are noted as: aVR, aVL, and aVF, and are derived from Leads I, II and III. The augmented leads can be determined using *AcqKnowledge* calculation expression channels, in real-time or in post-processing. For a 6-Lead ECG, just two ECG100C amplifier modules are required, as the third lead (LEAD III) and the augmented leads (aVR, aVL and aVF), can be calculated in real-time. No additional electrodes or leads are required to obtain the augmented leads as they are functions of the three standard Leads and can be calculated online or post-acquisition.



6-Lead ECG Recording

## 12-Lead ECG

To obtain a 12-lead ECG, the six precordial (chest) leads are also measured, in addition to Leads I, II, and III and the three augmented leads. A 12-Lead ECG can be performed with (at minimum) three ECG100C amplifier modules and a Wilson Terminal. The additional ECG amplifier module is used for precordial lead measurement and is referenced to the center point of the Wilson Terminal. In this mode, the precordial leads (V1-V6) are measured (in sequence) by simply alternating (switching) the desired precordial lead to the amplifier. To obtain a complete, simultaneous 12 lead ECG recording, then eight ECG100C amplifier modules are required. In this situation, each precordial lead (V1-V6) will have its own dedicated amplifier. The third lead (LEAD III) and the augmented Leads (aVR, aVL and aVF) can be calculated in real-time.



12-Lead ECG Recording

For more information on setting up a 12-lead ECG, see [Option # 2](#) later in this application note.

For continuous 12-lead ECG, see [Application Note #AH-206](#)

**EQUIPMENT OPTIONS TO RECORD FROM A 1-, 3-, 6- OR 12-LEAD ECG****1-Lead ECG Equipment:**

- [MP160/MP150](#) Data Acquisition system
- One (1) [ECG100C](#) Amplifier Modules
- Three (3) [LEAD110A](#) Electrode Leads (3 meters)
- Three (3) [EL503](#) Electrodes
- [GEL100](#) Electrode Gel

**For 1-Lead ECG (LEAD I, II or III) recording:**

1. Prep skin, place one EL503 electrode to the Right Leg (RL) location and then place two EL503 electrodes at the below indicated locations, for the desired LEAD, as illustrated in [Figure 1](#):

For LEAD I: Right Arm (RA = Vin-) and Left Arm (LA = Vin+)

For LEAD II: Left Leg (LL = Vin+) and Right Arm (RA = Vin-)

For LEAD III: Left Leg (LL = Vin+) and Left Arm (LA = Vin-)

2. Plug two LEAD110A into the ECG100C module's Vin+, Vin- inputs and then attach pinch clips to desired LEAD electrodes, as indicated in Step 1.
3. Plug one LEAD110A into the ECG100C module's GND input and then attach the pinch clip to the Right Leg (RL) electrode.

**3-Lead and 6-Lead ECG Equipment, all leads recorded simultaneously:**

- [MP160/MP150](#) Data Acquisition system
- Two (2) [ECG100C](#) Amplifier Modules
- One (1) [JUMP100C](#) Stackable Jumper
- Four (4) [LEAD110A](#) Electrode Leads (3 meters)
- Four (4) [EL503](#) Electrodes
- [GEL100](#) Electrode Gel

**For 3-Lead ECG (LEAD I, II and III) recording:**

1. Prep skin, then place EL503 electrodes at Right Arm (RA), Left Arm (LA), Left Leg (LL) and Right Leg (RL).
2. Use JUMP100C to link the Vin- inputs of both ECG100C amplifier modules together.
3. Plug a LEAD110A into stackable JUMP100C link and then attach pinch clip to RA electrode.
4. Plug a LEAD110A into either ECG100C module's GND input and then attach pinch clip to RL electrode.
5. Plug a LEAD110A into the first ECG100C module's Vin+ input and then attach pinch clip to LA electrode. This module output is LEAD I.
6. Plug a LEAD110A into the second ECG100C module's Vin+ input and then attach pinch clip to LL electrode. This module output is LEAD II.
7. Setup a calculation channel to determine  $LEAD\ III = LEAD\ II - LEAD\ I$ .

**For 6-Lead ECG (LEAD I, II, III and aVR, aVL, aVF) recording:**

1. Follow steps 1-6 for the 3-Lead ECG recording.
2. Setup calculation channels to determine aVR, aVL and aVF.

$$\mathbf{aVR} = - (\mathbf{Lead\ I} + \mathbf{Lead\ II})/2$$

$$\mathbf{aVL} = (\mathbf{Lead\ I} - \mathbf{Lead\ III})/2 = \mathbf{Lead\ I} - ((\mathbf{Lead\ II})/2)$$

$$\mathbf{aVF} = (\mathbf{Lead\ II} + \mathbf{Lead\ III})/2 = \mathbf{Lead\ II} - ((\mathbf{Lead\ I})/2)$$

Lead I correlates to software Channel A1, Lead II correlates to software Channel A2, and Lead III correlates to software Channel C0. Note that aVR, AVL and aVF can be expressed in terms of LEAD I, II and III or simply in terms of Lead I and II.

1. Click on **MP > Set Up Data Acquisition > Channels** and set three additional **Calculation channels** to acquire, plot and show values.
2. Set each new calculation channel to the **Expression** preset (click “Setup...” button) and enter the formulas for aVR, aVL, or aVF in each Expression setup dialog.
3. Click OK to close out of the dialog and proceed with the recording.

**12-Lead ECG Equipment, with precordial leads recorded in sequence:**

- [MP160/MP150](#) Data Acquisition system
- Three (3) [ECG100C](#) Amplifier Modules
- One (1) [TSD155C](#) Multi-lead ECG Cable
- Ten (10) [EL503](#) Electrodes per subject
- [GEL100](#) Electrode Gel

**HARDWARE SETUP**

1. Snap the three ECG100C modules to the UIM100C (Or HLT100C/AMI100D for MP160 Systems).
2. Set the first (closest to the UIM100C) ECG100C amplifier to Channel 1 on top.
3. Set the second ECG100C amplifier to Channel 2 on top.
4. Set the third ECG100C amplifier to Channel 3 on top.
5. Set the remaining switches on all three ECG100C amplifiers as follows:  
**Gain:** 2000                    **Mode:** Norm  
**35 Hz LPN:** ON                **HP:** 0.05 Hz
6. Plug the TSD155C into the front panels of the ECG100C as follows:  
**Lead I** = first ECG100C module (closest to UIM100C)  
**Lead II** = second ECG100C module  
**Chest (Precordial Leads)** = third ECG100C module
7. Power on the MP150 unit.

**ELECTRODE CONNECTIONS**

1. **Attach** the electrodes as shown below:
  - a. **Prepare** each electrode site. Abrading the skin site, before electrode placement, will decrease the impedance between the electrode and the skin surface.
  - b. Apply a small amount of electrode **gel** ([GEL100](#)) to each electrode cavity or holding sponge. A drop of electrode gel will further improve the electrode's recording performance.
  - c. Apply 10 **electrodes** to the Subject, illustrated as follows.

### Electrode placement for Leads I and II

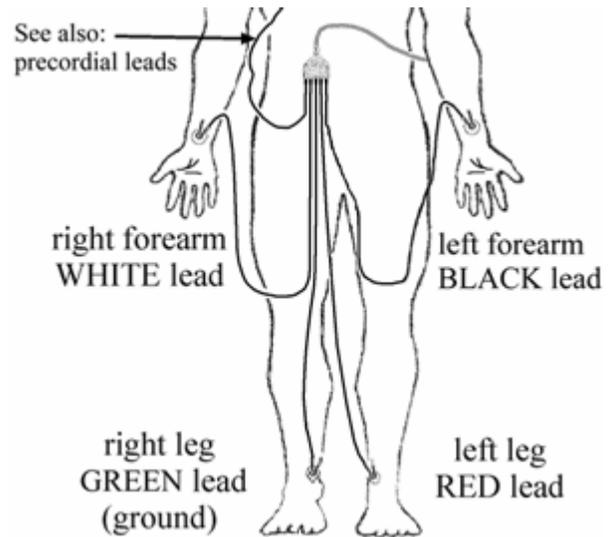
Left Leg (LL) = **RED** lead

Left Arm (LA) = **BLACK** lead

Chest (C) = **BROWN** lead (see V1-V6 attachment)

Right Arm (RA) = **WHITE** lead

Right Leg (LL) = **GREEN** lead



### Electrode placement for precordial leads (for 12-lead ECG option)

**V1** 4<sup>th</sup> intercostal space, right of sternum

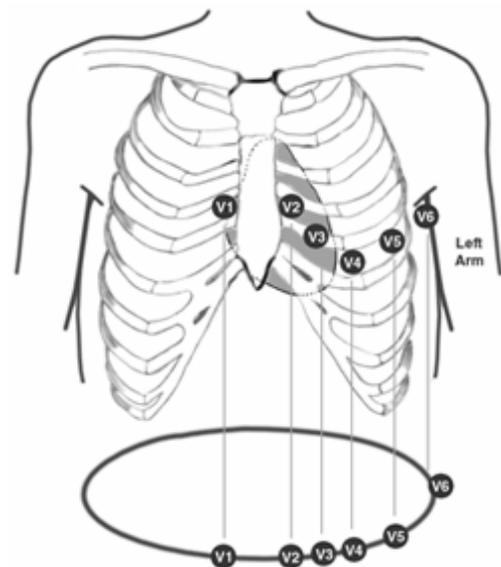
**V2** 4<sup>th</sup> intercostal space, left of sternum

**V3** midway between V2 and V4

**V4** 5<sup>th</sup> intercostal space, in the mid-clavicular line

**V5** same level as V4, at anterior axillary line (between V4 and V6)

**V6** in 5<sup>th</sup> intercostal space, in the mid-axillary line



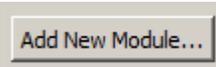
- Attach the **electrode lead** set (TSD155C) to the electrodes, paying close attention to the **lead colors** and starting with the precordial (chest) lead connected at **V1**.

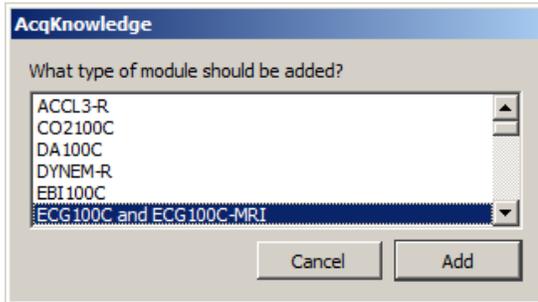
<b>Red</b>	LL	left leg
<b>Black</b>	LA	left arm
<b>Brown</b>	C	precordial
<b>White</b>	RA	right arm
<b>Green</b>	RL	right leg (ground)

- Position the electrode cables so they do not pull on the electrodes.
- Clip the electrode cable clip (where the cable meets the three individual colored wires) to a convenient location (such as the Subject's clothes) to relieve any cable strain. The cable weight should not be tugging excessively on a skin surface electrode.

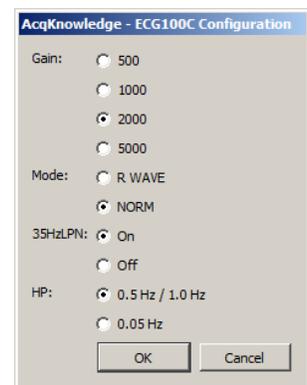
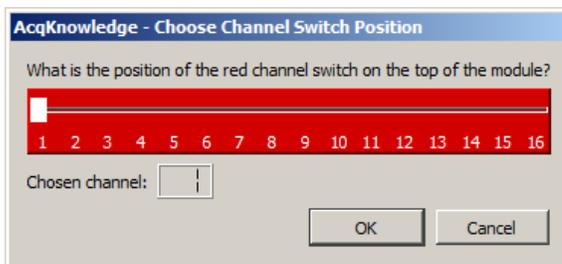
## SOFTWARE MODULE SETUP

1. Select **MP150 > Set Up Data Acquisition > Channels:**

- a. Click  choose **ECG100C** from the module list and click **“Add.”**



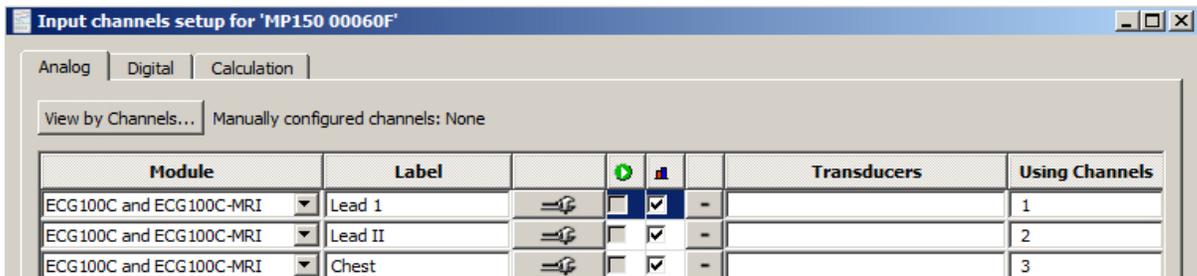
- b. Select **“1”** in the **Choose Channel Switch Position** dialog and click **OK**.



- c. In the **ECG100C Configuration** dialog (shown on right) click **OK** to accept the default software settings.

**Note:** The software settings **must** match the physical **ECG100C** amplifier settings described on page 7.

- d. In **Channels setup**. Enter **“Lead I”** as the **Label** for Channel 1. (See figure below)

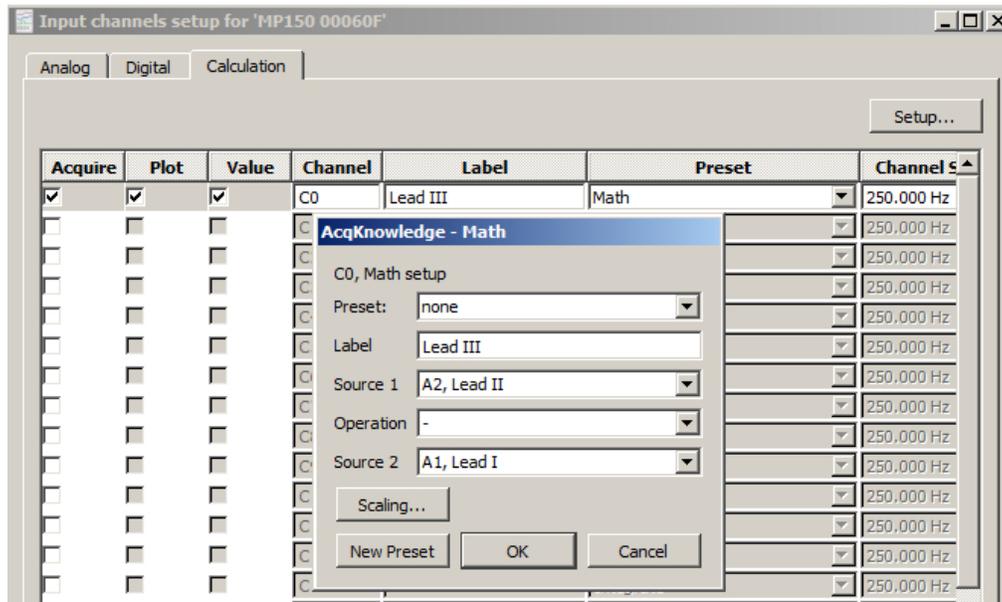


### Analog channel setup for 3-Lead ECG derived from 2 analog inputs (1 and 2)

- e. Repeat steps **a-d** above, choosing Channel 2 in step **b** by clicking the white channel selection box and sliding it to **“2.”** Following Step **c**, enter **“Lead II”** as the Label for Channel 2.
- f. Repeat steps **a-d** above, choosing Channel 3 in step **b** by clicking the white channel selection box and sliding it to **“3.”** Following step **c**, enter **“Chest”** as the Label for Channel 3.

**IMPORTANT:** Make certain the channel switch position on top of the ECG100C amplifier matches the channel switch position selected in the software.

- Click the **Calculation** tab and set calculation channel C0 to acquire and plot data. Select **Math** from the Preset menu and label it “**Lead III**.”
- Click “Setup...” button and set the Source and Operation options for “**A2 (Lead II) - A1 (Lead I)**.” Click OK (see figure below).



**Lead III set-up as a Math: Calculation channel (C0) derived from the difference between Leads II and I (A2 and A1, respectively)**

- Under **MP160/150 > Set Up Data Acquisition > Length Rate**, choose “**Record and Append using Memory**” and set the sampling rate to 250 Hz with an acquisition length of 10 seconds.

**Note:** To record data for HRV analysis, set sampling rate to 1000 Hz.

- In *Append* mode, when the acquisition is stopped and then re-started, data will be added onto the previous data. An append marker will automatically be inserted with a time stamp to indicate the new segment start time. You can re-label the marker at any time.

## PROCEDURE

- After completing the above steps for AcqKnowledge software setup, click on the software’s “**Start**” button.
  - Waveforms may take several seconds to settle properly.
- Wait for the acquisition to stop (set for 10 seconds) or click on the “**Stop**” button in the software when you have acquired the desired amount of data.
- Modify the vertical scale to the desired values and perform the “**Autoscale waveforms**” function from the **Display** menu.
- To record heart rate, select **Analysis > Find Rate** from the pull-down menus. This will create a new channel that records the BPM of the selected waveform (see figure below).



**Sample waveform with Analysis > Find Rate BPM channel**

## 12-Lead ECG

In some cases, a 6-lead ECG does not give enough information about the electrical activity of the heart. For a more comprehensive picture of the heart's behavior, it's possible to add six more leads for a total of 12 leads, hence the title "12-Lead ECG." The six new leads, called *precordial leads* (chest leads) are arranged across the chest in a horizontal plane and record electrical flows moving anteriorly and posteriorly.

To measure the six precordial leads, each chest (precordial) electrode lead is considered positive, and is referenced to a new potential which is derived from the signals recorded at the Left arm (LA), Right arm (RA) and Left leg (LL). This new potential is sourced from a "Wilson Terminal." The Wilson terminal is a passive summing junction that creates the precordial reference from the summed potentials measured at LA, RA and LL. The TSD155C incorporates a Wilson Terminal into its construction. The six positive electrodes establish the precordial leads, V1 through V6, and are positioned as shown in the [diagram](#) above and can be alternated through consecutive recording segments to provide 12-lead ECG data.

- For continuous 12-lead ECG, see [Application Note #AH-206](#)

### *Note:*

- The optimum setup is **Subject** relaxed and in a supine position.
- Record six 10-second segments, for a total recording of 60 seconds. Record Lead I, Lead II and a precordial (chest) lead in six positions (V1 through V6). In addition, Lead III and the "augmented leads" (aVR, aVL, aVF) will be calculated. Each chest electrode is positive and a Wilson Terminal establishes the reference.
- Wait at least 30 seconds after moving the precordial lead for each segment before clicking on "Start."
- A marker will be inserted each time clicking on "Start." Label markers after recording.
- Excessive EMG artifact or baseline drift should not be observed; if visible, check connections and repeat the segment.

1. Segment 1: Precordial V1
  - a. Confirm that the chest lead is still securely clipped to the Subject at position **V1**.
  - b. Click on the **Start** button.
    - Subject must maintain the same position for all segments.
  - c. After 10 seconds, click on the **Stop** button.
  - d. Review the data on the screen.
    - Excessive EMG artifact or baseline drift should not be observed; if visible, check connections and repeat the segment.
2. Segment 2: Precordial V2
  - a. Unclip the chest lead from position **V1** and clip it to position **V2**.
  - b. **Wait 30 seconds** and then click on **Start**.
    - Subject must maintain the same position for all segments.
  - c. After 10 seconds, click on **Stop**.
3. Segment 3: Precordial V3
  - a. Unclip the chest lead from position **V2** and clip it to position **V3**.
  - b. **Wait 30 seconds** and then click on **Start**.
    - Subject must maintain the same position for all segments.
  - c. After 10 seconds, click on **Stop**.
4. Segment 4: Precordial V4
  - a. Unclip the chest lead from position **V3** and clip it to position **V4**.
  - b. **Wait 30 seconds** and then click on **Start**.
    - Subject must maintain the same position for all segments.
  - c. After 10 seconds, click on **Stop**.
5. Segment 5: Precordial V5
  - a. Unclip the chest lead from position **V4** and clip it to position **V5**.
  - b. **Wait 30 seconds** and then click on **Start**.
    - Subject must maintain the same position for all segments.
  - c. After 10 seconds, click on **Stop**.
6. Segment 6: Precordial V6
  - a. Unclip the chest lead from position **V5** and clip it to position **V6**.
  - b. **Wait 30 seconds** and then click on **Start**.
    - Subject must maintain the same position for all segments.
  - c. After 10 seconds, click on **Stop**.
7. Remove the leads and electrodes from the Subject.
8. Label the markers V1-V6, at the start of each segment.
  - Note that the markers apply only to the “precordial” channel, and represent the alternation of the precordial lead from position V1 through V6.

## ANALYSIS

The 12-lead ECG data will be displayed as a conventional 6 channel recording, with an added precordial chest lead channel. This added chest lead channel shows precordial leads (V1-V6), as the chest lead is alternated (switched) from location to location. Sample data is shown here:



Channel	Displays
CH 1	Lead I
CH 2	Lead II
C1 (40)	Lead III (calculated)
C2 (41)	aVR (calculated)
C3 (42)	aVL (calculated)
C4 (43)	aVF (calculated)
CH 3	V1 – V6 (alternate per markers)

To **hide channels** in the display, **Alt+click** the channel box. The channel box will be crossed over and the channel will be dropped from the data display. No data is removed from the data file — this function affects data display only. To show a hidden channel, **Alt+click** the channel box again.

AcqKnowledge software offers a wide array of measurement and analysis tools to help you isolate the data segments of interest for your particular experiment. See the AcqKnowledge Software Guide for details.