Experiment BT-13: Biomedical Signal Filtering

Equipment Required

PC or Mac Computer

IX-TA-ROAM recorder, USB cable, power supply

A-BMET-B BMET Trainer Board

C-DIN-BB DIN to Breadboard Cable

C-BB-SL2 Snap to Breadboard Cables (2)

A-BMET-EC Electronic Components Set

Jumper Wires

Setup

1. Connect the C-DIN-BB Cable to port A5 on the TA-ROAM. Use extender cables for the yellow and brown leads.
2. Connect the C-BB-SL2 cable as follows.
   a) Leave the ROAM snapped into the dock. Keep the brown lead connected to Sim 2 (-) and the white lead connected to Sim 2 (+), but disconnect the red and black leads from Sim 1.

   b) Snap the C-BB-SL2 cable red lead into the Sim 1 (+) dock, and the black lead into the Sim 1 (-) dock, as shown in the image below.

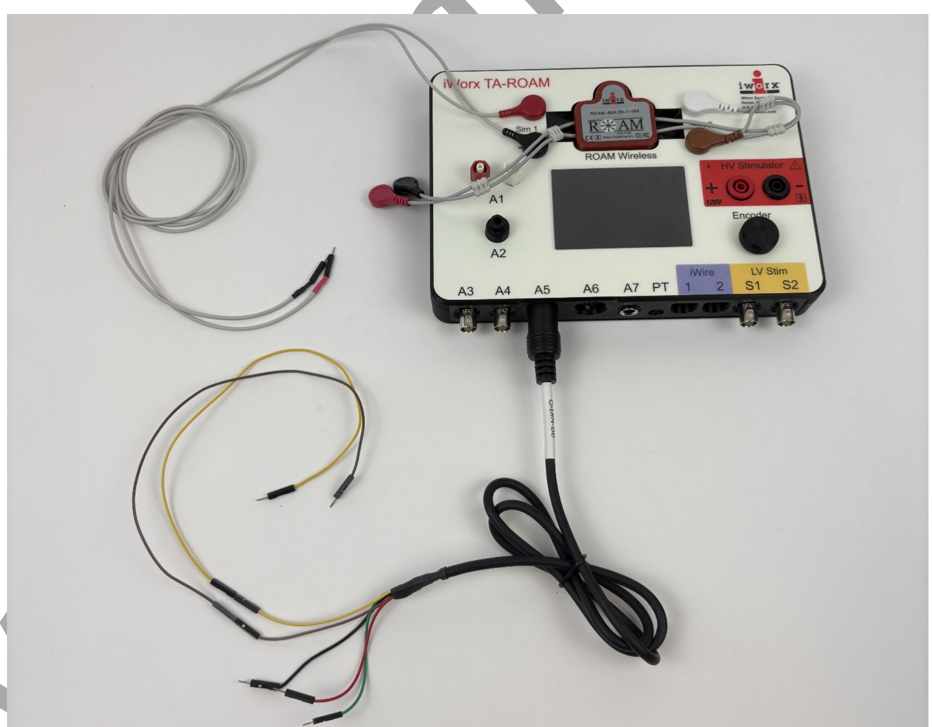

Figure BT-13-S1: IX-TA-ROAM, C-DIN-BB cable (port A5), C-BB-SL2 cable (Sim 1 + and -).

Experiment BT-13: Biomedical Signal Filtering and Troubleshooting

Background

Biomedical signals are typically very small and susceptible to noise from power lines, muscle activity, motion, and surrounding electronic equipment. Before these signals can be analyzed or displayed, they must pass through several signal-conditioning stages that amplify useful information while reducing unwanted interference.

A typical biomedical acquisition system contains several building blocks:

- Input protection circuits
- Voltage dividers and biasing networks
- Filters
- Amplifiers
- Buffers
- Analog-to-digital conversion

Each stage slightly changes the signal. Understanding how these stages work together helps biomedical technicians diagnose equipment problems and verify proper operation.

In this lab, students will first follow a biomedical signal through multiple signal-conditioning stages to observe how each circuit modifies the waveform. They will then practice troubleshooting common hardware faults using the BMET Trainer's fault switches.

A typical biomedical signal-conditioning system consists of several functional stages, each serving a specific purpose:

Theory

1. Input Protection

The first stage protects sensitive electronic components from excessive voltages, electrostatic discharge (ESD), or accidental misuse. Protection circuits often include current-limiting resistors, diodes, or transient suppression devices that prevent damage while allowing the desired signal to pass with minimal distortion.

2. Filtering

Biomedical signals are commonly contaminated by electrical interference from power lines (50/60 Hz), motion artifacts, muscle activity, and other environmental sources. Filters selectively attenuate unwanted frequency components while preserving the frequencies of interest. Low-pass, high-pass, band-pass, and notch filters are commonly used depending on the application.

3. Amplification

Physiological signals are often only a few millivolts in amplitude, making them difficult to measure directly. Amplifiers increase the signal amplitude without significantly altering its shape, improving the signal-to-noise ratio and allowing the signal to be processed by measurement equipment or analog-to-digital converters. The amplifier gain determines how much the input signal is increased.

4. Buffering

A buffer amplifier provides a high input impedance and a low output impedance, preventing one circuit stage from affecting the operation of the previous stage. Buffers reduce loading effects and ensure that signals remain accurate as they pass between different sections of the circuit.

5. Signal Tracing

One of the most effective methods of diagnosing biomedical equipment is to trace the signal through each stage of the circuit. By comparing the waveform at successive points, a technician can determine where the signal first changes unexpectedly, helping to isolate faulty components or circuit sections.

6. Troubleshooting Biomedical Circuits

Biomedical equipment faults may result from open circuits, short circuits, failed components, incorrect gain, poor connections, or damaged power supplies. Rather than replacing components at random, technicians use a systematic troubleshooting approach by comparing a known-good waveform to the measured waveform. Identifying where the signal deviates from normal operation significantly reduces troubleshooting time and improves repair accuracy.

7. Electrocardiogram (ECG) Signal Acquisition

The electrocardiogram (ECG) is a noninvasive measurement of the electrical activity generated by the heart during each cardiac cycle. As cardiac muscle cells contract and relax, they produce electrical changes that propagate through the body. These electrical signals can be detected using electrodes placed on the skin and recorded as an ECG waveform.

A typical ECG waveform consists of several key features that represent different stages of cardiac activity:

- **P wave:** Represents atrial depolarization, or the electrical activation of the atria.
- **QRS complex:** Represents ventricular depolarization, which occurs as the ventricles contract. This is typically the largest portion of the ECG waveform.
- **T wave:** Represents ventricular repolarization, or the recovery phase of the ventricles.

The amplitude of an ECG signal measured at the surface of the body is typically only a few millivolts. Because of its small amplitude, the ECG signal is highly susceptible to interference and requires additional processing before it can be accurately displayed or analyzed.

The TA-ROAM includes a built-in ECG simulator that provides a consistent and repeatable ECG waveform for testing and circuit analysis. Using snap-to-breadboard leads, the ECG signal can be configured and controlled through LabScribe, output from the TA-ROAM ECG simulator, and connected to the BMET Trainer Board for signal conditioning and analysis.

Pre-Lab Questions

1. Why do biomedical signals such as ECG require signal conditioning before they can be displayed or analyzed?
2. An ECG signal typically has an amplitude in the millivolt range. Why is amplification necessary when measuring an ECG signal?
3. What is the purpose of a filter in a biomedical signal-conditioning system?
4. Explain why a buffer amplifier is used between two circuit stages. What problem does it help prevent?
5. An ECG recording contains a large 60 Hz interference signal. Which type of circuit would be used to reduce this unwanted noise, and why?
6. Why is using an ECG simulator useful when testing biomedical instrumentation circuits?

Experiment BT-13: Biomedical Signal Filtering

Exercise 1: ECG Signal Conditioning and Filtering

Aim: To observe how signal-conditioning circuits modify an ECG waveform and evaluate the effects of filtering and amplification on the quality of the recorded signal.

Approximate Time: 30 minutes

Procedure

1) This lab will use the C-BB-SL2 cable, instead of the C-BNC-BB cable, to output the signal from LabScribe.

Note: Alternatively, you can use an ECG Simulator device, such as the A-ECG-SIM to output an ECG signal to the BMET Board.

2) Use Circuit J.
3) Connect the C-BB-SL2 cable to the circuit as follows.
   a) Connect the red lead (+) to INJ2.
   b) Connect the black lead (-) to INJ1.
4) Connect the C-DIN-BB cable to the circuit as follows.
   a) Connect the + (red lead) to the VCC pin in the Inputs section on the right.
   b) Connect the - (black lead) to the VEE pin.
   c) Connect the ground (green) to a GND pin.
   d) Connect the brown lead to the IN- pin.
   e) Connect the yellow lead to OUTJ.
5) Add a 100 ohm resistor at RJ1.

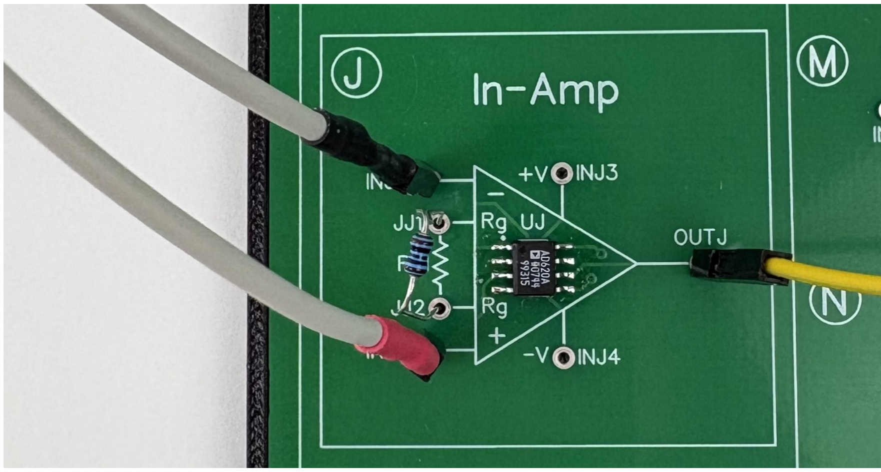

Figure BT-13-S1: In-AMP (Circuit J) connections INJ1, INJ2, RJ1, and OUTJ.

6) Press the red REC button to start the recording.

7) Record for ~10 seconds.

8) Press the STOP button to stop the recording.

9) Repeat steps 6-8 for the following filter configurations and filter component values. For each configuration, begin with the ECG signal at the output of the In-Amp and use a jumper wire to connect the In-Amp output (OUTJ) to the input of either the high-pass or low-pass filter. Record the filtered signal using the yellow lead connected to the appropriate output.

   a) Input → In-Amp → High Pass RC Filter → Output (OUTM)

      - Resistor: 100k
      - Capacitor: 1 uF

   b) Input → In-Amp → Low Pass RC Filter → Output (OUTR)

      - Resistor: 100k
      - Capacitor: 1 uF

   c) Input → In-Amp → High Pass RC Filter → Output (OUTM)

      - Resistor: 10k
      - Capacitor: 0.1 uF

   d) Input → In-Amp → Low Pass RC Filter → Output (OUTR)

      - Resistor: 10k
      - Capacitor: 0.1 uF

Data Analysis

1. Compare each signal input to the output from the different filter configurations.

Questions

1. Compare the filtered ECG signals to the original ECG signal from the instrumentation amplifier. What changes do you observe in the amplitude, waveform shape, and baseline?
2. For each high-pass filter, identify which components of the ECG signal appear to be attenuated or removed. How does changing the cutoff frequency affect the ECG waveform?
3. For each low-pass filter, identify which components of the ECG signal appear to be attenuated or removed. How does changing the cutoff frequency affect the ECG waveform?
4. Which filter produced the clearest ECG waveform? What characteristics of the signal were improved or degraded by this filter?

Exercise 2: Troubleshooting Faults

Aim: Troubleshoot the instructor applied faults.

Procedure

1. The instructor will apply a fault using one of the 16 fault switches. Each switch will introduce an open circuit at an unknown location within a circuit.
2. Connect the appropriate input signal to the circuit and configure the circuit according to the instructor's instructions.
3. Use **Preview** mode in LabScribe to observe the circuit output while troubleshooting.
4. Use the available test points to measure the signal at different locations in the circuit.
5. Work systematically through the circuit to determine where the signal is lost or altered. Use your measurements to narrow down the location of the fault.
6. Identify the component or circuit connection affected by the fault.
7. Record the circuit letter, suspected fault location, and evidence used to identify the fault.
8. Repeat the troubleshooting process for additional faults as assigned.

Note: Do not change or bypass the fault unless instructed to do so.

Example

F1:1 (F1, Switch 1) in the DOWN position (1) applies a fault to Circuit P.

1. Apply an input signal to the circuit.
2. Add components to the circuit.
3. Use the test points to troubleshoot where the fault location is, and discover what components are affected.

Questions

1. Describe the systematic troubleshooting process you used to locate the fault. Why is it useful to troubleshoot a circuit systematically rather than randomly testing components?
2. Why is it important to verify that the input signal is correct before troubleshooting the rest of the circuit?
3. A biomedical instrument produces an unexpected signal during normal operation. List three possible causes that should be considered before concluding that a circuit component has failed.