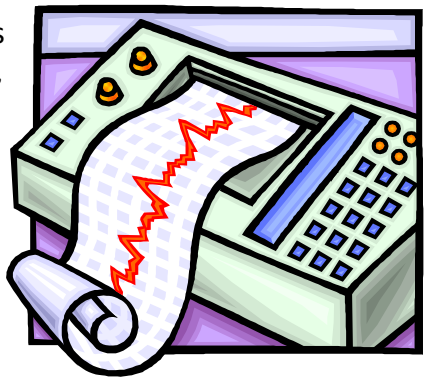
Data Acquisition Basics Lab

Data Acquisition Basics Laboratory

Introduction



Many systems in the body can be modeled as electrical systems that interact with various organs, such as the heart, the brain, and body muscle. These systems communicate by generating electrical impulses which can often be measured by placing electrodes on the surface of the skin. Before the advent of digital data acquisition, these electrodes would be connected to pen-based strip-charts. These recorders would move a pen on a moving paper chart to sketch the electrical signal recorded from each electrode.

Electrophysiological measurements are now recorded digitally with computers and saved on a permanent storage device. The data can be quickly analyzed and manipulated on a computer. Furthermore, computer-based review is more efficient, since a technologist can save relevant information for later review by a physician as opposed to reviewing a whole hour-long data recording which may only have 2-3 minutes of clinically relevant information.

This lab session will allow you to examine the contents of the CleveLabs Biomedical Engineering Course Kit, review basic principles of data acquisition, and explore the features available in the course software by actually recording an electrical signal.

Equipment required:

- CleveLabs Kit
- CleveLabs Course Software
- Microsoft® Excel, LabVIEW™, or MATLAB®

Background

The BioRadio is a wireless physiological monitor. The subject worn unit amplifies and digitizes the signal and then transmits the data over a wireless network to a computer for analysis and storage. A biotelemetry system consists of three main hardware sections:

1. Signal amplification
2. Digitization
3. RF link

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Each of these sections is explained in detail below.

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Signal Amplification

Biopotential Noise Contamination

As with any electrical measurement, noise occurs during the recording of biopotentials. Sources of this noise may include other electronic laboratory equipment, lights, radios, cell phones, and even other biopotentials. Noise is an important problem in the recording of biopotentials since the amplitude of biopotentials is often much smaller than that of the noise. One of the most common sources of noise in the recording of biopotentials is 60 Hz AC power in the United States. A patient may act as an antenna that receives this 60 Hz noise through electrical and magnetic field coupling.

Without noise rejection circuitry embedded in the front end of the electronic recording equipment, the 60 Hertz signal would contaminate the signal being measured, particularly if the amplitude of 60 Hz noise is much larger than the biopotentials being recorded. A differential amplifier can be used to greatly reduce this noise. Consider an electrocardiogram (ECG) recording. An ECG measures the electrical activity of the heart and will be explained in great detail in the next lab session. It can be measured by placing electrodes on the right and left wrists. The 60 Hz noise appears evenly on both wrists. However, the ECG signal is different on both wrists due to the potential difference created by the heart. Subtracting the two channels at the wrists will effectively cancel out the 60 Hz noise, leaving the patient's ECG signal intact. A differential amplifier is used to perform the subtraction between the two channels. Recall the basic principles of an ideal operational amplifier (Fig 1):

1. The op amp is configured so that the negative and positive input voltages of the operational amplifier are kept equal by the net currents produced by the input and output voltages flowing through the external resistors
2. The operational amplifier has a high gain
3. The operational amplifier has high input impedance and zero output impedance

For our example, the V^- and V^+ inputs would be the signals measured from the right wrist and left wrist, and V^{out} would be the desired ECG signal.

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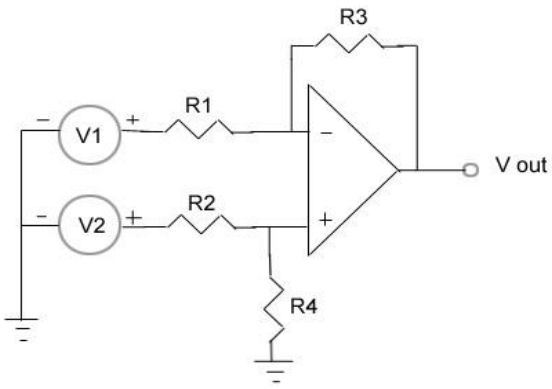

Figure 1: Simple Differential Amplifier.

By the rules of operational amplifiers, we know that V^+ equals V^-. Solving for V^+,

$$V^+ = \frac{V_2 R_4}{R_2 + R_4}$$

Similarly, solving for V^-,

$$V^- = V_1 - \frac{(V_1 - V_{OUT})R_1}{R_1 + R_3}$$

Since we know $V^+ = V^-$, we equate the two equations and solve in terms of V_{OUT}.

$$V_{OUT} = \frac{R_4(R_1 + R_3)}{R_1(R_2 + R_4)} V_2 - \frac{R_3}{R_1} V_1$$

In order for this differential amplifier to cancel out signals that are common to both inputs, the coefficients need to be equal. This is done by making $R_1R_4 = R_2R_3$. Doing so reduces the equation to

$$V_{OUT} = \frac{R_3}{R_1}(V_2 - V_1)$$

Thus, the output at V_{OUT} is proportional to the difference of the inputs. So, this value of R_3/R_1 will be the *Differential Gain* of the circuit. A differential gain is a measurement of the amplification done to signals that are different between the two inputs, such as the ECG signal. If the resistance condition above ($R_1R_4 = R_2R_3$) is not met (since real-world resistors cannot be perfectly matched), there will be some gain in the common mode. That common mode gain is measured as:

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$$Common\ Mode\ Gain = \frac{R_4 R_1 - R_2 R_3}{R_1 (R_2 + R_4)}$$

Common mode gain is a measurement of the amplification done to signals that are common to both inputs, like 60 Hz noise. Circuit designers can then determine the performance of a differential amplifier by calculating the common mode rejection ratio, or CMRR, which is measured in dB.

$$CMRR\ (dB) = 20 \log \frac{Differential\ Gain}{Common\ Mode\ gain}$$

Typical values for CMRR are 100 dB and higher. Ideally, if the resistors could be perfectly matched, the common mode gain would be zero, making the CMRR infinite.

One problem with the circuit above is that it does not have high input impedance for the two voltage inputs. The voltage inputs usually have sustained source impedances from the tissues and electrodes (Z in Fig 2), so attempts to draw a substantial current into the op-amp via low values of R1 and R2 will drag down the recordable potentials. The problem can be solved by adding voltage followers at the two voltage input sources, thus meeting the high input impedance criteria. The combined circuit is a general-purpose instrumentation amplifier (Fig 2), since the inputs have only unity gain. The voltage follower has unity gain for voltage, but provides a high input impedance and power gain so that reasonable values can be used for resistors R1-4.

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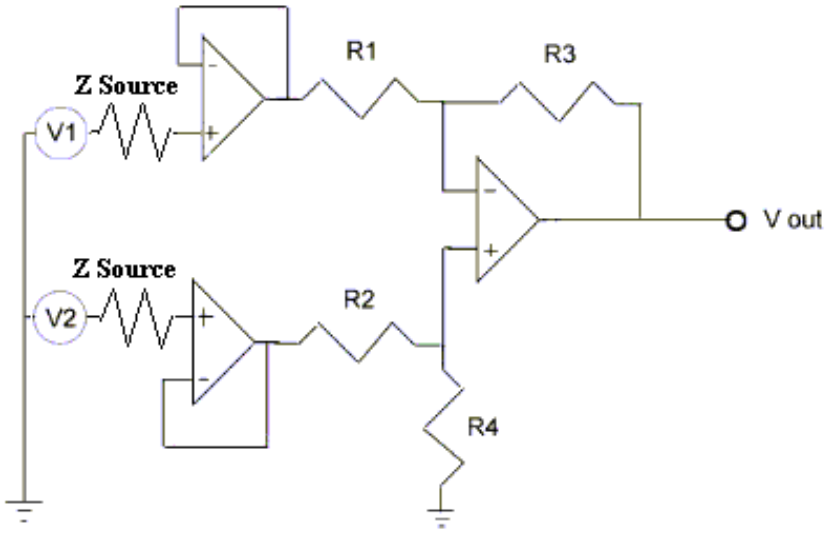

Figure 2: General Purpose Instrumentation Amplifier. Note the voltage followers at the two inputs.

The BioRadio front end circuitry has built-in circuits that utilize instrumentation amplifiers to remove common mode noise from the recorded signals. More advanced methods of removing 60-Hertz noise include using notch filters and digital filtering by the computer.

Noise can also arise from the human body itself. There are many biopotentials occurring in the body all the time and it is possible to record an undesired biopotential superimposed on the desired biopotential. For example, electroencephalogram (EEG) (brain wave) recordings can be polluted with noise from other biopotentials. Since the EEG electrodes are attached to the scalp, not only will the electrodes record brainwaves, but it may also pick up electrical signals originating from head, neck, and eye muscles if the patient shrugs their forehead or blinks their eye. This type of noise is difficult to remove, but computerized signal processing can be done to remove some of the artifacts created by this noise. In addition, proper placement of electrodes can help minimize this noise as well.

Sources of noise can also be analyzed in the frequency domain. White noise is considered noise that is evenly spread across all frequencies, whereas pink noise is noise that is distributed within a certain frequency band. Another type of noise encountered by engineers is thermal noise. All electronic components, particularly resistors and semiconductors, generate electrical noise from the random motion of electrons, depending on the temperature. Although these topics are not covered here, you should be aware that these sources of noise exist.

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Sensing, Reference, and Ground Electrodes

You will notice on the BioRadio harness that there are sixteen sensing inputs (eight channels), two reference inputs, and a ground input. Sensing electrodes are either black (negative) or red (positive) on your universal differential harness. These electrodes work in conjunction with the reference electrodes (REF) and ground (GND) electrodes to define the potential measured by the BioRadio. The universal differential harness allows you to easily setup each channel as either single ended or differential. For differential channel configurations, attach both the (+) and (–) leads to the area being monitored. For single ended channel configurations attach only the (+) lead to the area being monitored then take the corresponding (–) lead and connect it into the female end of either reference input. Each universal reference connector has both a female and male coupling for you to use. For each channel you configure for single ended use simply stack the (-) leads of the respective channels one on top of the other. You can have multiple (-) leads stacked to any one reference.

The reference inputs are redundant connections tied together internally. A potential must be measured between two electrodes. Therefore, the potentials that you measure with the BioRadio are measured between your sensing electrodes and the reference electrodes.

The ground connector on the BioRadio harness defines the zero output voltage. This is useful when the system that you are measuring does not share the same ground with the rest of the system. In this case, the BioRadio can be thought of as one system where as the system that we are measuring (i.e. biopotentials from the body or external sensors such as airflow cannulas or respiratory effort belts) is separate. The ground electrode allows you to define a specific offset and keeps the “floating” input signal you are measuring between the BioRadio system rails.

Safety

Designers of bioinstrumentation must ensure that the chances of passing current from the device to the patient are minimized. This means that biomedical instrumentation designers must ensure that the patient is never connected directly to ground. If a patient is directly connected to ground, equipment failure could lead to electrical currents passing directly across the patient and to ground. Low currents through the skin (from 1 mA to 100 mA), may cause a person to feel a tingling sensation or some moderate pain.

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However, if this current were to exceed 100 mA, there is a great risk of inducing ventricular fibrillation in the heart. Even lower currents introduced through implanted electrodes or catheters may be fatal. If nothing is done to restart the heart's natural rhythm, this will quickly lead to death. Therefore, isolating the subject from ground is a paramount issue in patient safety when designing biomedical instrumentation.

For instrumentation that is connected directly to a power source, hardware designers use isolation amplifiers. These are special amplifiers that electrically separate the patient from the power supply and grounding circuitry, either using optical or magnetic (transformer) coupling. With these methods, the patient is not directly connected to any circuitry that may cause a shock hazard. The BioRadio couples the patient using battery powered RF isolation. Since the BioRadio transmits its signals using radio waves and the patient is never directly connected to earth ground, the patient is totally isolated from power and ground lines, preventing risk of shock to the patient. (Fig 3)

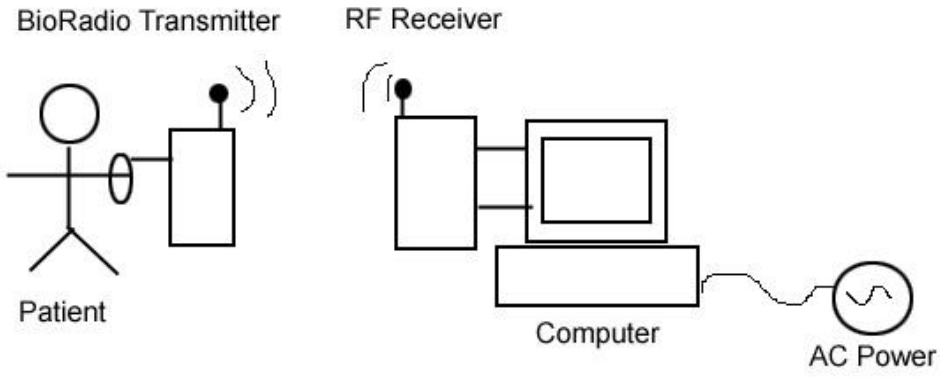

Figure 3: BioRadio Isolates Patient from a Direct Connection to Ground**.**

Digitization

Data Acquisition

The BioRadio uses a computer interface to display, record, and analyze biopotentials. The biopotentials have a continuous range of voltages varying over time (analog signals). This means that they have an infinite amount of possible values. Because a computer is digital, it cannot record an infinite number of values. Therefore, a computer samples discrete voltage levels at discrete points in time and then reconstructs the continuous signal from these discrete points. Since the computer operates with discrete units of data, we use an analog to digital converter (ADC) to

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convert between the two. The first step of the ADC is sampling. In other words, we sample the voltage at a discrete point of time of the original analog signal. Once a data point is sampled, it is then converted into a binary value. Typical resolutions for data acquisition are 8, 12, and 16 bits. This process is then repeated for the next sample.

When a computer reconstructs the sampled data to form a continuous graph, it connects all the discrete samples together to form a continuous plot. There are many techniques a computer uses to reconnect the points; however they will not be discussed here.

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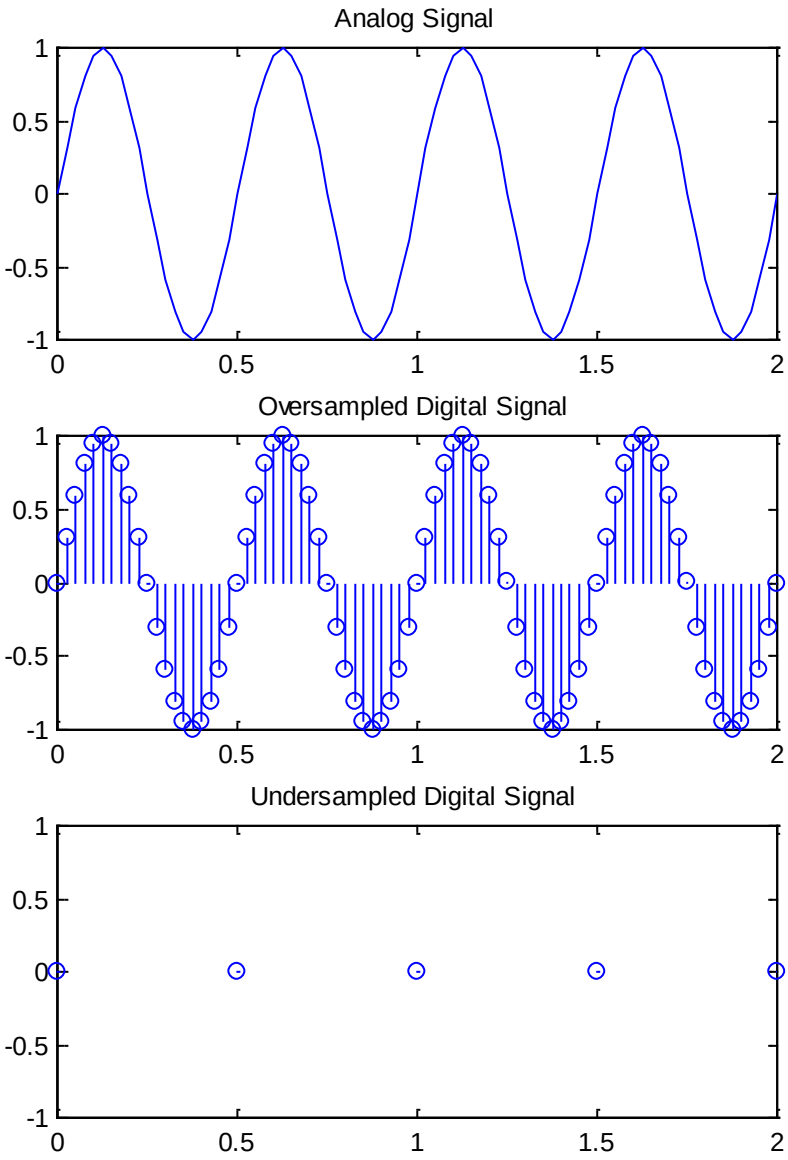

Figure 4: When a signal is sampled at a frequency greater than 2 times its highest frequency, it can be accurately reconstructed. Sampling slower, however, leads to aliasing, for example in this case, converting a sinusoidal signal to a DC value.

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Other data acquisition issues include aliasing, which, according to Nyquist's theory, requires the sampling rate to be at least two times higher than the highest frequency of the signal being recorded. However, for most practical applications, sampling is done at least 5 times faster than the highest frequency in the signal. Aliasing occurs when the sampling rate is not high enough to appropriately represent all the frequencies in a signal, causing some higher frequency signals to incorrectly appear as lower frequencies (Fig 4). In this example, the bottom plot (undersampled) shows the sine wave sampled *below* the Nyquist rate. Arbitrarily, it is sampled at the zero crossing, making what was a 2 Hz signal appear as a DC signal. However, imagine what would happen if this signal was sampled *at* the Nyquist rate and sampling was started at a zero crossing. The signal would still appear as a DC signal with zero amplitude! Therefore, it is important to sample at a frequency that is greater than 2 times the highest frequency in the signal.

Errors during ADC conversion can occur due to converting continuous data into discrete time data. Quantization error can be thought of as not having sufficient levels to accurately represent the data. For example, a 2-bit system can only represent 2^2 or 4 discrete values whereas an 8-bit system could represent 2^8 or 256 discrete values. The signal being measured is typically divided by the number of discrete values available. For example, imagine a 2-bit system used to measure a 0 - 3 volts signal. Since the system is 2-bit, only four discrete values could be measured. Therefore, the only values you could measure would be 0, 1, 2, and 3 volts. Anything in between these levels would be rounded off to one of these four values. Truncation is responsible for quantization noise. The more bits you have the greater the resolution of your measuring system. Values that go above the range of values that the computer will read will appear as the maximum value that the computer can read. For example, in the previous case, any values above 3 volts would appear as 3 volts. This is known as saturation of the signal. The dynamic response of the system is also an important characteristic. A recording device with ideal dynamic characteristics yields an output that is proportional to the input for all frequencies with no amplitude or phase distortion.

Clinicians are usually interested in recording more than one channel. Instead of having multiple ADCs for each channel, we can "time-share" a single ADC by sending each channel sample in a consecutive fashion. This efficient process is called multiplexing. Multiplexing can be visualized by the following. Imagine 3 channels being recorded, and this data is being sent to the computer in a multiplexed fashion. The data stream going into the computer would appear:

Ch. 1: sample	**Ch. 2:** sample	**Ch. 3:** sample	**Ch. 1:** sample	**Ch. 2:** sample	**Ch. 3:** sample	**Ch. 1:** sample	**Ch. 2:** sample	**Ch. 3:** sample	**etc…**

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1	1	1	2	2	2	3	3	3	

Once stored on the computer, the software can de-multiplex the channels and then display each channel individually.

Data acquisition can generate very large files if not carefully monitored. For example, a 10 minute 16 channel EEG recording using a sampling rate of 200 Hz and 16 bits per channel will generate a file that is

16 bits * 200 samples/sec * 600 seconds * 16 channels = 30,720,000 bits or 3.84 Megabytes!

RF Link

The BioRadio RF system is divided between two hardware platforms, a transmitter and a receiver. The transmitter is associated with the data collection and transmission end while the receiver collects the transmitted data and sends it to the serial port of the computer. The compact amplifier/transmitter unit consists of an eight-channel amplifier whose output is digitized (8, 12, or 16-bit resolution) and then sent to the radio section of the board. The radio board consists of a low-power (less than 1mW transmission power), narrow band, frequency shift modulated, and frequency synthesized transmitter that operates in the 902-928 MHz carrier frequency band. The entire operation of the unit (amplification, analog-to-digital conversion, and telemetry) is under the direction of a microcontroller. The receiver is a heterodyne design that has a narrow bandwidth (76KHz) allowing a large number of BioRadios to operate in the same area. Advantages of a biotelemetry system are that the patient is not directly tied to an outlet ground, they are free to move around, and patients can be monitored outside the laboratory setting.

Transmission Basics

The biopotentials and sensor outputs are input to the transmitter where they are sampled and conditioned. The overall bandwidth of the system is derived from the sampling rate, data resolution, and modulation format. The sampling rate must be at least two times the highest frequency component of the signal being monitored to ensure that no information is lost in the sampling process. Most sampling rates are four to five times the highest frequency component just to ensure no information loss. The data resolution is a result of the number of bits used in the data conversion process. The more bits that are available, the better the resolution is. There are many modulation formats that can be chosen with the tradeoffs being bandwidth vs. signal to

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noise ratio (SNR). A more compact spectrum requires higher SNR to recover the data while wider systems require lower SNR for data recovery. The BioRadio uses a minimum shift keying (MSK) which also can be thought of as 2 state frequency shift keying (FSK). The level of FSK is such that the required radio bandwidth is approximately equal to the overall bit rate. For example, if the highest frequency component of interest were 100 Hz, then sampling at 4 times that would yield 400 samples per second. If the analog to digital convert has 12 bits of resolution then there are 4800 bits per second. This would then require a radio bandwidth of 4800 Hz. If other channels were multiplexed in, then the required bandwidth would be the number of channels times the one channel bandwidth.

The sampled data is used to modulate a tuned oscillator in the 902 to 928 MHz frequency band and whose power can be controlled to preserve battery life. The tuned oscillator is created by phase locking a 900 MHz oscillator to a lower frequency reference oscillator. A typical phase locked loop configuration is used to control the frequency. The data is added to the tuned oscillator in the following manner. The phase locked loop is a basic control system where an output is made to look like the input via feedback. The control system has a bandwidth in that the output can track the input for changes up to a frequency where the bandwidth of the loop no longer can have the output track the input. Conversely, the loop can track out 'information' on the output source as long as the information is inside the loop bandwidth (can't track out signals outside the loop bandwidth). The BioRadio utilizes both effects to achieve a wide modulation bandwidth. The low frequency information is added to the reference of the control loop and the high frequency data is added to the output oscillator.

Receiving Basics

Sensitivity is the ability of a receiver to respond to incoming signals. The better the sensitivity, the more easily it will be able to respond to weaker signals. Selectivity refers to both the ability to receive the desired signal and also reject undesired signals. Dynamic range of the receiver is the decibel ratio between the largest tolerable receiver input signal and the minimum detectable signal.

The receiver is a single conversion heterodyne configuration. Using a multi-chain (i.e. double-conversion) increases the overall selectivity, but often degrades the dynamic range. The 900 MHz signal is conditioned to set the noise floor and remove interference via a low noise amplifier and 915 MHz band pass filter. That signal is then converted to 10.7 MHz via a tuned oscillator similar to the one in the transmitter (no modulation added to the receive oscillator). The overall resolution bandwidth of the receiver is set

by 10.7 MHz bandpass filters. 10.7 MHz is the standard IF frequency for most all FM radios and the variety of filters is plentiful and inexpensive. The signal is demodulated, and its power level is estimated via a standard, commercially available integrated circuit. The power level is useful data if there needs to be an adjustment to the power levels required over the radio link. The output of the FM demodulator is then reconverted back to data and passed on to a MODEM IC. The MODEM acquires bit synchronization, byte synchronization, and the data clock that is passed on the microprocessor for decoding.

Power

The power is controlled by controlling the bias of amplifiers following the 900 MHz oscillator. The gain of a transistor can be shown to be proportional to the collector current and the output power proportional to the DC power required. By controlling both of these factors, the gain as well as overall output, power can be controlled.

Experimental Methods

Each laboratory in this course uses a very similar software interface. This laboratory will explain in great detail how to use the Laboratory Course software. Later laboratories will build upon this laboratory and will not explain all of the software features in as great detail. This laboratory is meant to be an introduction to the Lab Course software as well as an introduction to Data Acquisition.

When you first run the CleveLabs software, the main menu will appear as shown below:

The first thing that you need to do is enter your student or group name in the top right corner and click on Log In. You need to log in so that all of your saved data and reports

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are sent to the appropriate user folder. You will not be able to enter any laboratory sessions until you are logged in.

Where are Data and Reports Stored?

Whenever you save data files in a laboratory session, the saved data will be stored in the following location in your "My Documents" folder:

My Documents\CleveLabs Data\"Login Name"\"Lab Session Name"\Data\"CustomName"

"Login Name" refers to the user name you entered on the front panel of the CleveLabs software interface.

"Lab Session Name" refers to the actual lab session in CleveLabs that you were running.

"Custom Name" refers to the actual filename that you entered at the prompt after you clicked on the Save Data button.

Whenever you capture a screen shot to a report in a laboratory session, the report will be stored as an .html file in the following location in your "My Documents" folder:

My Documents\CleveLabs Data\"Login Name"\"Lab Session Name"\Reports\
"LabSessionName"_Date_Time.html

"Lab Session Name" refers to the actual lab session in CleveLabs that you were running.

A new report will be created each time you begin a particular laboratory session.

Beginning a Laboratory Session

Once you are logged in, you can click on the "Begin Lab" button to begin a laboratory session that you select from the left hand column. The lab course software will automatically search for BioRadios that are attached to your computer.

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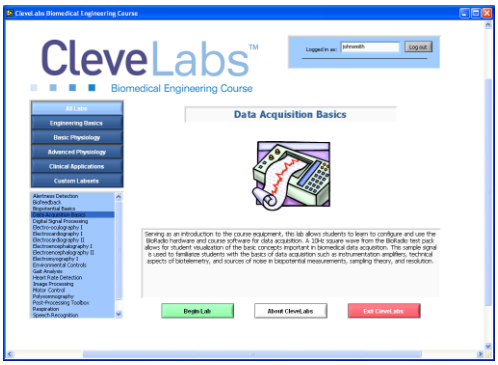

CleveLabs are broken down into five main groups including all labs, engineering basics, basic physiology, advanced physiology, and clinical applications. Additionally, custom lab sets can be setup. When you click on a particular laboratory session in the list, a description appears in the box. To begin a particular laboratory session, click on "Begin Lab".

Experimental Setup

1. Run the CleveLabs course software.

2. Your BioRadio should be programmed to the "LabDAQBasics" configuration file. If you are using the BioRadio 150 this will occur automatically at the beginning of the lab session.

3. Connect the Test Pack to the transmitter. If you are using a BioRadio 150, you should connect the testpack outputs to channels 1 and 2 on the unit. The blue test pack lead should get connected to ground input on the BioRadio. The metal limo connector should be connected to the pulse ox input. A red lead should get connected to a positive input of channel 1 and 2. A grey lead should get connected to a negative input of channel 1 and 2.

4. From either the "All Laboratories" or the "Engineering Basics" laboratory sets, select the "Data Acquisition Basics" laboratory. Then click on "Begin Lab" in the bottom right hand corner.

Procedure and Data Collection

Each laboratory software session has several "Tabs" that you may click on. For example, in this laboratory there are five tabs: "Background", "Test Pack Data", "Signal Noise", "Sampling Rate", and "Resolution".

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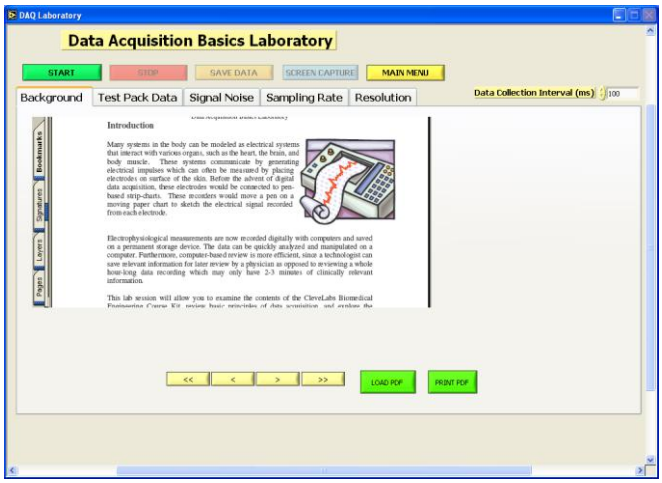
Background Information and Lab Session Instructions

For each laboratory session, the background tab contains a .pdf file of the laboratory session background material and instructions. You may print this from the laboratory session. In subsequent laboratory sessions, another tab exists called "Setup". This contains a movie illustrating the clinical setup for the laboratory session.



Main Controls

Each software laboratory session in this course is setup in a similar fashion. Each laboratory has the same "Main Controls". Clicking on "Start" will initialize communications between the software and the BioRadio. The BioRadio receiver will then begin collecting data sent by the BioRadio transmitter. Clicking on "Stop" will terminate communications between the BioRadio and the software. Clicking on "Main Menu" will cause the software to exit the individual lab session and return to the main menu lab selector. Some buttons will become grayed out at particular times. For example, after you click on "Start" the "Main Menu" button will be grayed out until you click on "Stop".

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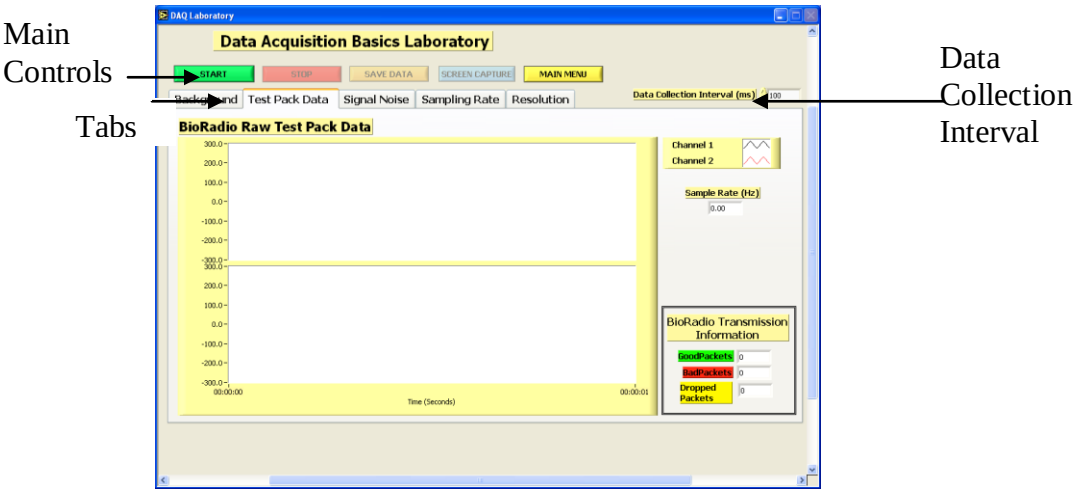
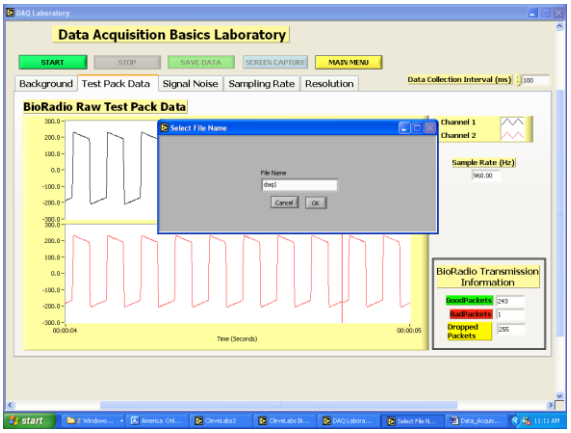


The main control buttons also include "Save Data" and "Screen Capture". For each laboratory session, you can save real-time raw and processed data to a file by clicking on the "Save Data" button. When you click the "Save Data" button, you will be prompted for a file name. Data will be saved to the file folder location described above.



Two data files will be created with your desired filename. The first has a .data extension and is simply all of the data points that you are writing to file. The second file that is saved has a .header extension and contains important information about your saved data. The first number in the header file is the sampling rate at which your data was saved. The rest of the file is the names of all the channels of data that were saved. When you are saving data, the "Save Data" button will flash to indicate data is saving. To stop saving data, click on the "Save Data" button again. The exact parameters that are saved to file for each laboratory are different. The exact parameters that are saved in this laboratory are "Channel 1 Raw", "Channel 2 Raw", "Data with Noise", "Resampled Data", and "Data Resolution".

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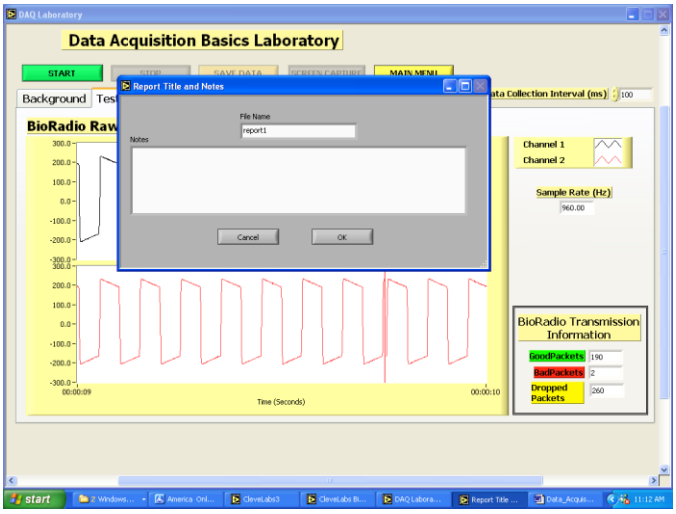
Finally, the software has a reporting feature. When you click on the "Report" button, a current screenshot will be captured and stored to a file. The first time you use the report feature during a laboratory session you will be prompted for a file name and any comments you would like to add. Each subsequent time that you click on the "Report" button during the laboratory session the screen shot will be sent to the original report filename, however, you can add new comments each time. You will not be able to create a new report file until you begin a new laboratory session.



BioRadio Transmission Information

The data tab on each laboratory has a box in the lower right hand corner labeled "BioRadio Transmission Information". This box has three indicators, which provide information on the radio link between the BioRadio transmitter and receiver. A packet refers to a chunk of information that was sent from the transmitter to the receiver. This "chunk" of data includes a time stamp, the sampled data, and other variables to allow the software to process the data. A packet can only include so much information as the packet size does not change. Therefore, if the unit is programmed to only 1 or 2 channels, a packet may have up to 3 samples for each of channel, whereas if you are programmed to eight channels, the packet will only have one sample for each channel. The number of "Good Packets" indicates the number of good packets that were received from the transmitter since the start of the lab. Typically, this number should continually be rapidly increasing when the transmitter is on. The number of "Bad Packets" indicates the number of bad packets that were received from the transmitter since the start of the lab. A bad packet is a packet received that has some how been corrupted and cannot be read by the software. Typically this number should remain

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extremely close to zero and should not increase during the lab. Finally, the number of "Dropped Packets" indicates the number of packets that were sent by the transmitter, but missed by the software. Dropped data packets can occur for several reasons. First, the transmitter may be located too far from the receiver and is out of transmission range. Secondly, another device may be interfering with the BioRadio signal. Finally, the data collection interval may be set too high which will be explained below. In general, the number of dropped packets should remain close to zero.

Data Collection Interval

For each laboratory you can set the "Data Collection Interval" while the software is running. The "Data Collection Interval" specifies how often (in milliseconds) the software collects data from the serial port that the receiver has placed there. The serial port has a finite buffer. Therefore, only so much data can be placed there before it overfills and is no longer capable of holding any extra data until it is cleared by being read. Therefore, if you set the data collection interval too high, the buffer will overfill and you will begin to see the "Dropped Packets" indicator begin to rise. We will illustrate this with an example later. The maximum time to which you can set the data collection interval and not drop packets is dependent upon your buffer size, the computer speed, and what else is taking up processing time in the computer.

Auto Scaling Plots

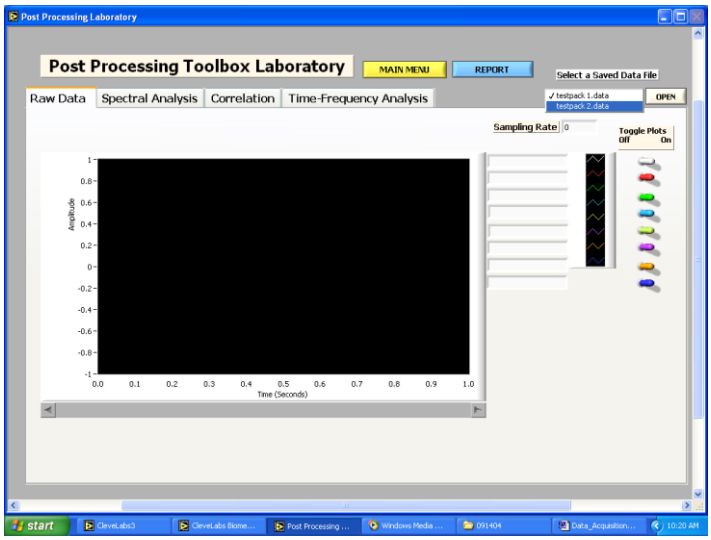
Plots in the lab course software have an auto scale feature. This can be useful, however in some instances you may wish to turn it off. Right clicking on the axis and then selecting or turning off the auto scale feature allows you to manually adjust the axis scale. To manually adjust the scale, simply double click on the scale numbers and type in your new range.

Data Acquisition Basics Laboratory

Post Processing Toolbox

The post processing toolbox is designed to provide quantitative tools to analyze saved data files. The toolbox will analyze saved data files that were created while you were logged in under the current student/group name. After you log in, click on the "Post Processing Toolbox" laboratory session from the "All Labs" menu.

This toolbox will list of all your saved data files as a drop down selection box. Select the saved data file that you wish to analyze and click on "Open".



All data saved will be plotted in the Raw Data tab plot. The channel names will be displayed to the right of the plot. You can turn various channels on and off using the toggle plot switches to the right. You can change the time frame of the saved data plots as well as use the scroll bar to search through the saved data file.

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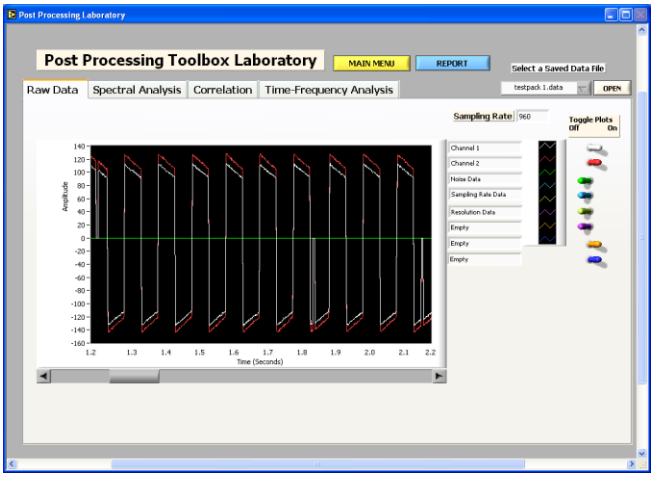
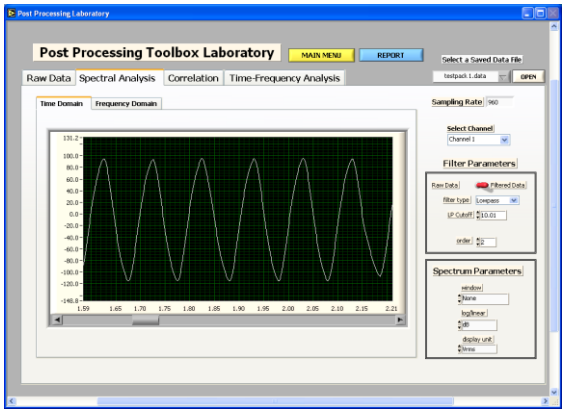
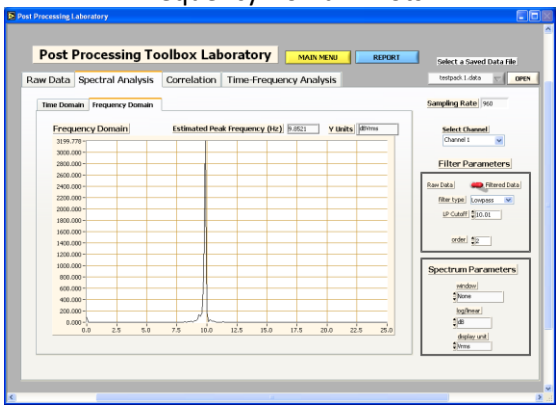


Using the spectral analysis tab, you can filter any channel of your saved data and view the results in the time and frequency domains.

Time Domain Plots

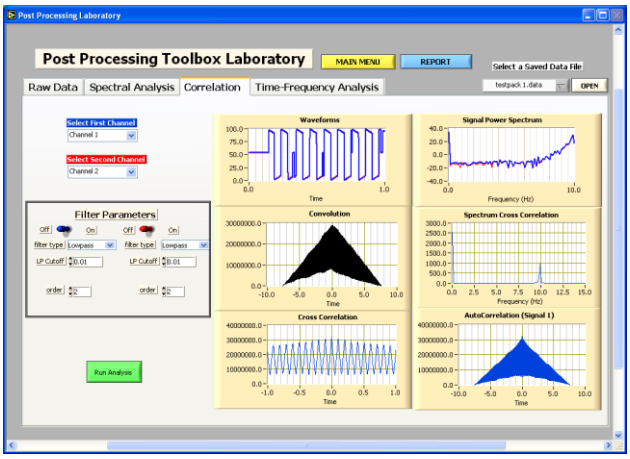


Frequency Domain Plots

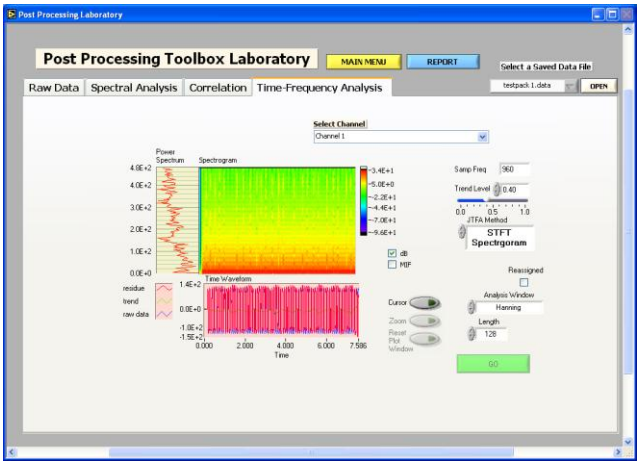


Data Acquisition Basics Laboratory

Finally, some quantitative analysis tools are provided under the correlation tab to look at statistical measures between collected data channels. You can perform correlations between different channels that are selectable from drop down menus. Additionally, you can change the filtering of any of the channels for the analysis. Once the parameters are set, you should click on the "Run Analysis" button to complete the analysis.



In addition, the post processing toolbox also provides methods for joint time-frequency analysis of collected data.

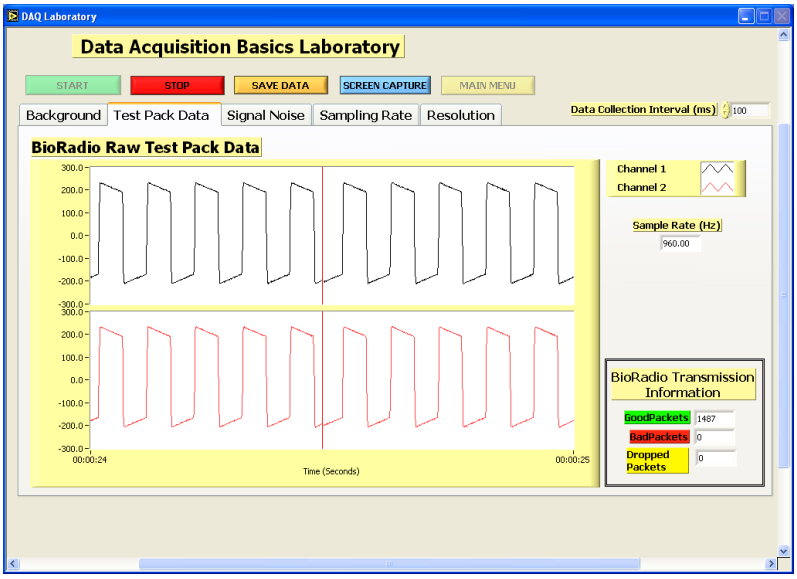


Data Acquisition Basics Laboratory

Now we are ready to begin the first laboratory using the CleveLabs Course Software.

BioRadio Raw Test Pack Data

1. Make sure the receiver is properly connected to the serial port on the computer and is powered on. Make sure your transmitter is still connected to the test pack. Turn the transmitter ON.
2. Click on the green "Start" button.
3. Click on the "Test Pack Data" tab. You should see the BioRadio Raw Test Pack Data plot. Make sure that the time scale is set to 1 second.
4. You should see the +/-150uV, 10Hz square wave begin scrolling across the screen. Create a screen capture and save the report as "DAQBasicsReport".

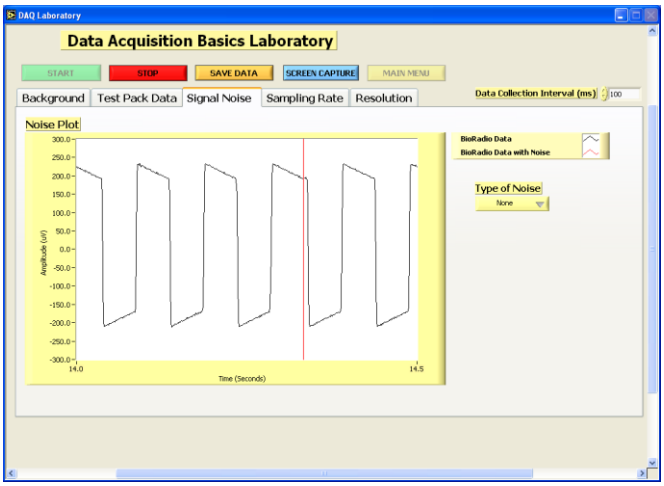


5. Save approximately 10 seconds of the test pack data to a file named "labdaqraw". We will examine this data later.
6. Examine the BioRadio Transmission Information box at the bottom right hand of the screen. A common cause for a dropped packet is when the transmitter is out of range from the receiver. Try to determine the maximum range for the BioRadio in your environment. Keep moving the BioRadio transmitter further and further from the receiver and have someone else watch the transmission information. You can test the range of your BioRadio transmitter and receiver this way. Note the range of your BioRadio. You should try to test the range of the BioRadio line of sight (when the transmitter and receiver can see each other) and also through a wall.

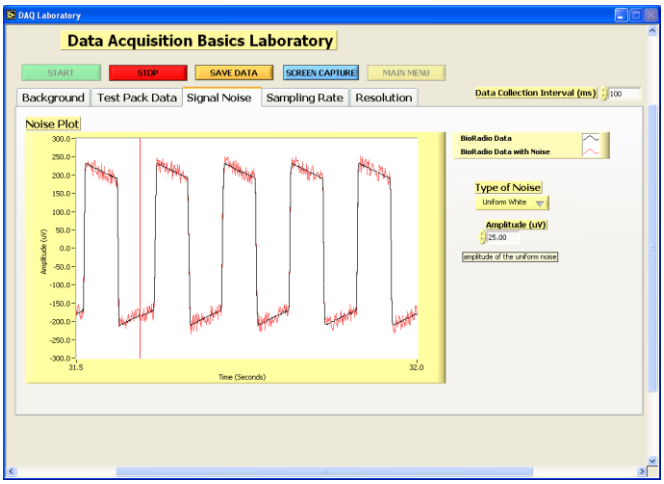
Data Acquisition Basics Laboratory

Signal Noise Simulation

1. Click on the tab labeled “Signal Noise”.
2. Set the time scale to be 0.5 seconds.
3. Set the noise type to be “None”. You should see the BioRadio Data and the Noise data plotted on top of each other. Save a screen shot of this to your report.



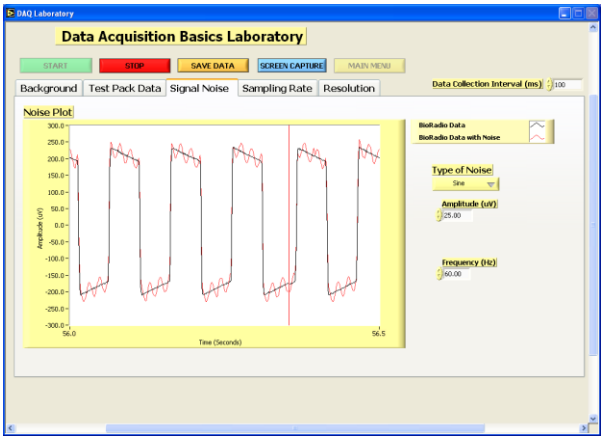
4. Now set the type of noise to “Uniform White” and the amplitude to 25uV. You should now see the noise in the Noise plot. Create a screen capture.



Data Acquisition Basics Laboratory

5. Now continue increasing the white noise amplitude until you can no longer tell that a square wave exists. Report this screen, and note the amplitude value.

6. Now set the type of noise to "Sine". Set the frequency to 60 Hz and the amplitude to 25uV to simulate what 60Hz noise could look like on top of the square wave.



7. Examine the other types of noise and their effect on the signal.

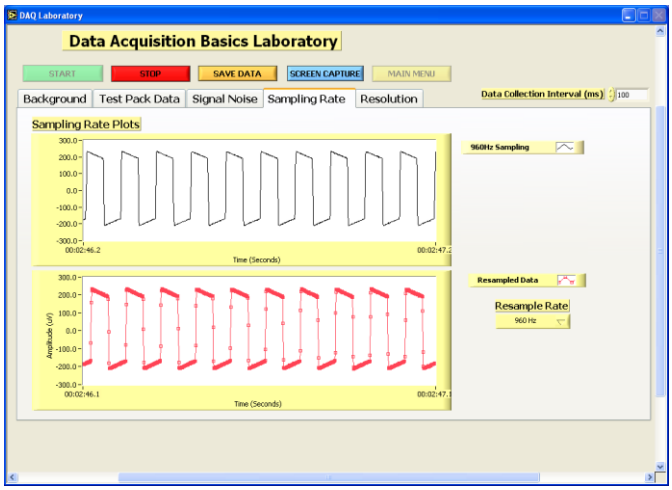
Sampling Rate Simulation

1. Click on the tab labeled "Sampling Rate".

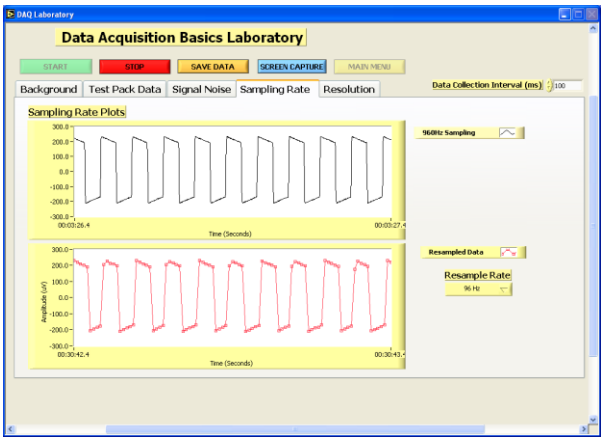
2. Set the resample rate to be 960 Hz.

3. Report this and note the sampling rate.

Data Acquisition Basics Laboratory

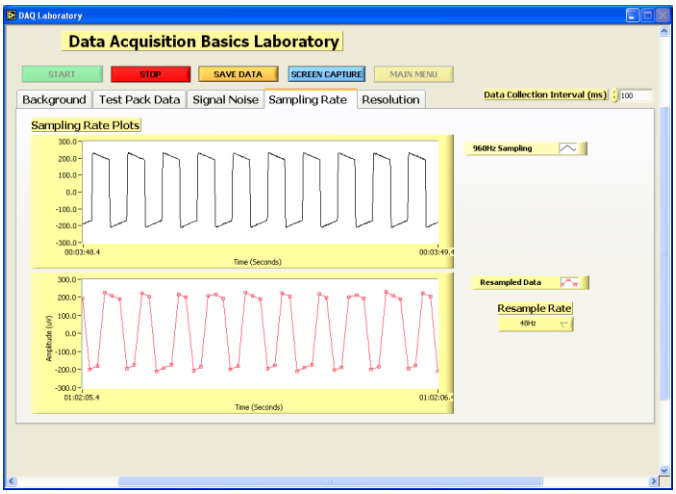


4. Reset the sampling rate to 96Hz and report this.

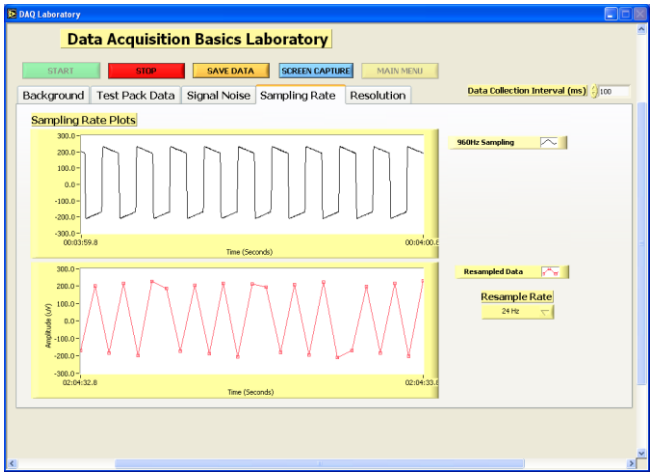


5. Repeat step 4 for each resample rate and report a screen shot of each to your report.

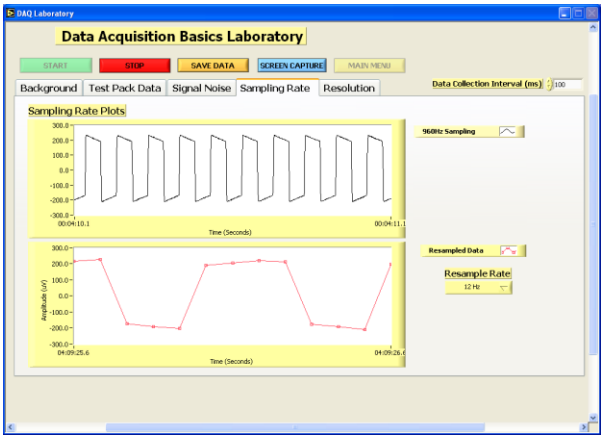
Data Acquisition Basics Laboratory



48 Hz



24 Hz



12 Hz

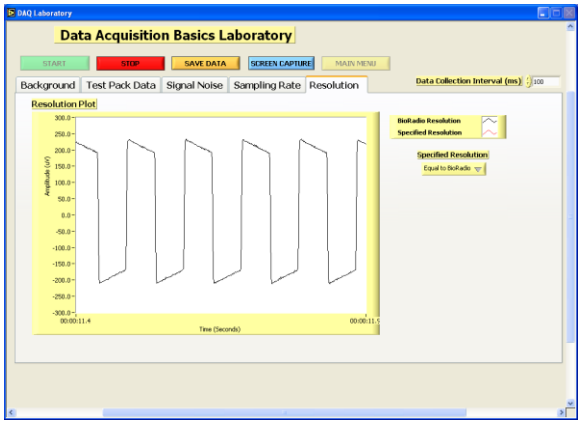
Data Acquisition Basics Laboratory

Resolution Simulation

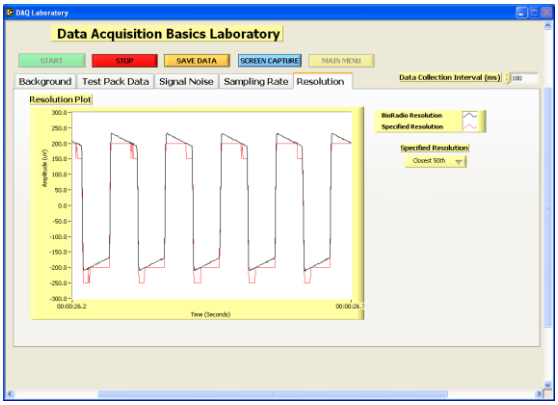
1. Click on the tab labeled “Resolution”.

2. Set the time scale to show 0.5 seconds of data and set the specified resolution to be equal to the BioRadio.

3. The two signals should be on top of each other. Report this screen to your report file.



4. Repeat step 3 for each resolution listed in the drop down menu and report each screen.



Opening Saved Data

Data Acquisition Basics Laboratory

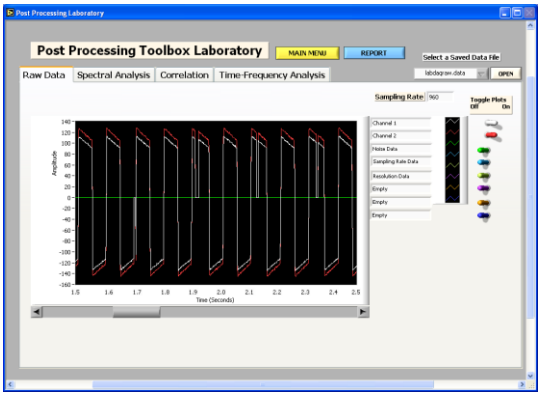
There are several software programs that you can utilize to open and analyze data files that you saved using the CleveLabs software. The data files are in ASCII format. First, you can utilize the Post Processing Toolbox included with the CleveLabs software. Additionally, you can use other standard software packages such as MATLAB®, LabVIEW™, and Microsoft® Excel. As a part of this exercise you should open the data files using several software programs to understand how to utilize each.

CleveLabs Post Processing Toolbox

1. From either the "All Laboratories" or the "Engineering Basics" laboratory sets, select the "Post Processing Toolbox" laboratory. Then click on "Begin Lab" in the bottom right hand corner.

2. Select the file named "labdaqraw" and open it.

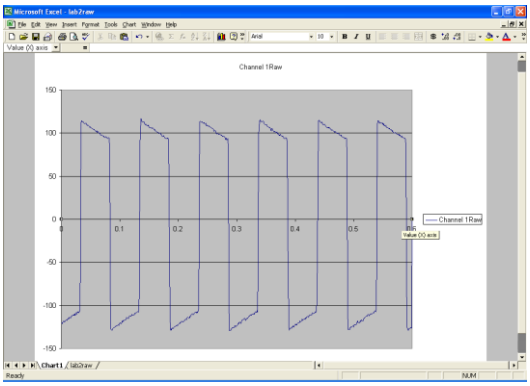
3. Turn off all channels except for channels 1 and 2. Notice how you can use the scroll bar at the bottom of the plot to scroll through the data.



Microsoft® Excel

Using Microsoft Excel open the "labdaqraw" data file that you saved and plot one of the channels of data. You can make a time column in the data file by recalling the sampling rate that was used during the lab session. If you don't remember the sample rate, you can examine the header file that was saved.

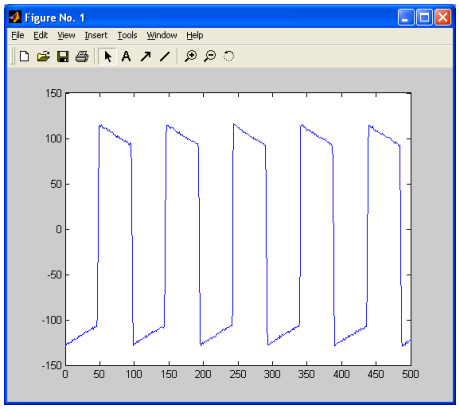
Data Acquisition Basics Laboratory



MATLAB® and LabVIEW™

Often times in this laboratory course, saved data files will be much longer than a few seconds and Excel will not be able to open them. Another useful tool for analyzing the saved data will be either LabVIEW or MATLAB. Try to open the file in MATLAB and LabVIEW and plot the first channel of data. An example of the code to do it follows and can be built upon for future laboratories.

```
M=dlmread('c:\labdaqraw','\t',1,0);
plot(M(:,1))
```



Discussion Questions

As a part of answering the discussion questions, you may want to refer to the report that you created using the software. Additionally, you may want to type your answers to these questions directly into the report that you created. To do this, open your

Data Acquisition Basics Laboratory

report with Microsoft Word. Once you open this in Word, save it as a Word document. You can then use it to type your answers to the following questions.

1. What was the data transmission range of your BioRadio unit? What factors may have had an influence on the transmission range of the BioRadio?

   Student's answers will vary for the first question. Factors that may influence transmission range are how many walls were in between, the materials that were in the walls, materials that were in the room, etc.

2. Examine the signal noise plots in your report. At what level of noise did the square wave become drowned out? What impact does this result have on noise during the recording of physiological signals?

   Noise must be kept to a minimum or filtered out in a physiological recording due to the fact that the amplitudes of the signals we wish to monitor can sometimes be much smaller than the amount of noise present in a room.

3. Examine the resolution plots that were created. What impact does resolution have on the quality of your recording?

   Information can be lost if an appropriate level of resolution isn't selected for the signal that is being measured.

4. In the lab procedure, the BioRadio was programmed for 2 channels. How many bits per sample are there? (Hint: refer to the manual) What is the range of values that can be represented by each bit for both the high-level and low-level signals? Would a high number of bits per sample be better for low-level or high-level recordings? Why? In what ways would this affect the amount of data acquired?

   The original statement in the lab sets the resolution to be 16 bits per sample. For low-level inputs, ranging from ±61mV, each bit represents 1.86 µV. (122 mV / 2^{16}). Similarly, in high-level inputs, ranging from ±1.25V, each bit represents 38.147 µV. (2.50V / 2^{16}) So, it is better to have the highest number of bits per sample as possible to achieve finer granularity between samples, particularly when sampling values that have a large range. However, a trade off exists between number of bits per sample and the amount of data that can be stored.

Data Acquisition Basics Laboratory

5. Assume you are going to use the BioRadio to record two channels for 30-minutes with the BioRadio configuration given in the lab procedure. How many bytes would you expect that file to be?

   2 channels * 16 bits/sample * 160 samples/sec * 60 sec * 30 minutes = 3.456 kilobytes.

6. How does the BioRadio ensure that the patient is not at risk for electric shock? What are some other methods for electrically isolating the patient?

   The patient is not directly connected to an earth ground, and the device is electrically isolated from power since the data is transmitted via radio. Other methods of isolating the patient are opto-couplers, and transformers that isolate the patient.

7. Assume an instrumentation amplifier has a CMRR of 100 dB and a differential mode gain of 100. What would be the amplitude at the output of the amplifier of 60 Hz noise and an ECG signal? Assume that the surrounding 60 Hz noise signal was 100 mV, and the ECG signal was 1 mV.

   CMRR = 20 log (differential gain/common mode gain)
   100 dB = 20 log (100 / common mode gain)
   common mode gain = .001

   Since 60 Hz noise is at 100 mV, the output is

   .001 * 100 mV = .1mV

   EKG signal is 1 mV

   100 * 1mV = 100 mV

8. What sources of noise would you expect when recording EMG, EEG, and EOG signals besides 60 Hz from power sources?

   Other biopotentials, other electronic laboratory equipment, lights, radios, and cell

   phones.

Data Acquisition Basics Laboratory

9. If the highest frequency in a given signal is 120 Hz, how fast must the signal be sampled to prevent aliasing?

   Nyquist's Law says that the signal must be sampled at least 2 times the highest frequency in the signal, so at least 240 Samples per second. In reality, it would be higher than that.

10. Examine the plots that were made during the sampling rate exercise. Closely examine the number of waves present at 24Hz and then again at 12Hz. What happens when you drop below a 20Hz resample rate?

    While the signal looks less and less like the square wave as the resample rate is reduced, the last rate at which you can still see a 10Hz signal is at 24Hz. After you drop below 2 times the highest frequency (or 20Hz for the 10Hz signal), the signal no longer contains a 10Hz wave i.e. the plot at 12Hz.

11. Illustrate, either mathematically or graphically, how an analog signal is sampled. Using this, derive why the Nyquist rate must be at least twice the highest frequency in the signal.

    A sampled signal can be represented as

    SampledSignal(t) = Signal(t) * δ(t), or Σ $g(nT_s)$ δ(t – nT_s), where T_s is the interval between samples, and n is the number of samples.

    Assume this analog signal had a bandwidth of B.
    Derivation of the Nyquist Rate:

    The impulse train δ(t) is a periodic signal with period T_s. Knowing this, the equivalent Fourier series can be done.

    δ(t) = $\frac{1}{T_s}(1+2\cos\omega_s t+2\cos\omega_s t+2\cos 3\omega_s t+\ldots)$ where $\omega_s = 2\pi f_s$

    Since the sampled signal is g(t) * δ(t), multiply δ(t) by g(t).

    SampledSignal(t) = $\frac{1}{T_s}(g(t)+2g(t)\cos\omega_s t+2g(t)\cos\omega_s t+2g(t)\cos 3\omega_s t+\ldots)$

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Take the Fourier transform of the equation above, and using the identity $2\cos(\omega_s t) = \cos(\omega-\omega_s) + \cos(\omega - \omega_s)$, you get

$\text{SampledSignal}(\omega) = (1/T_s)\ \Sigma\ G(\omega - n\ \omega_s)$
Consequently, the sampled signal would have its spectrum centered at 0, and again at $n\omega_s$ for n being all integers. In order for the signal spectrum not to overlap, ω_s would have to be at least 2*B.

12. The BioRadio allows you to specify the sampling rate and the amount of resolution that you can use. As the sampling rate you specify increases and more channels are used, the amount of resolution that you are allowed to use decreases. Explain this relationship in terms of bandwidth available in an RF signal.

    Using an RF link allows a finite bandwidth of information to be transferred. Therefore, in order to include more information in one area, you must decrease the amount of information in another area.

Data Acquisition Basics Laboratory

References

1. Guyton and Hall. Textbook of Medical Physiology, 9th Edition, Saunders, Philadelphia, 1996.

2. Normann, Richard A. Principles of Bioinstrumentation, John Wiley and Sons, New York, 1988.

3. Webster, John G. Medical Instrumentation Application and Design, 3rd Edition. John Wiley and Sons, New York, 1998.