Build an Arduino-Mayhew Seismic Recorder

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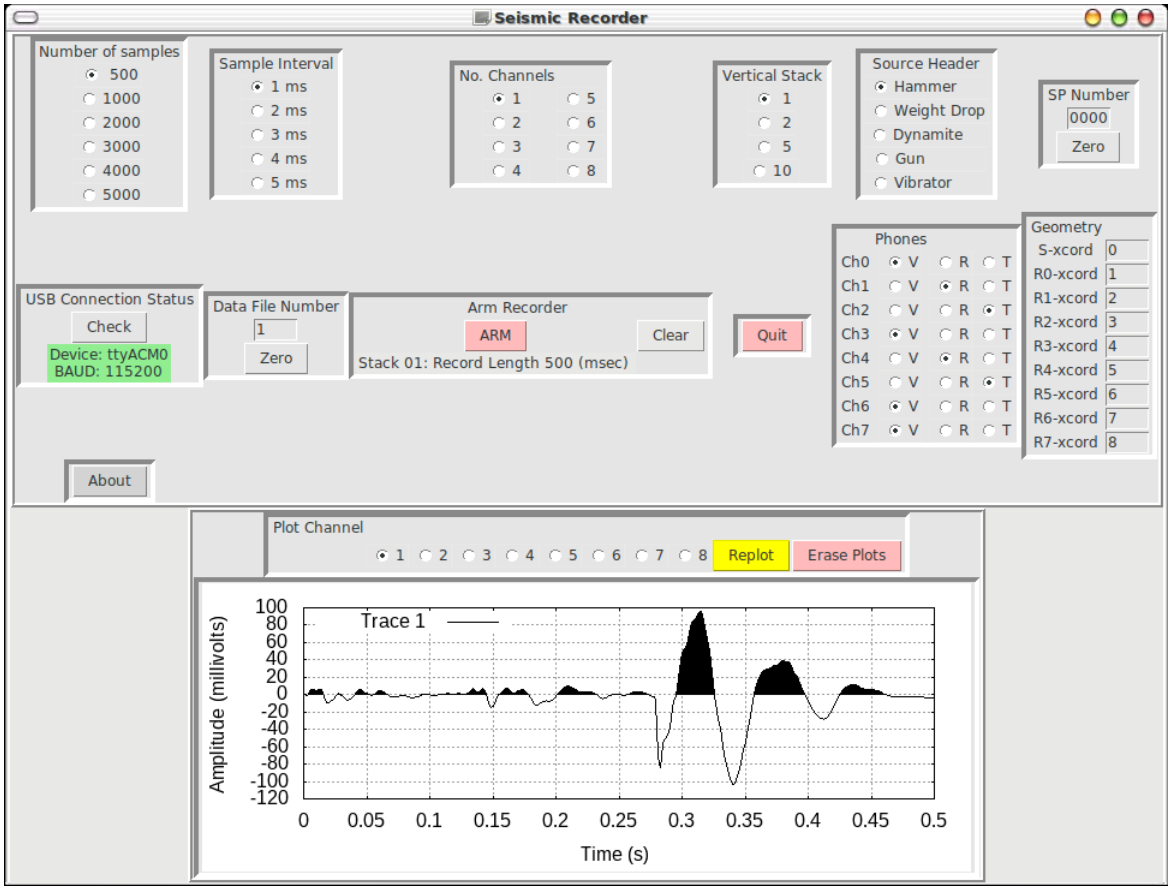

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1 Introduction

While there are a number of excellent engineering seismographs on the market, they are expensive. These instruments are designed to satisfy a number of survey techniques which often include refraction, reflection, surface wave, and bore-hole surveys. The required complexity of the design results in costs measured in thousands of dollars per channel. This project is designed to satisfy a narrow range of applications, surface wave and bore-hole surveys. Design goals include reducing complexity and cost. The result is a project suitable for students and those getting started in engineering geophysics. See section 6 for refinements of the original version of this document.

1.0.1 Design Components

The components of this project include the following:

- **Arduino microprocessor board**. While one might also consider a Raspberry Pi for this project, the multi-process feature of the Raspberry Pi makes millisecond sample interval accuracy unattainable. The Arduino does just one task without competition from other interrupts. The Arduino Uno cost was about $20.
- **Mayhew Extended ADC Shield**. The analog to digital converter (ADC) shield snaps directly on top of the Arduino board and provides 4 differential or 8 common ground channels. This project provides the 8 channel instance. The Mayhew shield comes in a number of precisions (12 bit, 14 bit, and 16 bit). This project uses the 16 bit shield. One can use this project's software to vertically stack to higher higher precisions, up to 32 bit if you have the time. The shield cost was about $40.
- **Two Pole Anti-Alias Filter, K-Gain of 10**. A separate printed circuit (PC) board is wired with point-to-point soldering. Four TLC272 Operational Amplifier chips are wired as eight Sallen-Key low pass Butterworth filters. The cut-off frequency is 100 Hz (-6 dB_v below the low frequency gain of 10). The TLC272 Op Amps are very low power, and run off the Arduino's 5 Volt supply. A virtual signal ground at 2.5 Volts is formed by a resistor voltage divider shunted with capacitors to prevent parasitic oscillations from forming. The cost for the Op Amps, resistors, capacitors, PC board would be about $30. You might have a lot of these parts in your junk box. See section 6 for refinements.
- **Inexpensive Lap Top Computer**. The above hardware are powered by a laptop via a USB cable. The lap top computer provides an LCD display, control software, serial communications software (USB), temporary memory, and solid state hard drive to save the recorded data in SEG-2 format (Pullan, 1990). The computer runs under the Linux operating system. As data are sampled by the Mayhew shield, the Arduino sends the samples as 16 bit binary integers on the fly, stored in the computer RAM memory (32 bits). When vertical stacking, each recording is summed in RAM using integer arithmetic. This increase the precision of the resulting sum. The SEG-2 format data are written as integers. The Dell laptop can run for up to 8 or more hours on a single charge while powering the acquisition hardware (solid state hard drives draw far less current than those that spin). The Dell Inspiron came with Windows 10. This was replaced with Ubuntu 18.04.1 LTS operating system running a Mate window manager. The processor is Intel Celeron(R) CPU N3060 at 1.60 GHz, 2 cores in a single physical processor, 2 threads. The graphics are 1366x768 pixels. RAM memory is 2G bytes with about 1GB free to save data on the fly. About 11 GB of disk are used for the OS, leaving about 15 GB to store data. The laptop computer cost was about $200.
- **Water Resistant Case**. Exclusive of the computer, the electronics are housed inside a Seahorse 300 case with O-ring sealed hinged lid ($21). A 16 gage piece of sheet metal was cut and drilled from a 12x12 inch piece (about $11 at Home Depot). The sheet metal provides a panel, screwed into the inside of the Seahorse case. After cutting holes for bulkhead connectors, switches, LED indicator, the panel was painted with 2 coats of Rust-Oleum 2X Hunt Club Green Satin spray paint ($4).
- **Software**. Software on the laptop includes:
  - **seisR.tk**. Tcl/Tk program that provides user interface.
  - **Status.cpp**. C++ program that checks USB connection and sets serial parameters. Called by seisR.tk when status button clicked.
  - **SEIS16v2.cpp**. C++ program that receives captured data and writes files in SEG-2 format . Called by seisR.tk when Arduino receives trigger (pin 2 drops to ground).

1.0.2 Compromises

On the plus side, commercial engineering seismographic recorders will have more channels, faster sample intervals, greater precision in the ADC, variable gain and filters. These features permit the tool to serve a wider range of applications, recording conditions, and energy sources. On the negative side, commercial recorders will cost more and require more power to operate. This means 12 Volt car batteries or some gel cell external batteries. They also will run using some form of Microsoft software (DOS or Windows).

A project like this is both educational and inexpensive. The decision to transmit data on the fly to the laptop RAM both limits the sample rate and introduces overhead that needs to be compensated for (as opposed to adding RAM to the Arduino). This is compensated for in the calibration (see section 4).

2 Design: Anti-Alias Filter, K-Gain

When digitizing an analog signal, there is the risk that high frequencies may become aliased. One limits that risk by filtering the analog signal with a low pass filter. The Nyquist frequency is the highest frequency that can be sampled without becoming aliased and falsely appearing to be a lower frequency. The Nyquist frequency is given as

$$F_{nyq} = \frac{1}{2 \cdot \Delta T} \quad , \tag{1}$$

where ΔT is the sample interval. This project permits the user to select sample intervals in the 5 to 1 ms range ($.001 \leq \Delta T \leq .005$ seconds). The largest sample interval poses the greatest risk. In this case, that would be 100 Hz. A rule of thumb is often to use 1/2 of the Nyquist. However, since most of my planned sources and sample interval would be less risky than this worst case, I decided on a cut-off frequency of 100 Hz. Most planned hammer-soil sources radiate energy at less than 100 Hz, and the sample interval most likely to be used would be 2 ms (250 Hz Nyquist). Of course, other noise might exist in the environment, so one is never safe. It is a matter of risk management. Avoid working in noisy environments and employ common sense.

2.1 Sallen and Key (VCVS Low Pass)

I decided on a 2-pole Butterworth filter of the Voltage Controlled Voltage Source (VCVS) topology. The Laplace transform is given by

$$\frac{V_2}{V_1} = \frac{K b_o}{s^2 + b_1 s + b_o} \quad , \tag{2}$$

where the left hand side of equation 2 is the ratio of the output to input voltage, K is the gain, s is the Laplace transform variable, and the constants b_o, b_1 determine the type of filter (Butterworth, Chebyshev, etc.). For a 2-pole Butterworth filter, $b_0 = 1$ and $b_1 = \sqrt{2}$. The topology of the filter is shown in Figure 1.

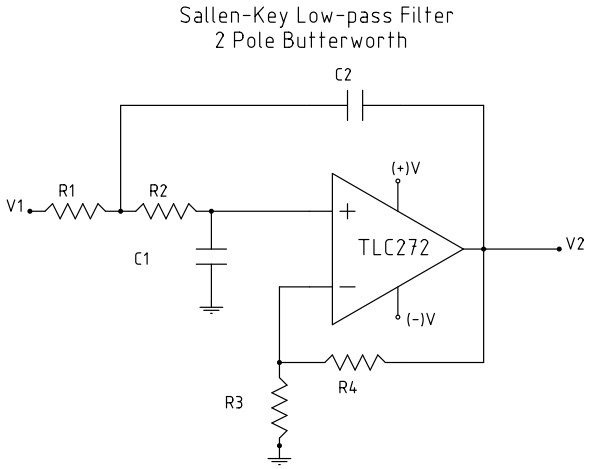

Figure 1: Low-pass Butterworth filter. Gain controlled by R3 and R4. If $R3 = \infty$ and $R4 = 0$, then unity gain.

2.2 Design Procedure VCVS Filter

In this discussion, "G" will be conductance of resistors "R". Thus, $G_1 = 1/R_1$. We will use a normalization procedure with a cut-off frequency of $\omega = 1\ rad/sec$ (Tedeschi, 1979).

1. We start with $C_2 = 1F$.
2. To keep it simple, make $C_1 = C_2$.
3. We choose gain, $K = 10$.
4. We calculate conductance G_1 as,
$$G_1 = \frac{b_1 + \sqrt{{b_1}^2 - 4.0 \cdot b_0 \cdot (C_1 + 1 - K)}}{2}. \tag{3}$$
5. We calculate the conductance G_2 as,
$$G_2 = \frac{C_1 \cdot b_o}{G_1}. \tag{4}$$
6. We calculate the resistor values $R1 = 1/G_1$ and $R_2 = 1/G_2$.
7. We compute the frequency normalization factor $U = 2\pi \cdot f_c$, where f_c = 100 Hz, our desired cut-off frequency.
8. We compute a starting Impedance Scale Factor, $ISF = f_c/(20\pi)$. This will be adjusted by trial and error until we get resistors and capacitors that fall in the range of convenient values. That is,
   - For resistors, $R_{convenient} = R_{norm} \cdot ISF$
   - For capacitors, $C_{convenient} = C_{norm}/(ISF \cdot U)$.
9. For this project, the ISF was found to be $ISF = \frac{f_c \cdot 100000}{(20\pi) \cdot 4.7}$.
10. The final values are
    $R_1 = 9.3K\Omega$
    $R_2 = 122.7K\Omega$
    $R_3 = 146.7K\Omega$
    $R_4 = 1.320M\Omega$
    $C_1 = C_2 = .047\mu F$
    Cut-off = 100 Hz, Gain = 10.0 (20dBv)
11. Since these are not all standard values, we round off to the following:
    $R_1 = 9.1K\Omega$
    $R_2 = 120K\Omega$
    $R_3 = 150K\Omega$
    $R_4 = 1.2M\Omega$
    $C_1 = C_2 = .047\mu F$
    Cut-off = 102.5 Hz, Gain = 9.0 (19dBv)

2.3 Connecting the Ant-alias with Gain to the Mayhew-Arduino

The op-amps are two to a chip. Figure 2 shows the how the first chip connects to the Mayhew extended ADC shield which is mounted on top of the Arduino. Note that there are two grounds. Pin 4 of the op-amp is the chassis ground, and the virtual ground for the signals from the geophones are at 1/2 of the supply voltage (see the voltage divider with 10K resistors and $0.1\mu F$ shunting capacitors which prevent oscillations from forming. Oscillations are also prevented with a 5.1K resistor shunt across the input. With the very high input impedance, leaving an input open resulted in oscillations forming when no geophone was connected. The typical geophone has a lower impedance, and is not significantly loaded by the 5.1K resistor. See section 6 for refinements.

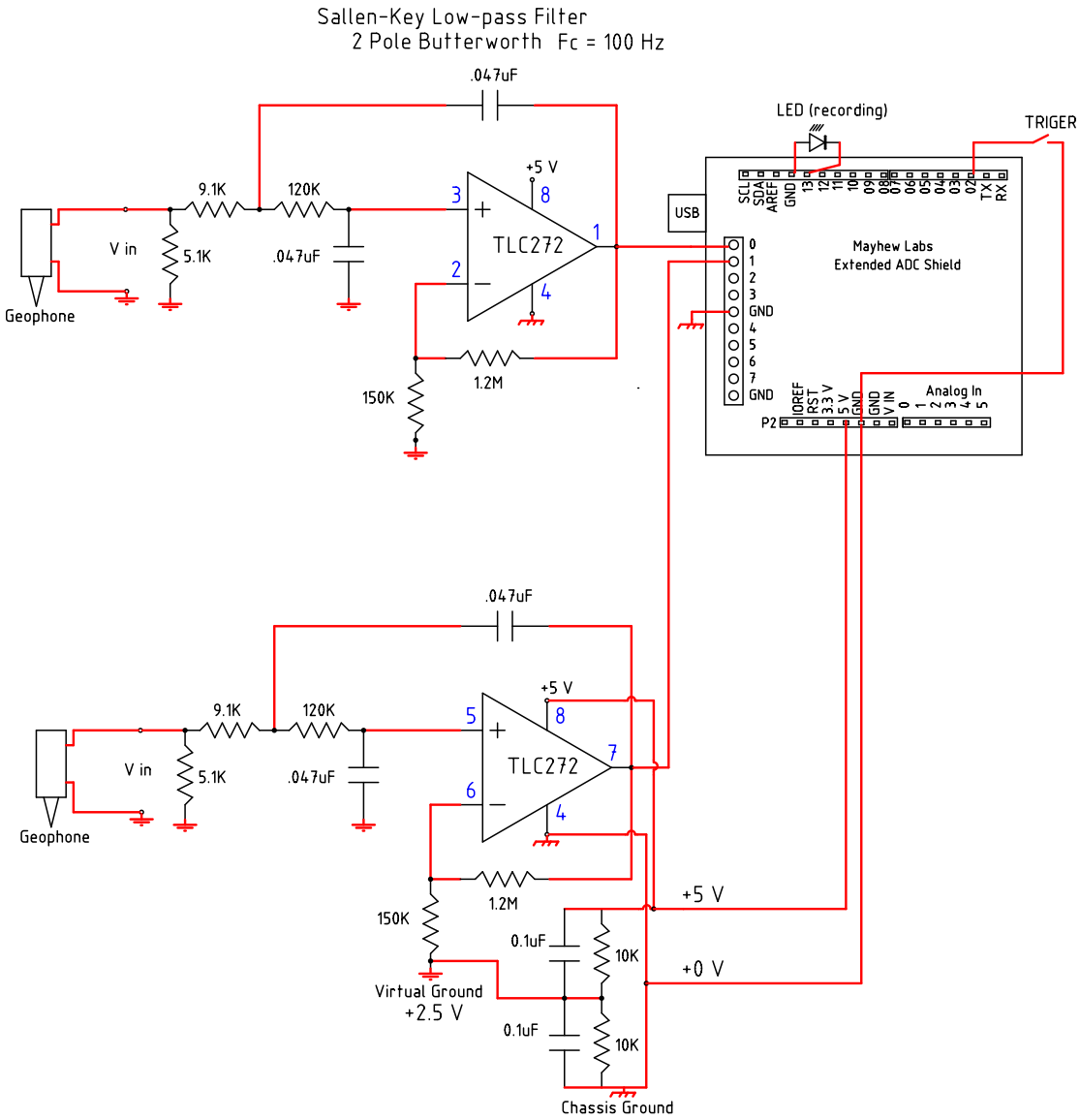

Figure 2: Low-pass Butterworth filters connect to the Mayhew shield. **See Figure 8 for refinements**.

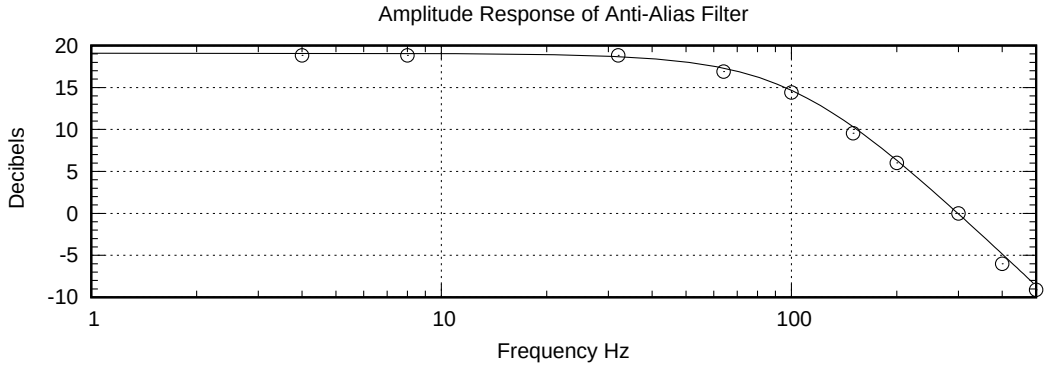

Figure 3: Measured and calculated amplitude response of anti-alias filter.

2.4 Wiring Filter/Pre-amp and Mayhew/Arduino

Figure 4 shows the point to point wiring of the anti-alias filter with gain. Resistors are stood on end to permit making connections on the top side of the board. Components are soldered on the bottom side (not in view). IC sockets are used for the TLC272 op-amps.

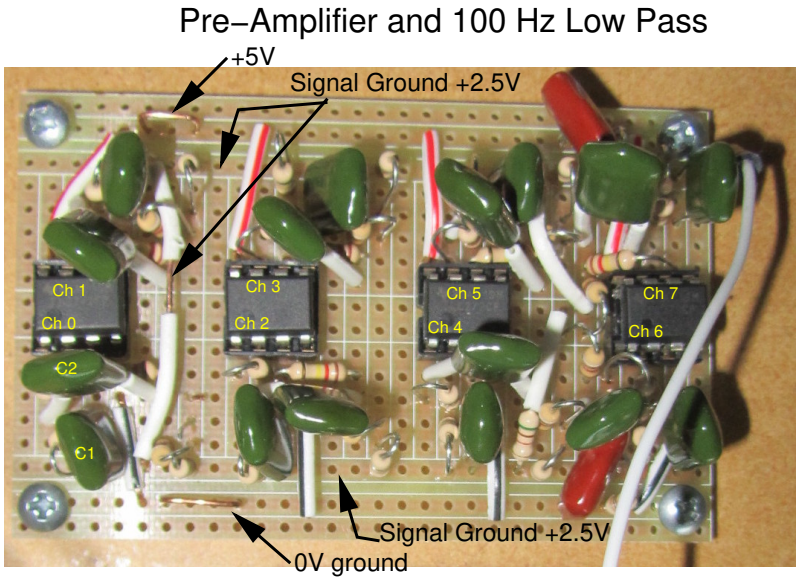

Figure 4: Wiring of the op-amps to form anti-alias filters with gain.

Figure 5 shows the wiring that connects the filter/pre-amp board to the Mayhew/Arduino board. The input signals pass from the banana plugs through a D-connector to the filter/pre-amp board. The D-connector also passes the LED signal (data recording) from pin 13 on the Mayhew to the LED mounted on the panel (not shown). The trigger signal is also passed through the D-connector. The Mayhew and Filter boards are screwed to a hardboard which is then later taped to the inside of the Seahorse water resistant container. The panel is then screwed to the Seahorse.

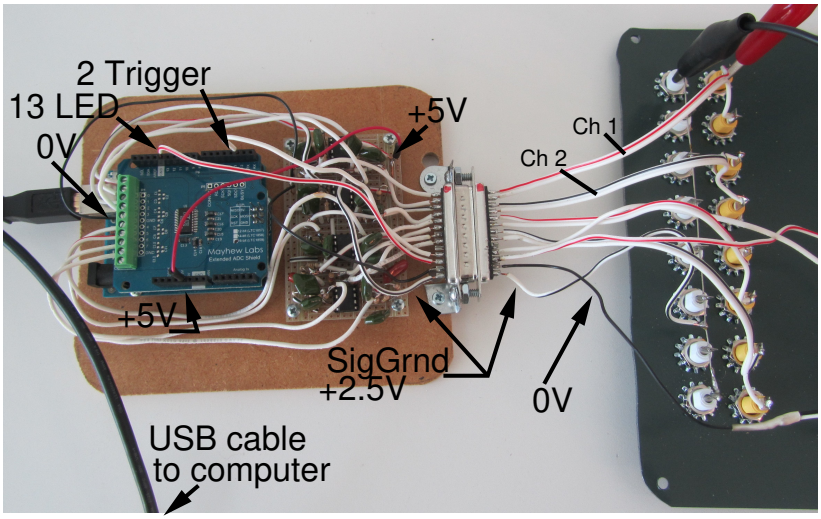

Figure 5: Wiring of filter/pre-amp board to the Mayhew and back of instrument panel. The Mayhew shield plugs directly over the Arduino.

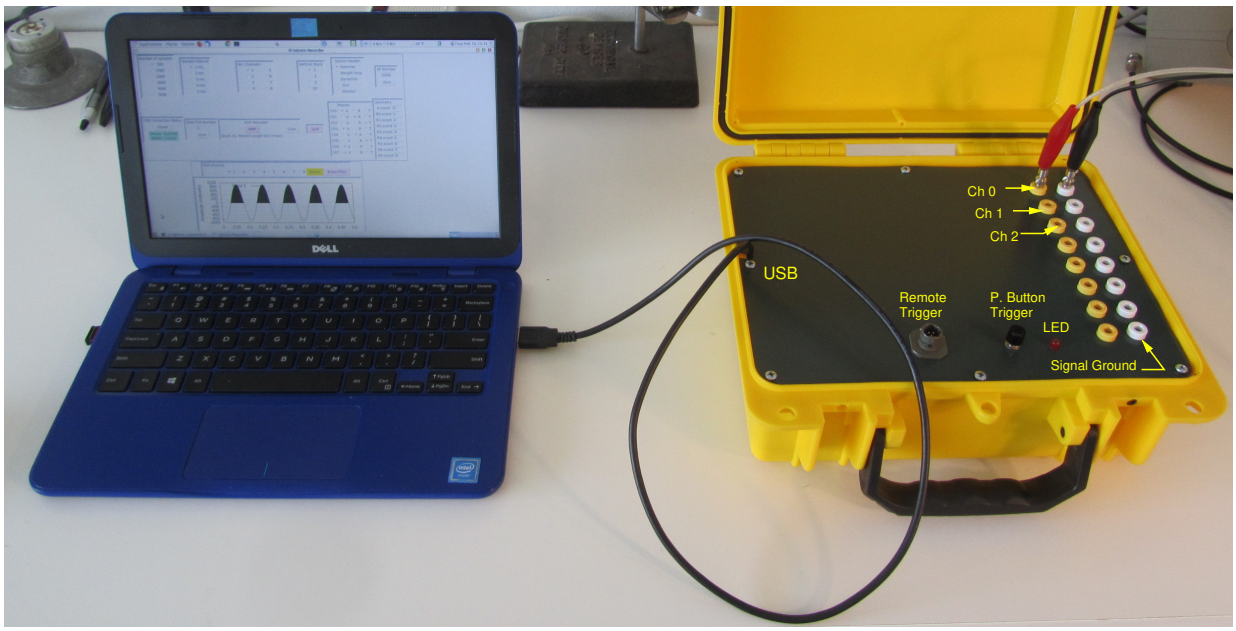

Figure 6: Final set up connecting the recorder to the laptop. The laptop software controls the recorder. There is no on/off switch on the recorder, it is on when plugged in with the USB. The LED will blink when connecting the recorder to the running laptop, and will stay lit when data are being collected. See Figure 10 for the revised panel.

Figure 6 shows the final set up connecting the seismic recorder to the laptop computer. The USB cable both provides power to the seismic recorder and captures the digital data on the fly when recording. **NOTE: This is important. Always check the status button on the software after connecting the USB to the computer.** This will set up the serial parameters for the USB. This can be done with the GUI or from the command line (see section 4.1.4).

2.5 Obtaining Components for Assembly

A number of online sources sell electronic, connector, and enclosure components. These include:

- **Arduino**. The Arduino Uno is the microcontroller board for the project.
  https://www.arduino.cc/
- **Mayhew Extended ADC Shield**. This analog to digital converter board plugs directly into the Arduino Uno. It comes in 12 bit, 14 bit, and 16 bit versions. This project software is configured for the 16 bit, but that is easily edited.
  http://mayhewlabs.com/products/extended-adc-shield
- **Digikey**. Good for banana plugs, sockets, and electronics.
  https://www.digikey.com/
- **Jameco**. Good for integrated circuits (like the op-amps), capacitors, resistors, PC circuit boards.
  https://www.jameco.com
- **Seahorse**. Good for the enclosure. They also sell panels, but I cut mine from 16 gage steel, obtained from Home Depot 12 in x 12 in.
  https://seahorse.net
  https://seahorse.net/shop/protective-cases/se300/

3 Laptop and Arduino Software

Software is installed in both the laptop computer and the Arduino. If you download the file, **SeisR-1.0.1.tgz**, you will not need to do a lot of typing. There is also a ZIP archived version for those less familiar with TAR and GZIP. It is **SeisR-1.0.1.zip**. The appendix contains listings of the source codes.

3.1 Prerequisites

The best idea is to use your operating system package manager to install these resources. Citations below are for books on these software packages. The Graphical User Interface, GUI is a **wish** program. Program **wish** is an interpreter and **seisR.tk** does not need to be compiled. But, you will need to install TCL and TK on your computer (Ousterhout, 1994). You will also need to be able to compile the C++ programs, so a compiler is needed. I recommend the GNU compiler (Various, 2019). You will also need to install Gnuplot for the graphics (Janert, 2010).

For converting from SEG-2 to other formats, you may wish to install my Basic Seismic Utilities (BSU) package (Michaels, 2018). The BSU package has binaries and source code, is open source, and can be run in Linux, Microsoft Windows, and Apple's Macbook-Pro. It is all included in a single ZIP archive, **BasicSeismicUtilities_PaulMichaels.zip**. Specific subsets are also available on the web if you don't want to download it all. There are many applications in the BSU package. Program **egg2seg** will convert a SEG-2 formatted file to BSU's processing format (bsegy). Program **seg2txt** can be used to go from bsegy to ASCII text format (perhaps for Matlab or Octave processing).

3.2 Compiling Software

There are Make files for compilation. If you download my file, **SeisR-1.0.1.tgz** or **SeisR-1.0.1.zip**, extract the archive. The best place to do this in Linux is from `/usr/local/src`. Type the following:

```
tar xvzf SeisR-1.0.1.tgz
cd SeisR-1.0.1
```

Next are the steps to follow:

- ```
  make
  ```

  If you have all the compiler packages installed, the response will be
  `g++ -g -Wall Status.cpp -o Status`
  `g++ -g -Wall SEIS16v2.cpp -o SEIS16v2`
  And you will have two new executable files, **Status** and **SEIS16v2**.

- ```
  make install
  ```

  If you have not edited the Makefile PREFIX, the response will be
  `install Status /usr/local/bin`
  `install SEIS16v2 /usr/local/bin`
  `install seisR.tk /usr/local/bin`

- ```
  cd Arduino
  cd A16
  ```

  With the USB cable connecting the Seismic Recorder and Laptop, do the next step:

- ```
  Status
  make
  make upload
  ```

  If all goes well and after a bunch of output, the binary will be compiled and then uploaded to the Arduino inside the Seismic Recorder. Because we are using optimization level 3, we don't use the IDE.

4 Calibrating the Seismic Recorder

The sample interval may need to be calibrated. There will be some computational overhead that may vary with the speed of the laptop and the connection of the Arduino to the laptop via the USB cable. See section 4.1.4 for a command line alternative to GUI.

1. Boot the laptop and login.
2. Plug the USB cable into the laptop from the recorder.
3. Type `seisR.tk`

   This will start the controller program and provide the graphical interface. If it does not come up, you may need to fix your PATH variable. The default location for the executable is in `/usr/local/bin`.
4. **TEST THE CONNECTION STATUS**. Do this by clicking on the USB Connection Status "Check" button. It will either come up in red saying that there is no connection, or green background giving the device name and baud rate. If you don't get the green message, check to make sure you have done step (2) above.
5. Click on the 1000 sample button, sample interval 1 ms.
6. Click the ARM.
7. Trigger the recorder manually by the push button. You can connect a geophone and do a tap test during recording, or have nothing connected to channel 0. We are checking the timing.
8. After the data collection finishes, a message will appear below the arm button. Ideally, it should read `Stack 01: Record Length 1000 (msec).`

   It might indicate a different record timing length. If it displays a smaller value, say 994 msec, then we need to increase the sample interval in the Arduino code. If it displays a larger value, say 1005 msec, we need to decrease the sample interval. The variation is due to the computational overhead being different for different hardware. In practice, a value of 998 or 1002 is probably good enough (ie. 2 ms out of 1000 ms). But the explanation of how to adjust this will follow.

4.1 Editing Arduino Program A16.ino

The factor that needs updating is called **shft**. This is computed from a linear function. This is on line 120 of the A16.ino code. The problem is with the variables **slope** and **intercept** on lines 43 and 44 of the code. The variable **k** is the number of channels. We comment out line 120 with two slashes at the beginning of the line:

```
// shft = ceil((slope*(float) k ) + intercept); //shft = overhead
```

Then we insert a line above that will be temporary.

```
shft = 0;
```

We will conduct a trial and error adjustment of **shft** for the two cases that are as follows:

1. Number of samples = 1000, No. Channels = 1, Sample interval = 1 ms.
   This should produce a 1000 msec recording
2. Number of samples = 1000, No. Channels = 8, Sample interval = 5 ms.
   This should produce a 5000 msec recording

4.1.1 First Case 1 Channel

The initial value of **shft = 0** will result in a recording aperture that is longer than the desired 1000 msec for the first case.

1. Quit the seisR.tk GUI
2. Save the modified A16.ino file.
3. Recompile and Upload (`make` followed by `make upload`).
4. Start seisR.tk, set number of samples, channels, sample interval for case 1.
5. click on Status button.
6. click on ARM button, then trigger manually. Observe the temporal aperture. For example, it might display 1844 (msec) below the ARM button. This is larger than the desired 1000 msec.
7. Return to editing file A16.ino
8. Change **shft = 0;** to **shft = 800** (about 1844-1000).
9. Save the modified A16.ino
10. Recompile and Upload (`make` followed by `make upload`).
11. Start seisR.tk, set number of samples, channels, sample interval for case 1.
12. click on Status button.
13. click on ARM button, then trigger manually. Observe the temporal aperture. For example, it might display 1039 (msec) below the ARM button. This is larger than the desired 1000 msec but closer to the desired.
14. Quit the seisR.tk GUI
15. Return to editing file A16.ino
16. Change **shft = 800;** to **shft = 839** (about 1039-1000 added to 800).
17. Save the modified A16.ino
18. Recompile and Upload (`make` followed by `make upload`).
19. Start seisR.tk, set number of samples, channels, sample interval for case 1.
20. click on Status button.
21. click on ARM button, then trigger manually. Observe the temporal aperture. For example, it might display 1000 (msec) below the ARM button. This is the desired temporal aperture. GREAT! Now move on to the next case and repeat the procedure for 8 channels.

4.1.2 Second Case 8 Channels

Following the same procedure as above, but with 8 channels and 5 ms sample interval we might see the following:

- **shft = 0** with a result of 9063 msec. This is way larger than 5000.
- **shft = 4000** with a result of 5038 msec. Why 4000? This is about the difference between 9063 and 5000.
- **shft = 4038** (5038-5000 added to 4000) with a result of 5000 msec. GREAT! We can now compute the slope and intercept needed to make line 120 give the desired **shft** value. We solve two equations in two unknowns as follows.

4.1.3 Solving for slope and intercept

The two equations are:

$$slope \cdot 1 + intercept = 839 \tag{5}$$
$$slope \cdot 8 + intercept = 4038 \tag{6}$$

Subtracting equation 5 from equation 6 gives

$$slope(8-1) = slope \cdot 7 = 3199 \tag{7}$$

We solve for slope

$$slope = \frac{3199}{7} = 457.0 \tag{8}$$

Now we can use either equation 5 or 6 to solve for the intercept. Let's use equation 5.

$$intercept = 839 - 457.0 = 382.0 \tag{9}$$

1. We remove the temporary line in A16.ino, delete the line **shft = 4038;**. This is following the above example, your value may differ from 4038 when you run your calibration.
2. We remove the comment double slashes from line 120. It will return to the following:
   `shft = ceil((slope*(float) k ) + intercept); //shft = overhead`
3. Then we can edit lines 43 and 44, or comment them out and replace with alternative lines. You would replace the slope and intercept values with those determined from your own testing.

4.1.4 Using the Command Line

Programs Status.cpp and SEIS16v2.cpp can be run from the command line in a terminal. Doing this can be faster than running the GUI when calibrating the time base. For example,

```
Status
```

The program responds typically as

```
Device: ttyACM0              or          Not Connected
BAUD: 115200
```

and if connected, sets the serial parameters. The command line help for SEIS16v2 is found by typing the command in a terminal,

```
SEIS16v2
```

```
USAGE: SEIS16v2 nsamp ndt nchannels nstack file source phones SP SX RX
Ex: SEIS16v2 1000 5000 8 1 0 H VRTVRTVV 0 5 1 2 3 4 5 6 7 8
source: H=hammer W=weight_drop D=dynamite G=gun V=vibrator
phones: V=vertical R=radial T=transverse (8 channels)
SP: Shot point number, SX Shot point X-coord
RX: Array of X-coordinates geophones
```

There are defaults for all parameters. You only need to type the first few parameters when doing the time base calibration. For example, sample interval is in microseconds, so 1000 samples, 1 millisecond (1000 microseconds), 1 channel, type:

```
SEIS16v2 1000 1000 1
```

Press the trigger button and it will respond:

```
Stack 01: Record Length 1001 (msec)
```

confirming a 1.001 second recording aperture which is satisfactory.

5 Collecting Data

There are no protections against excessive voltages on the signal inputs and trigger input. Adding protections might be a good idea. The following are recommendations for collecting data with the current version:

1. Deploy cables, geophones, and a source if one will be used. Connect the source trigger cable to the trigger input unless you are going to record ambient signals using the push button trigger.
2. Turn on the laptop computer.
3. Shutdown any services not needed on the laptop (ex. wireless, ssh, printer, apache web host, etc.) This is not essential, but why leave these on, they might lead to interrupts that could affect sample interval accuracy.
4. Connect the USB cable from the recorder to the laptop USB port.
5. Check the USB status with the **Check** button. If you don't get a green status showing the serial device and baud rate, check your connections or the trouble shooting section.
6. Click on the desired input settings:
   - Number of samples.
   - Sample Interval.
   - No. Channels.
   - Vertical Stack (this is how many source efforts will be added to a single file record.
   - Source Header.
   - Phone orientations. V=vertical, R=inline radial, T=transverse
   - Geometry (coordinates in meters of source and geophones. This is kept very simplistic (assume a straight line recording). If you have 3 component phones, then 3 R_i-xcord values can be the same. If you don't like this restriction, edit the **seisR.tk** and **SEIS16Rv2.cpp** files.

     NOTE: This is only for the SEG-2 headers, and if you keep an observer's log on paper (and you should!), you can do more complicated shooting with elevations and both x, and y coordinates. Geometry headers can always be edited later during processing.
   - Set the SP Number if needed.

     NOTE: This is NOT incremented automatically. You have to do it manually, it is just a label in the headers, has nothing to do with file numbers.
   - Set the Data File Number if needed. When the program starts, this is initialized to zero. But if you have been recording and already have a number of files saved on disk, you don't want to write over them. So set this to 1 more than where you left off. **The data file number increments automatically after each file is written**.

     NOTE: If your executables are in your path, you can create a directory to record the day's data. Change into that directory before you start seisR.tk, and then the data files will be stored in that directory.
7. Check to make sure all the geophone and trigger cables are connected.
8. Click on the ARM button.
9. Activate the source (contact closure trigger, ie. momentary short of trigger lines). For ambient recording, press the push button on the recorder. The red LED should light up during the recording, and go out once the recording maximum time has completed.

   NOTE: If you do a vertical stack of more than 1, the red LED is your communication that data recording for a source effort is completed. The ARM button will stay hot (bright red) continuously until all source efforts to be summed are collected. WATCH the red LED for the all clear to take the next source effort/trigger.
10. To terminate the seisR.tk program, click on the **Quit** button.

5.1 Trouble Shooting

- **Unexpected Long Recording** The software is fairly bullet proof and will try to avoid bad choices. For example, if you increase the number of channels, it may reset the sample interval to a larger value in the GUI. This is because there is too much overhead to permit a large number of channels to satisfy a short sample interval. It is possible to defeat this protection in the GUI, but the code **SEIS16Rv2** is a backup that will not be defeated. Depending on the order of your checking options you can create this effect. Say you click on 8 channels and then reset the sample interval to 1 ms. **SEIS16Rv2** will override your choice for sample interval. If you see the recording aperture has increased to a value larger than you expected, it is because the code reset the sample interval to a larger value, but has no way to tell the GUI about it. This will be obvious in the plot.

- **Status Won't Work**. OK, so the code **Status.cpp** (lines 46-55) is limited in the expectation of a device name. If your Arduino does not use either `/dev/ttyACM0` or `/dev/ttyACM1`, then you may need to edit the **Status.cpp** program for what your Arduino will use. Try using your IDE to figure this out. Either add an additional device name to look for, or edit one of the ones I have included.

- **Things are really SCREWED UP !!**. Right, this can happen if you forget to check the **Status** before ARM and recording data. For the worst case, quit the GUI (seisR.tk), unplug the USB, and start over. MAKE SURE you check status first thing next time.

- **The Plot didn't work**. Right, you might get an error message instead of a plot if you choose a plot channel that is beyond the number of channels being recorded. No biggy. Click OK and cancel the message. Then choose a channel to plot in the range of those acquired. Then click **Replot**.

  NOTE: If you are acquiring more than one channel, you can set the plot to show any valid channel. In fact, after looking at one channel, you can move on to another channel and **Replot**.

  Unless you click **Erase Plots**, plots will remain in the directory with names like `plot0.png`. If you switch to recording fewer channels at some point, the old plots will still exist, possibly leading to confusion (like how come there is a plot 7 when I only recorded 5 channels?).

- **Channel Order, Number of Channels**. Channels are added starting from channel 0 working up to channel 7. For example, if you choose to record 3 channels, these will be channels 0,1, and 2. **You can NOT just record channel 8 and no other channels**. If you want to record only 1 channel, it will be channel 0. This decision is implemented in the Arduino and the order it scans channels. You can change this, but you will have to edit **A16.ino** and recompile/upload.

- **OOPS, I plugged the signal input into a high voltage!!**. OK, if you blow the anti-alias filter op-amp, you can pull that chip out of the socket and replace it. Review the first comment under **Collecting Data**.

- **SEIS16Rv2 hangs on bytes_avail**. It is hard to predict what the laptop serial buffer length might be. Line 43 of program **SEIS16Rv2.cpp** specifies a BLOCKLEN value that, if set too large, will assume a buffer longer than the one that actually exists. Setting the BLOCKLEN is a trial and error project. If the program does not hang, recommend you leave it alone.

- **The SEG-2 Fixed Gain needs changing**. If your Anti-alias filter includes a gain different than the one I built, then look at line 803 of program **SEIS16Rv2**. For example, if your gain is 20 instead of my 19, change the definition of FG to `FG= 20;`

- **Cross-talk between channels**. Right, this will happen. If you don't go to extra effort shielding the signal lines (and maybe even if you do), you will notice some cross-talk picked up on a channel without a signal input. For example, if you choose 2 channel recording, but only input a 100 mv P-P sine wave into channel 0, you will see it also on channel 1. It will be about 1 mv P-P on channel 1. In other words, the cross-talk appears to be down by 40dBv.

- **Data Shifted**. If you put the laptop on a charger and then hook up test equipment (oscilloscope for example), you may short the chassis and signal grounds through the AC house outlet ground. Unplug the charger.

- **USB serial settings seem wrong**. With the IDE and Arduino plugged in, use the command
```
stty -F /dev/ttyACM0 -a
```
(assuming the IDE shows this device). Use the result to modify lines 095-109 in Status.cpp.

- **Clipping of the Signal**. Unless you are picking first break refraction data, clipping eliminates the option of further processing of digital signals. Clipping will occur in either of two ways:
  - **Analog Clipping**. The signal input to the pre-amplifier (anti-alias filter) is too large. The default is to use the Arduino 5 volt supply for the op-amps. This makes the virtual ground ideally at 2.5 volts, and analog clipping will occur on signals exceeding about 200 mv (remember the gain is almost 10). So a 200 mv input becomes almost 2 volts. If we add this 2 volt peak signal that to the 2.5V virtual signal ground, the ADC sees about a 4.5 volt input, and that is getting close to the supply. As it turns out, there is also a DC offset in the op-amp output. The solution turns out to be shunting the voltage divider lower resistor to bring the virtual ground close to 2.0 volts (see section 6.1).
  - **Digital Clipping**. The Mayhew ADC can be set to either a 5 volt or a 10 V digitization range. The default software setting is to use the 5 volt range which results in more resolution (counts per volt). Programs **SEIS16Rv2.cpp** and **A16.ino** can be modified to the 10 volt range for large signals (see section 6.3).

- **Signal too Weak**. The other extreme opposite of clipping. Either add another pre-amp stage or a source with more energy.

6 Modifications

Some improvements to the original plan became apparent with a bit of testing. For this discussion, the pre-amplifier and anti-alias filter module will be referred to as the pre-amp.

1. **Pre-amp output bias** observed when a test signal was clipped. Shunting the lower resistor in the virtual signal ground addressed that problem, shifting the virtual ground below 2.5 volts for a 5 volt pre-amp supply.

2. **Adding a second alternative DC power supply** for the pre-amp permitted recording with both the 5 volt and 10 volt ranges on the Mayhew ADC. The 5 volt range powers the pre-amp with the Laptop via the USB. The 10 volt range requires an external battery to realize any benefit (caution, max is 16 volt for Op-amps). I picked 9 volts for setting a second bias shunt resistor. A DPDT toggle switch permits switching both pre-amp supply and shunt resistors. Figure 8 shows the modification.

3. **Recording DC signals**. DC signals are not recorded with the original software which removed the mean of the recorded signal. This was addressed by adding a BIAS variable which permits using a measured constant voltage. This involved adding a chassis ground banana plug socket (black) on the panel so that the voltage of the virtual ground (white) can be measured without opening the case.

4. **Switch to UNIPOLAR** option of the Mayhew. Unsigned integers are now transfered to the Laptop where either the subtraction of the mean or the constant voltage **BIAS** are subtracted to produce a bipolar final result. Why? Because all signals are positive above chassis ground. Permits an extra bit of resolution and slightly faster conversions than BIPOLAR mode.

6.1 Pre-amp Output Bias

The pre-amp virtual ground was chosen mid-way between the supply rails. This choice resulted in the output signal being biased slightly toward the higher voltage rail. A test signal was applied to note where analog clipping began. The result produced analog clipping on the peak of a sine wave test signal before clipping on the trough. Figure 7 (A) shows the situation, the clipped sine wave exhibits more clipping on the peaks than the troughs.

Modification. A shunt was applied across the lower 10K resistor of the voltage divider that produced a virtual ground. The virtual signal ground was shifted from 2.5 volts down to about 2.0 volts (actually 1.949 volts). The shunt is a 20 turn 50K potentiometer (set to 16.47 K Ω). This modification affects all 8 channels simultaneously since they share a common virtual signal ground. Figure 7 (B) shows the change on the recorded signal.

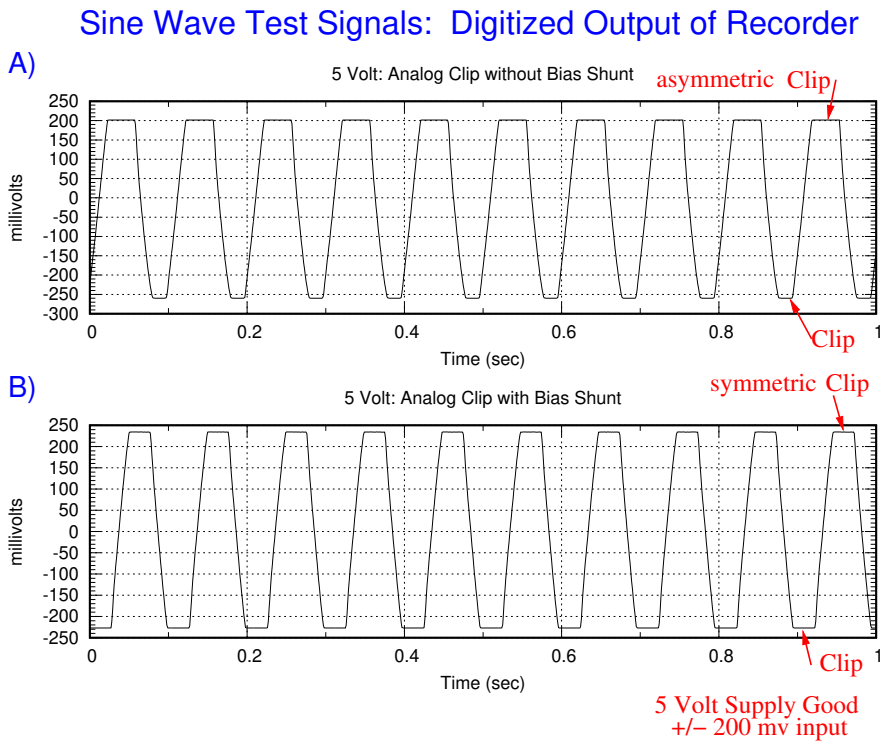

Figure 7: Input exceeds $\pm$ 200 *mv*. A) Sine wave amplitude clips asymmetrically, B) Sine wave clips symmetrically with bias resistor. Mayhew set for 5V range in this instance.

6.2 Adding Second Pre-amp Power Supply

The initial concept was to use the USB wire from the Laptop to power the pre-amp. As long as the input signal's amplitude does not exceed $\pm$200 *mv*, this works well. Recall that the current design is UNIPOLAR, range setting 5 volts on the Mayhew. The modifications include adding a 2.1 mm male panel jack to provide an alternative pre-amp DC power. A double pole double throw (DPDT) toggle switch permits switching between the USB and the external battery. With a 9 volt external battery, we also need a different shunt resistor to increase the virtual ground voltage with respect to the chassis ground. See lower right area of Figure 8. Again, a 20 turn, 50 K potentiometer is used, this time set for 23.35 $K\Omega$. This raises the virtual ground voltage to +3.874 volts. This voltage can be measured between the virtual ground (white banana plugs) and the chassis ground (black banana plug, new).

NOTE: In order to use the 9 volt battery, you should recompile and install the software for the 10 volt range. See section 6.3 on how to change the range from 5 volts to 10 volts on the Mayhew.

6.3 Modification Of Software, 5V to 10V Range

One can change the program codes to permit a larger input, but this will only become effective if an external 9 Volt battery powers the pre-amplifier (rather than the Arduino 5 volt supply via the USB). One can also do this for a 12 volt external battery, but the bias shunt resistor will need to be changed for the higher voltage.

- **Arduino Code: A16.ino**. Comment out lines 30 and 31 with double slashes at the beginning of the lines. Uncomment out lines 32 and 33 (remove the double slashes). This will reset the ADC to the 10 volt range. You then must compile with the `"make"` and `"make upload"` commands (see section 3.2).
- **Laptop Code: SEIS16Rv2.cpp**. Comment out line 41 with double slashes and uncomment in line 42 by removing the double slashes. Recompile (see section 3.2) and install.

With the above changes, you should be able to digitize input signals with a maximum amplitude of $\pm$ 400 *mv* instead of $\pm$ 200 *mv*.

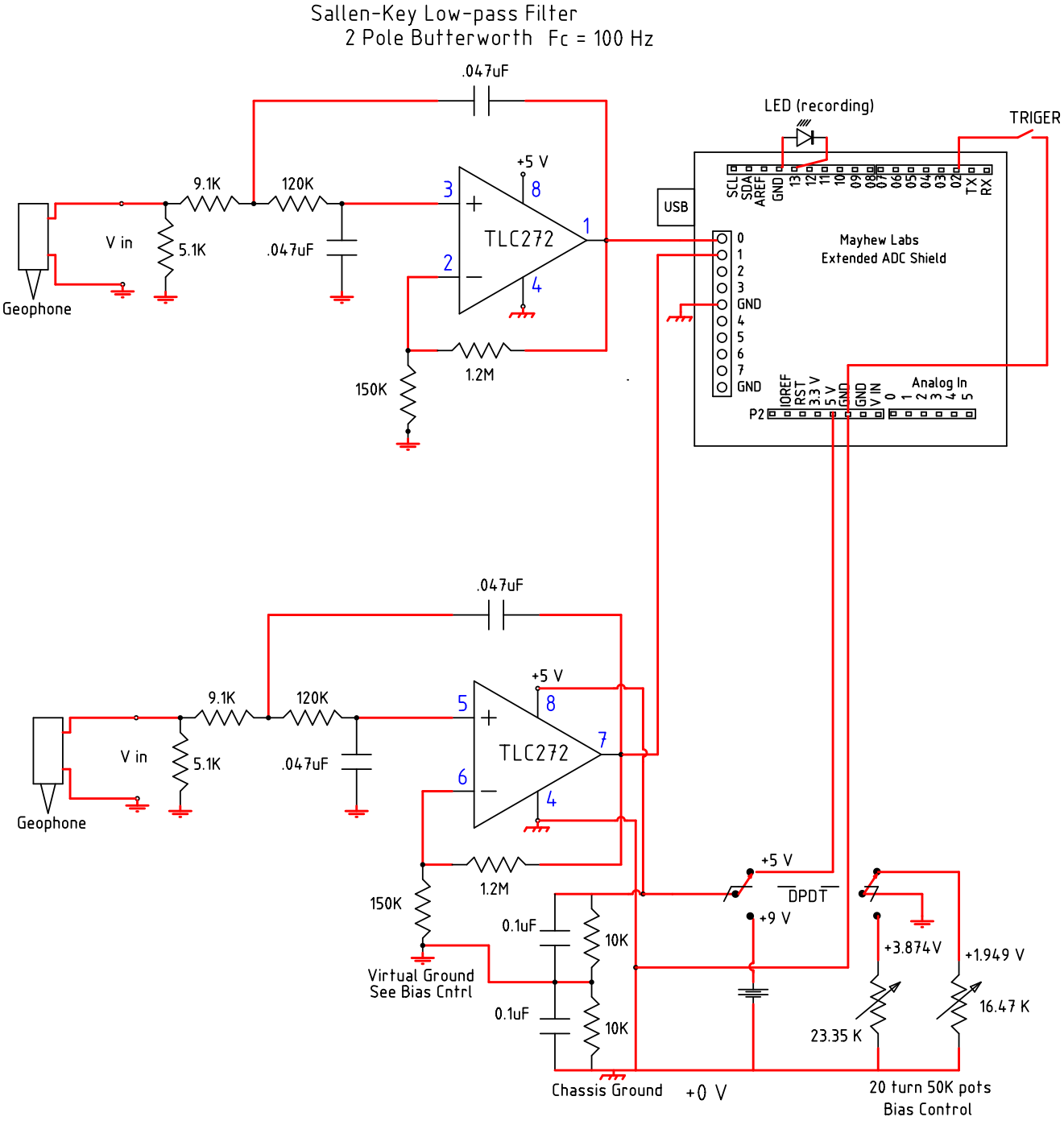

Figure 8: Modifications applied to pre-amp. The shunt on the 10K-10K voltage divider sets the bias. A DPDT toggle switch permits alternative voltages to power the pre-amp and simultaneously switch bias resistors which shunt virtual to chassis ground. To capture DC, edit the **BIAS** parameter in SEIS16v2.cpp to match in microvolts the corresponding bias value (see 6.6.1).

6.4 Test Signals, Unipolar and Range Impact

With the change to UNIPOLAR Mayhew calls and the alternative power supply for the pre-amp, test signals were used to fully understand the choices that are required.

Figure 9 (A) illustrates the 5V range setting employed with a $\pm$ 200mv input signal, bias resistor set at 16.47 $K\Omega$. The virtual ground is at 1.949 volts above chassis ground. The gain for a 10 Hz signal is 19 dbV (factor of 8.9125). Thus the peak input voltage becomes 1.782 + 1.949 = 3.731 volts at the analog to digital converter (ADC). This will not be clipped with a 5V range. The minimum voltage presented to the ADC will be 0.166 volts. This will not be clipped. The software backs out the gain for the plot and storing the data in the SEG-2 file.

Figure 9 (B) illustrates how analog clipping results with a larger amplitude signal ($\pm$ 400mv). The virtual ground voltage is the same as in (A) and the peak voltage after gain presented to the ADC is 3.564 + 1.949 = 5.513 volts. This exceeds the supply rail for the pre-amp filter. It is analog clipping because it happens before the signal reaches the ADC. The evidence for analog clipping will be values that fluctuate in a small ripple about the clipped maximum.

Figure 9 (C) shows digital clipping that occurs with the larger, 9 volt supply voltage for the pre-amp. The virtual ground is now 3.874 volts, and we calculate the voltage at the ADC as 3.564 + 3.874 = 7.438 volts, and this will NOT clip in the pre-amp for which the supply rail is now at 9.000 volts. However, since the ADC range is set to 5V, this will become digitally clipped. If one looks at the values, the evidence for digital clipping is exactly the same values (no fluctuation around the clipped value). CAUTION: If the battery voltage is not regulated, then as the battery becomes discharged, the virtual ground voltage changes, making the above calculations approximate for a fresh battery. There is no clip at the low values since the minimum will be about 3.564 -3.874 = -.31 volts. The plot shows this as just below -300 mv. The other thing to remember is that the mean value is subtracted before plotting and writing to a SEG-2 formatted file. The mean for a clipped signal will be shifted from what it would be for an unclipped signal.

Figure 9 (D) shows how recompiling the codes for a 10V range permits avoiding clipping all together for a $\pm$ 400mv signal.

6.5 Mayhew Floating Point to Integer for USB and SEG-2 Files

The Mayhew provides floating point voltages converted from the 16 bit ADC. The Arduino software, A16.ino, undoes this so that 16 bit unsigned integers can be sent over the USB. The relevant lines are 28-33, 62, 63, 68-70, 76-80, 174-183, 189-194.

The variable **ch0** is returned as a float from the Mayhew ADC. Relevant constants are diff and imax. These are computed:

```
061: //const int imax=pow(2,Nbits-1);  // 2^Nbits-1 since bipolar
062: const unsigned int imax=(unsigned int) pow(2,Nbits);  // 2^Nbits since Unipolar
063: const float diff = RNG/(float) imax;  // volts/count
```

I included line 61 for those who might want to do bipolar conversions, but it is commented out here. The float is converted to integer as follows:

```
179:   ch0=extendedADCShield.analogReadConfigNext(kk, SINGLE_ENDED, UNIPOLAR, Range);
180:   fcounts = ch0/diff;  // fcounts is volts/(volts/count)
181:   value = round(fcounts);
182:   return(value);
. . . .
193:    Serial.write(lowByte(value));
194:    Serial.write(highByte(value));
```

The 16 bit integers are sent to the laptop. Program SEIS16Rv2.cpp then converts these integers to microvolts. Relevant codes in SEIS16Rv2.cpp are:

```
095:     const unsigned int imax = floor(pow((double)2.,(double)(Nbits)));
096:     const float diff = RNG/(float)imax;  //volts/count
097:     float mvolts;
```

```
098:     int    microvolts;
. . . .
247:          read(serialfd,&Lbyte,1);
248:   ivalue=Lbyte;
249:   read(serialfd,&Hbyte,1);
250:   ivalue=Hbyte*256+ivalue;
251:          mvolts = ((float)(ivalue) * diff)*1000.0;
252:   microvolts = floor( (mvolts * 1000.0 +.5)) ;
```

The integer value microvolts is what will be written to the SEG-2 file. If there is a vertical stack, microvolts are accumulated in RAM variable s1[]. The array s1[] is then written to the output file after removing either the mean value or a constant.

```
260:  s1[sendcount] = microvolts + s1[sendcount];
. . . .
349:  WriteSEG2(nsamp,nchannels,fsamin,s1,ybase,fname,nstack,source,phones,nSP,
350:  sx,rx);
```

The SEG-2 headers include a value that converts the integer to millivolts. This computation uses the fixed gain of the preamp, FG.

```
845:  sprintf(STRING,"  SAMPLE_INTERVAL %.6f  ",fsamin);
846:  /* Arduino A/D -->SEIS16v2 s1[] is in microvolts, SEG-2 Standard
847:  requires a descaling factor applied to the SEG-2 data which will
848:  yield mvolts */
849:  writestring(STRING,RES,LTC,h1);
850:
851:     DSF = 1.000 / (1000. * pow((double) 10., (double) ((float) FG)/20.0));
852:  sprintf(STRING,"  DESCALING_FACTOR %14.7E  ",DSF);
853:  writestring(STRING,RES,LTC,h1);
```

The program you use to read SEG-2 files will matter, depending on the target file format. My egg2seg program converts to my bsegy processing format. The code, egg2seg, recognizes what factor would result in millivolts, but chooses to write files in microvolts since that retains the precision in converting to floats (bsegy format). For more on this topic, see my Basic Seismic Utilities (BSU) processing package available on my documentation and download pages.

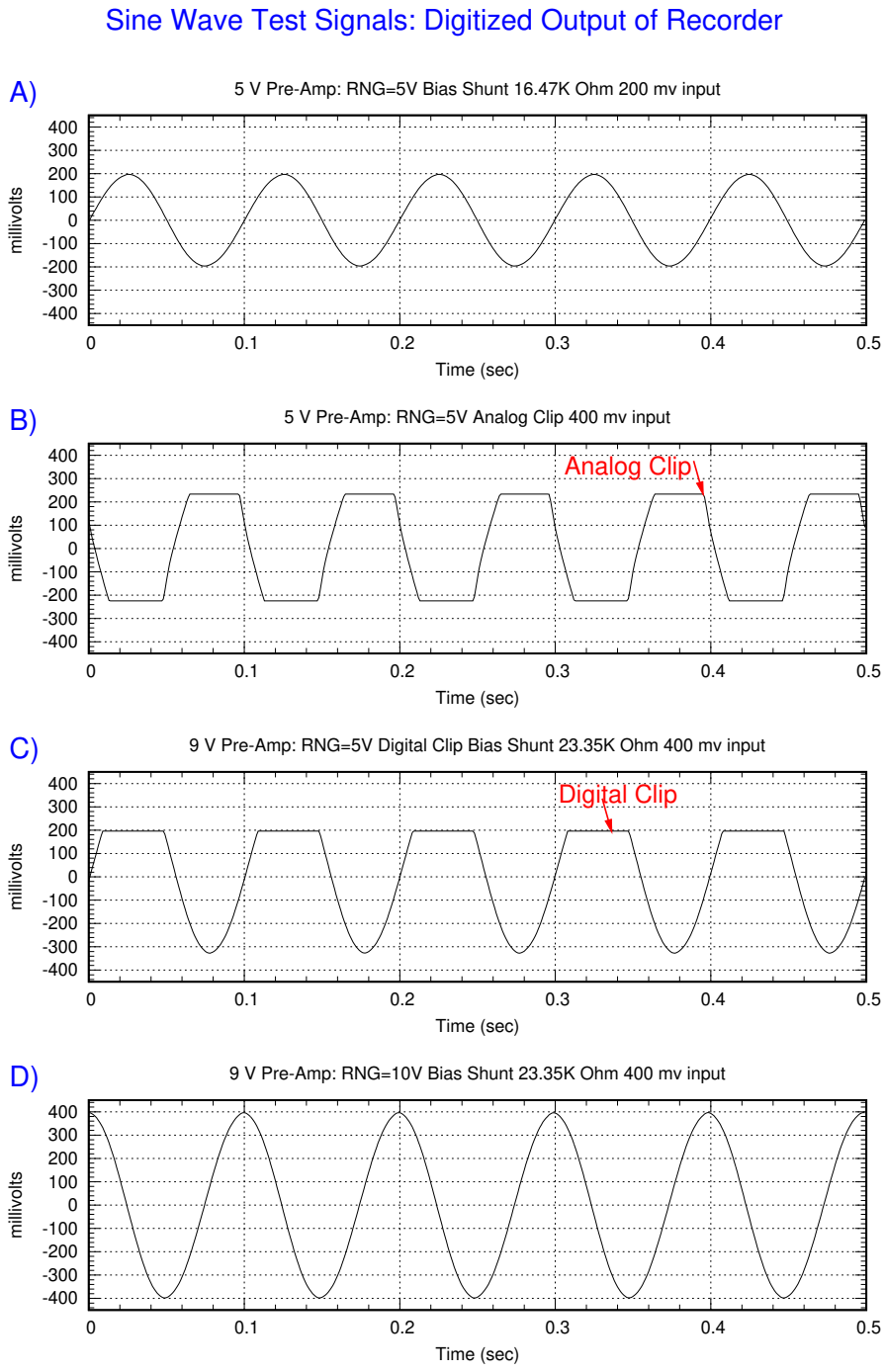

Figure 9: Case DC not recorded, mean removed. A) Recording a 10 Hz $\pm$ 200*mv* signal using 5 volt pre-amp supply, software range RNG=5V. B) Recording, increasing amplitude of input to $\pm$ 400*mv* illustrates analog clipping. C) Switching to 9 volt alternative battery for pre-amp but RNG=5V, clipping now digital. This requires recompiling software for range RNG=10V. D) Neither analog or digital clipping with the larger software range (RNG=10V) and alternative 9 volt battery.

6.6 Recording DC (0 Hz Frequency) Signals

While geophones and sources do not produce DC signals, recording with a short temporal aperture of a low frequency signal may introduce a recording that has a DC bias. The default setting in the software removes the mean before displaying or saving recordings to a file. See functions **meanval()** and **saveplot()** in the laptop program **SEIS16v2.cpp** for the relevant code. For example, consider recording a low frequency sine wave with an aperture time of half a cycle. Subtracting the mean value will shift the result. Or, maybe you want to use the recorder for another application where DC content is important. Here is how that is done.

6.6.1 Modifications

First, I have edited the original **meanval()** function to permit an alternative return value of a constant. This constant is the voltage in microvolts of the difference between the virtual signal ground and the chassis ground. The variable name for this value is **BIAS**. There are also changes to **saveplot()**. **IMPORTANT: This value will vary with the supply voltage of the pre-amp**. Consider the alternatives of the laptop 5 volts vs. a 9 volt external battery. To make the determination of this value easy, I added an additional banana plug socket (black) to the panel that brings the chassis ground to the top of the panel. A digital volt meter is then used to measure the voltage between the chassis ground (black) and the virtual signal ground (white). With my electronics, the values measured in microvolts were:

- **5 Volt Laptop Pre-amp Supply**: BIAS = 1949000 microvolts (1.949 volts)
- **9 Volt Battery Pre-amp Supply**: BIAS = 3874000 microvolts (3.874 volts)
- **Original Default (remove DC)**: BIAS = 0 (this is a switch to remove the mean and not record DC.

These values depend on the shunt applied to the voltage divider to center the output signal between the supply rails (see section 6.4 and Figure 9). NOTE: The default setting in the code is to remove DC. So to record DC, you need to edit the BIAS value for your intended pre-amp supply voltage, recompile, and then make install. See lines 112 to 114 in the appendix, **SEIS16v2.cpp**. The modified panel is shown in Figure 10.

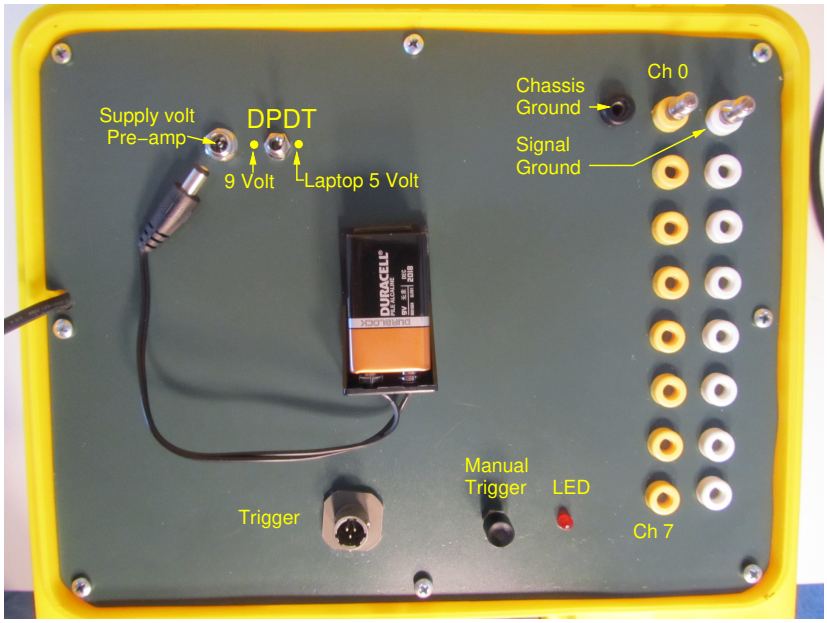

Figure 10: Modified Panel. DC BIAS is measured between chassis and signal grounds (black and white banana plug sockets). Convert voltage to microvolts for **BIAS** constant in SEIS16Rv2.cpp to record DC signals. Recommend voltage regulation for external power source stability (particularly if recording DC is an objective).

References

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Pullan, S. E. 1990. Recommended standard for seismic (/radar) data files in the personal computer environment. *Geophysics*, **55**(9), 1260–1271.

Tedeschi, F. P. 1979. *The Active Filter Handbook*. Tab Books.

Various. 2019. *GCC, the GNU Compiler Collection*. https://gcc.gnu.org/.

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7 Software Appendix

One should download the software archive, **SeisR-1.0.0.tgz** since it includes the libraries not listed here. **The line numbers (start of a line, xxx:) are given for reference, should not be included if you cut and paste from these listings.**

7.1 Arduino, A16.ino

7.1.1 Makefile

```
001: # Arduino Make file. Refer to https://github.com/sudar/Arduino-Makefile
002: # Some commands:
003: # type make
004: # type make upload
005: # type make clean
006:
007: BOARD_TAG    = uno
008: OPTIMIZATION_LEVEL = 3
009:
010: #include ../../Arduino.mk
011: include /usr/share/arduino/Arduino.mk
```

7.1.2 A16.ino

```
001: //   $Id: A16.ino,v 1.10 2019/04/02 23:00:47 pm Exp $
002: /* |-----------------------------------------------------------|
003:    |A16.ino     Seismic Recorder Arduino program               |
004:    |Author: Dr. P. Michaels, PE <pmsolid@cableone.net>         |
005:    |or <paulmichaels@boisestate.edu>                           |
006:    |  NOTICE:                                                  |
007:    |  Copyright (C) 2019 Paul Michaels                         |
008:    |  This program is free software; you can                   |
009:    |  redistribute it and/or modify it under the terms         |
010:    |  of the GNU General Public License as published           |
011:    |  by the Free Software Foundation; either version          |
012:    |  3 of the License, or (at your option) any later          |
013:    |  version.  This program is distributed in the             |
014:    |  hope that it will be useful, but                         |
015:    |  WITHOUT ANY WARRANTY; without even the implied           |
016:    |  warranty of MERCHANTABILITY or FITNESS FOR A             |
017:    |  PARTICULAR PURPOSE.  See the GNU General Public          |
018:    |  License for more details.                               |
019:    |  You should have received a copy of the GNU               |
020:    |  General Public License along with this program;          |
021:    |  If not, see <https://www.gnu.org/licenses/>              |
022:    |-----------------------------------------------------------|
023:  */
024: // UNIPOLAR VERSION
025: #include <ExtendedADCShield.h>
026: #include <SPI.h>
027:
028: #define nchar 20
029: #define Nbits 16
030: #define Range RANGE5V   /*Set RNG to match Range choice */
031: #define RNG 5.  // +/- volts
032: //#define Range RANGE10V   /*Set RNG to match Range choice */
033: //#define RNG 10.  // +/- volts
034:
```

```
035: //       optimization "s", IDE
036: //const float slope = 479.0;   // overhead in microseconds
037: //const float intercept = 393.5;  // slope*k + intercept
038: //       desktop dell
039: //       optimization "3", make file
040: //const float slope = 453.2857; // overhead in microseconds
041: //const float intercept = 376.7142; // slope*k + intercept
042: //       opt = 3 blue dell laptop
043: const float slope = 448.7142;  // overhead in microseconds
044: const float intercept = 374.2857; // slope*k + intercept
045: unsigned int shft =0;
046: int i,j,k;                    // k= number channels
047: int trig = LOW;
048: int nsamp;
049: unsigned int ndt;  //sample interval in microseconds
050: char buf[nchar];
051: char nsampbuf[nchar];
052: char ndtbuf[nchar];
053: char nchbuf[nchar];
054: //String S ;          /*dummy string to clear serial for next trigger  */
055: char ch;
056:
057:
058:
059: const int ledPin = 13;
060: const int inputPin = 2;
061: //const int imax=pow(2,Nbits-1);  // 2^Nbits-1 since bipolar
062: const unsigned int imax=(unsigned int) pow(2,Nbits);  // 2^Nbits since Unipolar
063: const float diff = RNG/(float) imax;  // volts/count
064:
065: //Initialize the ADC Shield with default pins and 16-bit ADC (LTC1858)
066: ExtendedADCShield extendedADCShield(Nbits);
067:
068: float ch0;
069: unsigned int value;
070: float fcounts;
071: int armed = 1;
072: const long DELAY = 1000;
073: int fieldx;
074: int parm[3];
075:
076: // Prototype functions----------------------------------------------------
077: unsigned int getvalue(int m);
078: int SampleSendValues(int m);
079: void sendBinary(unsigned int value);
080: void sendBinary(long value);
081:
082: // SETUP-----------------------------------------------------------------
083: void setup() {
084:   Serial.begin(115200, SERIAL_8N1);
085:   pinMode(ledPin, OUTPUT);
086:   pinMode(inputPin, INPUT);
087:   digitalWrite(inputPin,HIGH);  /*turn on pull up resistor for trigger pin 2
088:                                 trigger by shorting pin 2 to ground  */
089:   digitalWrite(ledPin,LOW);
090:   //SPI.begin must be called here on Due only
091:   SPI.begin();
092:   //Throw out first read (junk data) and configure input 0 as single ended bipolar -5 to +5V
093:   extendedADCShield.analogReadConfigNext(0, SINGLE_ENDED, UNIPOLAR, Range);
```

```
094:  // while(ch=Serial.read() >= 0) ; //flush the receive buffer
095:   Serial.setTimeout(DELAY);
096:
097: } //end setup
098:
099: // LOOP----------------------------------------------------------------------
100: void loop() {
101:
102:       if ( Serial.available() >= (nchar - 1) ) {
103:  for (fieldx =0; fieldx < 3; fieldx++)
104:  {
105:  parm[fieldx] = Serial.parseInt(); //get a parameter
106:  } //next fieldx
107:
108:  nsamp = parm[0];
109:  ndt = parm[1];
110:  k = parm[2];
111: /*          S= Serial.readString();
112:           S.toCharArray(buf,nchar);
113:           for (i=0; i<5; i++) nsampbuf[i]=buf[i];      // 99999 99999 99999
114:           for (i=6; i<11; i++) ndtbuf[i-6]=buf[i];    //  5 digits with space between
115:           for (i=12; i<17; i++) nchbuf[i-12]=buf[i];
116:           nsamp = atoi(nsampbuf);
117:           ndt = atoi(ndtbuf);
118:           k = atoi(nchbuf);
119: */
120:             shft = ceil((slope*(float) k ) + intercept); //shft = overhead
121:             if (ndt > shft) {
122:             ndt = ndt - shft;  //subtract extra code overhead
123:             } //endif extra
124:
125:             Serial.print('H');
126:
127:
128:   /*
129:           Serial.println(nsamp);
130:           Serial.println(ndt);
131:           Serial.println(k);
132:           Serial.println(shft);
133:  */
134:
135:           } //end if serial available
136:
137:
138:
139:           i = 0;
140:           if (armed == 1) {
141:           trig = digitalRead(inputPin);
142:           }
143:            if (trig == HIGH)  {
144:              digitalWrite(ledPin,LOW);
145:            } else {
146:              digitalWrite(ledPin,HIGH);
147:      //       Serial.flush();
148:
149:             long int starttime=millis();
150:
151:             armed = SampleSendValues(k);
152:
```

```
153:             long duration = millis() - starttime;
154:
155:
156:   //          Serial.print('q');              /* send done signal */
157:
158:             sendBinary(duration);  /* send long value  */
159:      Serial.flush();
160:    //        Serial.println(" ");
161:    //        Serial.print(duration);
162:    //        Serial.flush();
163:    //        S = Serial.readString();
164:         /* clear serial line read into dummy string
165:                                          and turn off TX, otherwise next trigger
166:                                          will pick up garbage left in serial line*/
167:
168:          } //end Trigger loop
169:          armed = 1;
170:          trig = HIGH;
171:
172: }  //endloop
173:
174: // GETVALUE FUNCTION-----------------------------------------------------------------------
175: unsigned int getvalue(int kk)
176: {
177:   //Read input 0, set up input 0 as bipolar -RNG to RNG Volts (single ended neg goes to ground)
178:   // bipolar relative to board ground +/-RNG volts
179:   ch0 =  extendedADCShield.analogReadConfigNext(kk, SINGLE_ENDED, UNIPOLAR, Range);
180:   fcounts = ch0/diff;  // fcounts is volts/(volts/count)
181:   value = round(fcounts);
182:   return(value);
183: }  //end getvalue
184:
185: // SAMPLE SEND VALUES FUNCTION-------------------------------------------------------------
186: int SampleSendValues(int k)
187: {
188:   int kk;
189:   for (j=0; j<nsamp; j++) {
190:      extendedADCShield.analogReadConfigNext(0, SINGLE_ENDED, UNIPOLAR, Range);
191:     for (kk = 0; kk<k; kk++) {
192:   value = getvalue(kk+1);
193:    Serial.write(lowByte(value));
194:    Serial.write(highByte(value));
195: // Serial.print(lowByte(value));
196: // Serial.print(" ");
197: // Serial.print(highByte(value));
198: // Serial.print(" ");
199: // Serial.println(value);
200:     }
201: //Serial.println(value);
202:   if (ndt <= 10000)  {
203:   delayMicroseconds(ndt);                   /* delay ndt microsec.  */
204:   } else {
205:   delay(ndt/1000);                               /*delay msec */
206:   } //endif
207:   } //next j
208:   return(0);
209: }
210:
211: // SEND BINARY FUNCTIONS-------------------------------------------------------------------
```

```
212: void sendBinary(int value)
213: {
214:  Serial.write(lowByte(value)); //send low byte
215:  Serial.write(highByte(value)); //send high byte
216: }
217: //-------------------------------------------------------------------------------------------
218: void sendBinary(long value)
219: {
220:   //first send the low 16 bit integer value
221:   int temp = value & 0xFFFF;  //get value of lower 16 bits
222:   sendBinary(temp);
223:   // then send the higher 16 bit integer value:
224:   temp = value >>16; //get higher 16 bits
225:   sendBinary(temp);
226: }
```

7.2 Laptop Software

The line numbers (start of a line, xxx:) are given for reference, should not be included if you cut and paste from these listings.

7.2.1 Makefile

```
001: # Makefile for C++ Arduino serial USB com and Arduino control
002: # $Id: Makefile,v 1.4 2019/02/11 19:52:48 pm Exp $
003: # Paul Michaels <pmsolid@cableone.net> OR <paulmichaels@boisestate.edu>
004: PREFIX = /usr/local
005: EXEC=  Status SEIS16v2
006:
007: all: $(EXEC)
008:
009: SEIS16v2: SEIS16v2.cpp
010:  g++ -g -Wall SEIS16v2.cpp -o SEIS16v2
011:
012: Status: Status.cpp
013:  g++ -g -Wall Status.cpp -o Status
014:
015: install: ${EXEC}
016:  install Status ${PREFIX}/bin
017:  install SEIS16v2 ${PREFIX}/bin
018:  install seisR.tk ${PREFIX}/bin
019:
020: clean:
021:  rm -f Status
022:  rm -f SEIS16v2
023:
024: uninstall:
025:  rm -f ${PREFIX}/bin/Status
026:  rm -f ${PREFIX}/bin/SEIS16v2
027:  rm -f ${PREFIX}/bin/seisR.tk
```

7.2.2 seisR.tk (GUI)

This file will be installed when Makefile is run with the command, `make install`.

```
001: #!/usr/bin/wish
002: # $Id: seisR.tk,v 1.7 2019/02/18 14:52:21 pm Exp $
003: #   |-----------------------------------------------------------|
004: #   |seisR.tk    Seismic Recorder Requires TCL/TK installed     |
005: #   |Author: Dr. P. Michaels, PE <pmsolid@cableone.net>         |
006: #   |or <paulmichaels@boisestate.edu>                          |
007: #   |-----------------------------------------------------------|
008:
009: set MSG1 "  NOTICE:
010:   Copyright (C) 2019 Paul Michaels
011:   <pmsolid@cableone.net>
012:   This program is free software; you can
013:   redistribute it and/or modify it under the terms
014:   of the GNU General Public License as published
015:   by the Free Software Foundation; either version
016:   3 of the License, or (at your option) any later
017:   version.  This program is distributed in the
018:   hope that it will be useful, but
019:   WITHOUT ANY WARRANTY; without even the implied
020:   warranty of MERCHANTABILITY or FITNESS FOR A
021:   PARTICULAR PURPOSE.  See the GNU General Public
022:   License for more details.
023:   You should have received a copy of the GNU
024:   General Public License along with this program.
025:   If not, see <https://www.gnu.org/licenses/> "
026:
027: wm maxsize . 1000 800
028: wm minsize . 300 300
029: wm title . "Seismic Recorder"
030:
031: #set bgc #ffffddddbbbb
032: #set bgc2 #bbbbdddd0000
033: set bgc gray90
034: set bgc2 gray90
035: set armc red
036: set ltred #ffffbbbbbbbb
037:
038: #set fNumber
039: if { [info exists fNumber] }  {incr fNumber 0001} else {set fNumber 0000}
040: #set  spN
041: if { [info exists spN] }  {incr spN 0} else {set spN 0000}
042: #set  sx
043: if { [info exists sx] }  {incr sx 0} else {set sx 0}
044: #set r$ix
045: for {set i 0} {$i < 8 } {incr i +1} {
046: if { [info exists rx$i ]} {incr rx$i 0} else {set rx$i [expr $i+1]}
047: }
048:
049: # MASTER RECORDING FRAME
050: grid [frame .m -borderwidth 4 -relief ridge -padx 1  -bg $bgc ] -row 0 -column 0
051: # MASTER PLOT FRAME
052: grid [frame .p -borderwidth 4 -relief ridge -padx 1  -bg $bgc ] -row 1 -column 0
053:
054: # NUMBER SAMPLES
055: grid [frame .m.nsamp -borderwidth 4 -relief sunken -padx 1  -bg $bgc ] -row 0 -column 0
056: grid [label .m.nsamp.label1 -text "Number of samples" -bg $bgc ] -row 0 -column 1
```

```
057: grid [radiobutton .m.nsamp.b1 -text " 500" -variable nsampl -value "500" -bg $bgc ] \
058:  -row 1 -column 1
059: grid [radiobutton .m.nsamp.b2 -text "1000" -variable nsampl -value "1000" -bg $bgc ] \
060:  -row 2 -column 1
061: grid [radiobutton .m.nsamp.b3 -text "2000" -variable nsampl -value "2000" -bg $bgc ] \
062:  -row 3 -column 1
063: grid [radiobutton .m.nsamp.b4 -text "3000" -variable nsampl -value "3000" -bg $bgc ] \
064:  -row 4 -column 1
065: grid [radiobutton .m.nsamp.b5 -text "4000" -variable nsampl -value "4000" -bg $bgc ] \
066:  -row 5 -column 1
067: grid [radiobutton .m.nsamp.b6 -text "5000" -variable nsampl -value "5000" -bg $bgc ] \
068:  -row 6 -column 1
069: .m.nsamp.b1 select
070:
071: # NUMBER OF CHANNELS
072: grid [frame .m.nch -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 0 -column 2
073: grid [label .m.nch.label1 -text "No. Channels" -bg $bgc2 ] -row 1 -column 0
074: grid [radiobutton .m.nch.b1 -text "1 " -variable nch -value "1" -bg $bgc2 \
075: -command ".m.ndt.b1 select"  ] -row 2 -column 0
076: grid [radiobutton .m.nch.b2 -text "2 " -variable nch -value "2" -bg $bgc2 \
077: -command ".m.ndt.b2 select" ] -row 3 -column 0
078: grid [radiobutton .m.nch.b3 -text "3 " -variable nch -value "3" -bg $bgc2 \
079: -command ".m.ndt.b2 select"  ] -row 4 -column 0
080: grid [radiobutton .m.nch.b4 -text "4 " -variable nch -value "4" -bg $bgc2 \
081: -command ".m.ndt.b3 select"  ] -row 5 -column 0
082: grid [radiobutton .m.nch.b5 -text "5 " -variable nch -value "5" -bg $bgc2 \
083: -command ".m.ndt.b3 select"  ] -row 2 -column 1
084: grid [radiobutton .m.nch.b6 -text "6 " -variable nch -value "6" -bg $bgc2 \
085: -command ".m.ndt.b4 select"  ] -row 3 -column 1
086: grid [radiobutton .m.nch.b7 -text "7 " -variable nch -value "7" -bg $bgc2 \
087: -command ".m.ndt.b4 select"  ] -row 4 -column 1
088: grid [radiobutton .m.nch.b8 -text "8 " -variable nch -value "8" -bg $bgc2 \
089: -command ".m.ndt.b5 select"  ] -row 5 -column 1
090: .m.nch.b1 select
091:
092: # SAMPLE INTERVAL
093: grid [frame .m.ndt -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 0 -column 1
094: grid [label .m.ndt.label1 -text "Sample Interval" -bg $bgc2 ] -row 0 -column 1
095: grid [radiobutton .m.ndt.b1 -text "1 ms" -variable ndt -value "1000" -bg $bgc2 ] -row 1 -column 1
096: grid [radiobutton .m.ndt.b2 -text "2 ms" -variable ndt -value "2000" -bg $bgc2 ] -row 2 -column 1
097: grid [radiobutton .m.ndt.b3 -text "3 ms" -variable ndt -value "3000" -bg $bgc2 ] -row 3 -column 1
098: grid [radiobutton .m.ndt.b4 -text "4 ms" -variable ndt -value "4000" -bg $bgc2 ] -row 4 -column 1
099: grid [radiobutton .m.ndt.b5 -text "5 ms" -variable ndt -value "5000" -bg $bgc2 ] -row 5 -column 1
100: .m.ndt.b1 select
101:
102: # VERTICAL STACK
103: grid [frame .m.stk -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 0 -column 3
104: grid [label .m.stk.label1 -text "Vertical Stack" -bg $bgc2 ] -row 1 -column 1
105: grid [radiobutton .m.stk.b1 -text " 1" -variable stk -value "1" -bg $bgc2 ] -row 2 -column 1
106: grid [radiobutton .m.stk.b2 -text " 2" -variable stk -value "2" -bg $bgc2 ] -row 3 -column 1
107: grid [radiobutton .m.stk.b3 -text " 5" -variable stk -value "5" -bg $bgc2 ] -row 4 -column 1
108: grid [radiobutton .m.stk.b4 -text "10 " -variable stk -value "10" -bg $bgc2 ] -row 5 -column 1
109: .m.stk.b1 select
110:
111: # SOURCE HEADER
112: grid [frame .m.src -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 0 -column 4
113: grid [label .m.src.label1 -text "Source Header" -bg $bgc2 ] -row 1 -column 1
114: grid [radiobutton .m.src.b1 -text "Hammer      " -variable src -value "H" -bg $bgc2 ] \
115:  -row 2 -column 1
```

```
116: grid [radiobutton .m.src.b2 -text "Weight Drop" -variable src -value "W" -bg $bgc2 ] \
117:  -row 3 -column 1
118: grid [radiobutton .m.src.b3 -text "Dynamite     " -variable src -value "D" -bg $bgc2 ] \
119:  -row 4 -column 1
120: grid [radiobutton .m.src.b4 -text "Gun            " -variable src -value "G" -bg $bgc2 ] \
121:  -row 5 -column 1
122: grid [radiobutton .m.src.b5 -text "Vibrator       " -variable src -value "V" -bg $bgc2 ] \
123:  -row 6 -column 1
124: .m.src.b1 select
125:
126: # SOURCE NAME
127: grid [frame .m.sloc -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 0 -column 5
128: grid [label .m.sloc.label1 -text "SP Number"  -bg $bgc2 ] -row 1 -column 1
129: grid [entry .m.sloc.myEntry -relief ridge -bg $bgc2 \
130: -width 4 -textvariable spN -justify left ] -row 3 -column 1
131: grid [button .m.sloc.b1 -text "Zero" -command {set spN 0}  -bg $bgc2 -relief raised] \
132:  -row 4 -column 1
133:
134: # STATUS FRAME
135: grid [frame .m.stat -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 1 -column 0
136: grid [label .m.stat.label1 -text "USB Connection Status" -bg $bgc2 ] -row 2 -column 0
137: grid [button .m.stat.b1 -text "Check" \
138:  -command {set msg1 [exec Status]; MSG $msg1 } -bg $bgc -relief raised] -row 3 -column 0
139:
140: # DATA FILE NAME FRAME
141: grid [frame .m.data -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 1 -column 1
142: grid [label .m.data.label1 -text "Data File Number"  -bg $bgc2 ] -row 1 -column 1
143: grid [entry .m.data.myEntry -relief ridge -bg $bgc2 \
144: -width 4 -textvariable fNumber -justify left ] -row 3 -column 1
145: grid [button .m.data.b1 -text "Zero" -command {set fNumber 0000} -bg $bgc2 -relief raised]\
146:  -row 4 -column 1
147:
148: # ARM BUTTON
149: grid [frame .m.arm -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 1 -column 2
150: grid [label .m.arm.label1 -text "         Arm Recorder" -bg $bgc2 ] -row 2 -column 2
151:
152: grid [button .m.arm.b1 -text "ARM" \
153:  -command {catch {clearplots}; set msg2  \
154: [ exec SEIS16v2 $nsampl $ndt $nch $stk $fNumber \
155:  $src $r0$r1$r2$r3$r4$r5$r6$r7 $spN $sx \
156:  $rx0 $rx1 $rx2 $rx3 $rx4 $rx5 $rx6 $rx7 ];  \
157:   ARMCMD $msg2 ; incr fNumber 1 ; goplot "plot$pchnl.png" $bgc2 }  \
158:  -activebackground red -bg $ltred -relief raised] -row 3 -column 2
159: grid [button .m.arm.b2 -text "Clear" \
160:  -command {set msg2 " "; ARMCMD $msg2}] -row 3 -column 3
161:
162: #QUIT BUTTON
163: grid [frame .m.exit -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 1 -column 3
164: grid [button .m.exit.b1 -text "Quit" -command exit -bg $ltred -activebackground lightgreen \
165:  -relief raised ] -row 1 -column 0
166:
167: # GEOPHONE HEADER
168: grid [frame .m.rec -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 1 -column 4
169: grid [label .m.rec.label1 -text "Phones" -bg $bgc2 ] -row 0 -column 1
170: for { set i 0; set m 0} { $i < 8} {incr i +1; incr m +3} {
171: set ROWH [expr 1+$i]
172: set j [expr 1+$m]
173: set k [expr 2+$m]
174: grid [label .m.rec.bb$i -text "Ch$i" -bg $bgc2] -row $ROWH -column 0
```

```
175: grid [radiobutton .m.rec.b$m -text "V" -variable r$i -value "V" -bg $bgc2 ] \
176:  -row $ROWH  -column 1
177: grid [radiobutton .m.rec.b$j -text "R" -variable r$i -value "R" -bg $bgc2 ] \
178:  -row $ROWH  -column 2
179: grid [radiobutton .m.rec.b$k -text "T" -variable r$i -value "T" -bg $bgc2 ] \
180:  -row $ROWH  -column 3
181: }
182: .m.rec.b0 select
183: .m.rec.b4 select
184: .m.rec.b8 select
185: .m.rec.b9 select
186: .m.rec.b13 select
187: .m.rec.b17 select
188: .m.rec.b18 select
189: .m.rec.b21 select
190:
191: # GEOMETRY
192: grid [frame .m.geom -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 1 -column 5
193: grid [label .m.geom.label1 -text "Geometry"  -bg $bgc2 ] -row 1 -column 0
194: grid [label .m.geom.sX -text "S-xcord" -bg $bgc2] -row 2 -column 0
195: grid [entry .m.geom.myEntryS -relief ridge -bg $bgc2 \
196: -width 4 -textvariable sx -justify left ] -row 2 -column 1
197: # Receivers
198: for { set i 0} { $i < 8} {incr i +1} {
199: set ROW [expr 3+$i]
200: grid [label .m.geom.rX$i -text "R$i-xcord" -bg $bgc2] -row $ROW -column 0
201: grid [entry .m.geom.myEntryR$i -relief ridge -bg $bgc2 \
202: -width 4 -textvariable rx$i -justify left ] -row $ROW -column 1
203: }
204:
205: # COPYRIGHT MESSAGE BUTTON
206: grid [frame .m.about -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 2 -column 0
207: grid [button .m.about.b1 -text "About" -command {GPL $MSG1} -bg lightgrey \
208:  -activebackground lightgreen -relief raised ] -row 0 -column 0
209:
210:
211: # SELECT CHANNEL TO PLOT
212: grid [frame .p.chnl -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 0 -column 0
213: grid [label .p.chnl.label1 -text "Plot Channel" -bg $bgc2 ] -row 0 -column 0
214: grid [radiobutton .p.chnl.b1 -text "1" -variable pchnl -value "0" -bg $bgc2 \
215:   ] -row 1 -column 1
216: grid [radiobutton .p.chnl.b2 -text "2" -variable pchnl -value "1" -bg $bgc2 \
217: -command ".m.nch.b2 select"    ] -row 1 -column 2
218: grid [radiobutton .p.chnl.b3 -text "3" -variable pchnl -value "2" -bg $bgc2 \
219: -command ".m.nch.b3 select"  ] -row 1 -column 3
220: grid [radiobutton .p.chnl.b4 -text "4" -variable pchnl -value "3" -bg $bgc2 \
221: -command ".m.nch.b4 select"  ] -row 1 -column 4
222: grid [radiobutton .p.chnl.b5 -text "5" -variable pchnl -value "4" -bg $bgc2 \
223: -command ".m.nch.b5 select"  ] -row 1 -column 5
224: grid [radiobutton .p.chnl.b6 -text "6" -variable pchnl -value "5" -bg $bgc2 \
225: -command ".m.nch.b6 select"  ] -row 1 -column 6
226: grid [radiobutton .p.chnl.b7 -text "7" -variable pchnl -value "6" -bg $bgc2 \
227: -command ".m.nch.b7 select"  ] -row 1 -column 7
228: grid [radiobutton .p.chnl.b8 -text "8" -variable pchnl -value "7" -bg $bgc2 \
229: -command ".m.nch.b8 select"  ] -row 1 -column 8
230: .p.chnl.b1 select
231: grid [button .p.chnl.b11 -text "Erase Plots" -command  {catch {clearplots}} \
232:  -bg $ltred -activebackground red  -relief raised] -row 1 -column 10
233: grid [button .p.chnl.b21 -text "Replot" -command  {catch {goplot "plot$pchnl.png" $bgc2}} \
```

```
234:  -bg yellow -relief raised] -row 1 -column 9
235:
236: # FORM ARM COMMAND FOR SEIS16
237: proc ARMCMD msg2 {
238: destroy .m.arm.value
239: label .m.arm.value -text "$msg2"
240: grid .m.arm.value -row 4 -column 2
241: }
242:
243: # CHECK STATUS CONNECTION
244: proc MSG msg1 {
245: destroy .m.stat.value
246: if { $msg1 == "Not Connected" } {set scolor red} else {set scolor lightgreen}
247: grid [label .m.stat.value -text "$msg1" -bg $scolor  ] -row 4 -column 0
248: }
249:
250: # DISPLAY RECORDING IMAGE
251: proc goplot {filename bgc2} {
252: destroy .p.img
253: grid [frame .p.img  -borderwidth 4 -relief sunken -padx 2 -bg $bgc2 ] -row 2 -column 0
254: image create photo imgobj -file $filename -width 640 -height 240
255: grid [label .p.img.imgobj ] -row 1 -column 0
256: .p.img.imgobj configure -image imgobj
257: }
258:
259: proc clearplots {} {
260: eval exec rm [glob *.png]
261: }
262:
263: proc GPL {MSG1} {
264: toplevel .gpl
265: grid [frame .gpl.about -borderwidth 4 -relief sunken -padx 2 -bg white ] -row 0 -column 0
266: grid [message .gpl.about.m1 -width 20c -justify left -bg white -text $MSG1 ] -row 0 -column 0
267: grid [button .gpl.about.b1 -text "OK" -command {destroy .gpl} -bg lightgrey \
268:  -activebackground lightgreen -relief raised ] -row 1 -column 0
269:
270: }
```

7.2.3 Status.cpp

To capture the serial settings with the IDE and Arduino plugged in, use the command:
`stty -F /dev/ttyACM0 -a`

```
001: //   $Id: Status.cpp,v 1.5 2019/02/17 22:29:00 pm Exp $
002: /* |-------------------------------------------------------------|
003:    |Status.cpp  Seismic Recorder called by TK Program            |
004:    |Author: Dr. P. Michaels, PE <pmsolid@cableone.net>           |
005:    |or <paulmichaels@boisestate.edu>                             |
006:    |  NOTICE:                                                    |
007:    |  Copyright (C) 2019 Paul Michaels                           |
008:    |  This program is free software; you can                     |
009:    |  redistribute it and/or modify it under the terms           |
010:    |  of the GNU General Public License as published             |
011:    |  by the Free Software Foundation; either version            |
012:    |  3 of the License, or (at your option) any later            |
013:    |  version.  This program is distributed in the               |
014:    |  hope that it will be useful, but                           |
015:    |  WITHOUT ANY WARRANTY; without even the implied             |
016:    |  warranty of MERCHANTABILITY or FITNESS FOR A               |
```

```
017:    |  PARTICULAR PURPOSE.  See the GNU General Public           |
018:    |  License for more details.                                 |
019:    |  You should have received a copy of the GNU                |
020:    |  General Public License along with this program;           |
021:    |  If not, see <https://www.gnu.org/licenses/>               |
022:    |-------------------------------------------------------------|
023:  */
024: #include <termios.h>
025: #include <cstdio>
026: #include <cstring>
027: #include <string.h>
028: #include <unistd.h>
029: #include <fcntl.h>
030: #include <errno.h>
031: #include <stdlib.h>
032: #include <time.h>
033:
034:  short debug = 1;
035:  short serialfd;
036:  struct termios attribs;
037:     char deviceserial[] = "/dev/ttyACM0";
038:  speed_t speed;
039:  short usbnumber = 0;
040:
041: //prototypes
042:  void  setusb(short usbnumber);
043:
044: int main () {
045:  if (access("/dev/ttyACM0",F_OK) != -1 ) {
046:  sprintf(deviceserial,"/dev/ttyACM0");
047:  usbnumber = 0;
048:  puts("Device: ttyACM0"); }
049:
050:
051:  if (access("/dev/ttyACM1",F_OK) != -1 ) {
052:  sprintf(deviceserial,"/dev/ttyACM1");
053:  usbnumber = 1;
054:  puts("Device: ttyACM1"); }
055:
056:  if (usbnumber == 0 || usbnumber == 1) {
057:  serialfd = open(deviceserial,O_RDWR | O_NOCTTY | O_NDELAY);
058:  if (serialfd == -1) {
059:  puts("Not Connected");
060:  return (0);
061:  //fprintf(stdout,"ABORT failed to open port \n");
062:  } //endif
063:  }
064:  else {
065:  puts("Device Not found");
066:  return(0);
067:  } //endif
068:
069: /* Set USB */
070:  setusb(usbnumber);
071:
072: /* Check that serialfd points to a TTY device */
073:  if(!isatty(serialfd)) {
074:  fprintf(stdout,"ABORT, not TTY\n");
075:  return(0); } //endif
```

```
076:
077: /* get the current settings */
078:  if(tcgetattr(serialfd, &attribs) < 0) {
079:  fprintf(stdout,"ABORT, can not get configuration\n");
080:  return(0);} //endif
081:
082:
083: if(debug !=0 ) {
084:  speed = cfgetispeed(&attribs);
085:  if (speed == 4098) puts("BAUD: 115200");
086: // fprintf(stdout,"input speed: %lu\n", (unsigned long) speed);
087: // speed = cfgetospeed(&attribs);
088: // fprintf(stdout,"output speed: %lu\n", (unsigned long) speed);
089: // puts("---------------\n");
090:  } //endif
091:
092:   return(0);
093: } //endmain
094:
095: void  setusb(short usbnumber) {
096: char command0[] = "stty -F /dev/ttyACM0 -parenb -parodd -cmspar cs8 115200 \
097:   -hupcl -cstopb cread clocal -crtscts \
098: -ignbrk brkint ignpar -parmrk -inpck -istrip -inlcr -igncr -icrnl ixon -ixoff \
099: -iuclc -ixany -imaxbel -iutf8 \
100: -opost -olcuc -ocrnl -onlcr -onocr -onlret -ofill -ofdel nl0 cr0 tab0 bs0 vt0 ff0 \
101: -isig -icanon iexten -echo echoe echok -echonl -noflsh -xcase -tostop -echoprt \
102: echoctl echoke -flusho -extproc";
103: char command1[] = "stty -F /dev/ttyACM1 -parenb -parodd -cmspar cs8 115200 \
104:   -hupcl -cstopb cread clocal -crtscts \
105: -ignbrk brkint ignpar -parmrk -inpck -istrip -inlcr -igncr -icrnl ixon -ixoff \
106: -iuclc -ixany -imaxbel -iutf8 \
107: -opost -olcuc -ocrnl -onlcr -onocr -onlret -ofill -ofdel nl0 cr0 tab0 bs0 vt0 ff0 \
108: -isig -icanon iexten -echo echoe echok -echonl -noflsh -xcase -tostop -echoprt \
109: echoctl echoke -flusho -extproc";
110:  if (usbnumber == 0) {
111:  system(command0);}
112:  else {
113:  system(command1);}
114: } //endsetusb
```

7.2.4 SEIS16Rv2.cpp

```
001: // $Id: SEIS16v2.cpp,v 1.6 2019/03/29 22:06:55 pm Exp $
002: /* |-------------------------------------------------------------|
003:    |SEIS16v2.cpp  Seismic Recorder called by TK Program          |
004:    |Author: Dr. P. Michaels, PE <pmsolid@cableone.net>           |
005:    |or <paulmichaels@boisestate.edu>                             |
006:    |  NOTICE:                                                    |
007:    |  Copyright (C) 2019 Paul Michaels                           |
008:    |  This program is free software; you can                     |
009:    |  redistribute it and/or modify it under the terms           |
010:    |  of the GNU General Public License as published             |
011:    |  by the Free Software Foundation; either version            |
012:    |  3 of the License, or (at your option) any later            |
013:    |  version.  This program is distributed in the               |
014:    |  hope that it will be useful, but                           |
015:    |  WITHOUT ANY WARRANTY; without even the implied             |
016:    |  warranty of MERCHANTABILITY or FITNESS FOR A               |
017:    |  PARTICULAR PURPOSE.  See the GNU General Public            |
```

```
018:    |  License for more details.                                  |
019:    |  You should have received a copy of the GNU                 |
020:    |  General Public License along with this program;            |
021:    |  if not, write to the Free Software Foundation,             |
022:    |  Inc., 675 Mass Ave, Cambridge, MA 02139, USA.              |
023:    |-------------------------------------------------------------|
024:  */
025: // UNIPOLAR VERSION
026: #include <stdio.h>
027: #include <termios.h>
028: #include <cstdio>
029: #include <cstring>
030: #include <string.h>
031: #include <unistd.h>
032: #include <fcntl.h>
033: #include <errno.h>
034: #include <stdlib.h>
035: #include <time.h>
036: #include <math.h>
037: #include <float.h>
038: #include <sys/ioctl.h>
039: #define nchar 20
040: #define Nbits 16
041: #define RNG 5.0 //set for +/- 5 Volts (Arduino RANGE5V)
042: //#define RNG 10.0 //set for +/- 10 Volts (Arduino RANGE10V)
043: #define BLOCKLEN 1900 // if hangs at bytes_avail, then decrease BLOCKLEN
044:
045:
046:
047: //Function Prototypes
048:  int   setprop(int serialfd, struct termios attribs, short debug);
049:  int   CheckDTnchan(int ndt, int nchannels);
050:  int   getparm(int argc,char *argv[],
051:          int *nsamp, int *ndt, int *nchannels, int *nstack,
052:  int *fnum, char *source, char *phones, short *nSP,float *sx,
053:  float rx[]);
054:  float Time(int *sendcount, int nchannels,int ndt, int *tmod,
055:  int *tcount);
056:  int  saveplot (int y[], int npts, int nchannels, int ndt, int chnl, int BIAS );
057:  int  meanval(int y[],int npts, int sendcount, int nchannels, int chnl, int BIAS) ;
058:  void writestring(char STRING[], char RES, char LTC,FILE *h1);
059:  int  WriteSEG2(int npts, int nchnl, float fsamin, int s1[],
060:       int ybase[], char ofile[], int stack, char source[],char phones[],
061:       short nSP, float sx, float rx[]);
062:
063: int main(int argc, char *argv[]) {
064:     struct termios attribs;
065:     short serialfd;
066:
067:     char snd[nchar+1];
068:     char c;
069:     int  i;
070:     unsigned short  ivalue= 0;
071:     short ivalueLow;
072:     short ivalueHigh;
073:     int  lvalue = 0;
074:     int nsamp;
075:     int ndt;
076:     int icount=0;
```

```
077:     int istop=0;
078:     int nstack = 1;
079:     int nchannels = 1;
080:     char fname[10];
081:     unsigned char Lbyte;
082:     unsigned char Hbyte;
083:     short debug = 0;
084:     int fnum = 0;
085:     int chnl; //channel number to plot
086:     float fsamin;
087:     short nSP;
088:     float sx;
089:     float rx[8];
090:
091: //    clock_t start,stop;
092: //    float deltexe;
093:     char deviceserial[] = "/dev/ttyACM0";
094:     //const int imax = floor(pow((double)2.,(double)(Nbits-1)));
095:     const unsigned int imax = floor(pow((double)2.,(double)(Nbits)));
096:     const float diff = RNG/(float)imax;  //volts/count
097:     float mvolts;
098:     int    microvolts;
099:     int   mspace;
100:     int  *s1;
101: int bytes_avail;
102: int sendcount = -1;
103: int block = 0;
104: int left = 0;
105: int nmax  ;
106: short iard;
107: int ybase[8];
108: char source[2];
109: char phones[10];
110:
111: /* Alternative Recording of Data with or without DC level
112: Set BIAS to virtual ground value in Microvolts above chassis ground */
113:
114: int BIAS = 0;  //if BIAS == 0 then compute mean and subtract, no DC saved
115: //int BIAS = 1949000; // BIAS used instead of mean value, DC saved 5Volt case
116: //int BIAS = 3874000; // BIAS used instead of mean value, DC saved 9Volt case
117:
118:
119:  if (access("/dev/ttyACM0",F_OK) != -1 ) {
120:  sprintf(deviceserial,"/dev/ttyACM0");
121:  //fprintf(stdout,"Serial Device = /dev/ttyACM0 \n");
122:  }
123:
124:  if (access("/dev/ttyACM1",F_OK) != -1 ) {
125:  sprintf(deviceserial,"/dev/ttyACM1");
126:  //fprintf(stdout,"Serial Device = /dev/ttyACM1 \n");
127:  }
128:
129: // open serial port
130:  serialfd = open(deviceserial,O_RDWR | O_NOCTTY | O_NDELAY);
131:  if (serialfd == -1) {
132:  fprintf(stderr,"ABORT failed to open port \n");
133:  } //endif
134:
135:
```

```
136: // set serial properties
137:        if (setprop(serialfd, attribs, debug) != 0) {
138:  perror(" setprop failure"); }
139:
140: //start loop
141:  while (istop != 1) {
142:
143:
144: // Send number of samples to arduino
145: // fprintf(stdout,"Clocks per second = %ld \n",CLOCKS_PER_SEC);
146:      if (icount == 0) {
147:
148: // blank snd array
149:  for (i=0; i<nchar; i++) {
150:  snd[i]=' ';
151:  }
152:  snd[nchar]='\0';
153:
154:  if(getparm(argc,argv,&nsamp,&ndt,&nchannels,&nstack,&fnum,
155:  source,phones,&nSP,&sx,rx) !=0) return(1);
156:
157:   nmax = nsamp*nchannels ;
158:
159: // ndt =sample interval in microseconds
160:  fsamin = ((float) ndt)/1.E6;
161:         sprintf(fname,"%4.4d.DAT",fnum);
162:
163: // Allocate RAM for recording
164:  mspace = nsamp*nchannels;
165:  s1 = (int*) calloc(mspace,sizeof(int));
166:            if(s1==NULL)
167:          {
168:           fprintf(stderr,"ABORT:s1 can't allocate enough RAM \n");
169:           fprintf(stderr," npts = %d",mspace);
170:           return(1);
171:          }
172:
173: // Zero out s1
174:  for (i=0; i<mspace; i++) s1[i]=0;
175:
176: // Check overhead for specified sample interval
177:  ndt = CheckDTnchan(ndt,nchannels);
178:  if (ndt == 0) {
179:  puts("ABORT !! sample interval channel error");
180:  return (1);}
181:
182:         if(debug !=0 ) fprintf(stderr,"ndt =%d  nchannels=%d \n",ndt,nchannels);
183:
184:  sprintf(snd,"%5.5d %5.5d %5.5d",nsamp,ndt,nchannels);
185:  snd[nchar-1]='\n';
186:  snd[nchar]='\0'; }
187:  else {
188:  sprintf(snd,"%5.5d %5.5d %5.5d",nsamp,ndt,nchannels);
189:  snd[nchar-1]='\n';
190:  snd[nchar]='\0';
191: // puts("ready for trigger ");
192:      } //endif
193:
194: //        fprintf(stdout,"snd=:%s \n",snd);
```

```
195:
196: //send paramaters to Arduino
197:  if(write(serialfd,&snd,nchar) < 0) {
198:  perror("failed to write");
199:  }
200:  if(debug !=0) fprintf(stdout,"snd = %s \n",snd);
201: //----------------------------test code------------------------
202:
203:  iard =0;
204:  while (iard ==0) {
205:  ioctl(serialfd,FIONREAD,&bytes_avail);
206:  if (bytes_avail >= 0) {
207:          read(serialfd,&c,1);
208:  if (c == 'H' ) {
209:     //fprintf(stdout,"%2.2d Arduino Ready:  ",icount);
210:     fprintf(stdout,"Stack %2.2d: ",icount+1);
211:  iard=1;
212:  }
213:  }
214:  } //endwhile
215:
216: //----------------------------test code------------------------
217:
218:
219: // puts("ready for trigger ");
220:
221: i=0;
222: Hbyte=0;
223: Lbyte=0;
224: c='N';
225:  sendcount = -1;
226:  block = 0;
227:  left = 0;
228:  nmax = nsamp*nchannels ;
229: // check if more than buffer bytes to send
230:  if (nmax > BLOCKLEN) {
231:  block = BLOCKLEN;
232:  left = nmax - BLOCKLEN;}
233:  else {
234:  block =nmax;
235:  left = 0; }
236:
237:   while(c !='q')   // Receive from Arduino until 'q' received
238:   {
239:
240:
241:  ioctl(serialfd,FIONREAD,&bytes_avail);
242: // fprintf(stderr,"available =%d \n",bytes_avail);
243:
244:          if (bytes_avail >= 2*block )   // check how many bytes available
245:         {
246:  for (i=0; i<block; i++) {
247:          read(serialfd,&Lbyte,1);
248:   ivalue=Lbyte;
249:   read(serialfd,&Hbyte,1);
250:   ivalue=Hbyte*256+ivalue;
251:          mvolts = ((float)(ivalue) * diff)*1000.0;
252:   microvolts = floor( (mvolts * 1000.0 +.5)) ;
253:
```

```
254: //**    stime=Time(&sendcount,nchannels,ndt,&tmod,&tcount);
255:  sendcount = sendcount + 1;
256: //      stime=((float) (tcount-1) * ndt)/1E6; // time (seconds)
257: //      fprintf(h1," %f %f \n",stime,mvolts);
258: //**    fprintf(h1," %f %8.8ld \n",stimfsamine,microvolts);
259: //      fprintf(h1," %f %d \n",stime,ivalue);
260:  s1[sendcount] = microvolts + s1[sendcount];
261:
262:  } // next i
263:
264: //      fprintf(stderr,"left = %d",left);
265:  if (left == 0) {
266:  c = 'q'; } //endif
267:
268:  if (left >BLOCKLEN) {
269:  left = left - BLOCKLEN;
270:  block = BLOCKLEN;} //do another block of samples
271:  else {
272:  block = left;
273:  left = 0;} //endif
274:
275:         } //endif bytes_avail
276:  }  //end while c !='q'
277:  if(debug != 0) fprintf(stderr,"finished q \n");
278:
279: // Get duration in msec
280:  bytes_avail=0;
281:         while (bytes_avail < 4) {
282:  ioctl(serialfd,FIONREAD,&bytes_avail);
283:  }
284: //         if (bytes_avail == 4) {
285:  if(debug != 0) fprintf(stderr,"bytes avail=%d \n",bytes_avail);
286: // Lower 16 bits
287:          read(serialfd,&Lbyte,1);
288:   ivalue=Lbyte;
289:   read(serialfd,&Hbyte,1);
290:   ivalueLow=Hbyte*256+ivalue;
291: // Higher 16 bits
292:          read(serialfd,&Lbyte,1);
293:   ivalue=Lbyte;
294:   read(serialfd,&Hbyte,1);
295:   ivalueHigh=Hbyte*256+ivalue;
296:
297:   lvalue = ivalueHigh << 16;
298:   lvalue =ivalueLow + lvalue;
299:
300:
301:  fprintf(stdout,"Record Length %d (msec) \n",lvalue);
302: // } //endif 4 bytes
303:
304:
305:
306:    if(debug !=0 ) fprintf(stdout," %d Samples Read by SEIS16v2 \n",sendcount);
307:    icount += 1;
308:    if(icount > nstack-1 ) istop =1;
309:
310:
311:  } //end while istop !=1
312:
```

```
313: // Open Output File
314:  icount = 0;
315: /*
316:         sprintf(fname,"%8.8d.dat",fnum);
317:  FILE *h1;
318:  if ( (h1=fopen(fname,"w"))==NULL)
319:         {
320:           printf("\n ABORT !! Error opening output.dat");
321:           exit(1);
322:         }
323:
324: // write from RAM to a file
325:  int stime;
326:  int tmod;
327:  int tcount;
328:  sendcount=-1;
329:  for (i = 0; i < (nmax); i++)
330:  {
331:  stime=Time(&sendcount,nchannels,ndt,&tmod,&tcount);
332:         fprintf(h1," %f %8.8d \n",stime,s1[i]);
333:  } //next sendcount
334:    fclose(h1);
335: */
336: // find mean value each channel
337:  for (chnl =0; chnl < nchannels; chnl++) {
338:  sendcount = -1;
339:  ybase[chnl] = meanval(s1,nmax,sendcount,nchannels,chnl,BIAS);
340: //fprintf(stderr,"meanval = %d \n",ybase[chnl]);
341:  }
342:
343:
344: // write from RAM to a file
345: /*NOTE:  WriteSEG2 removes mean from data so SEG-2 file will have traces with
346:  zero mean. If run before saveplot(), the plotx.png files will also be
347:  without mean. If you want to see the mean, move saveplot() loop (below) above
348:  WriteSEG2() call.  */
349:  WriteSEG2(nsamp,nchannels,fsamin,s1,ybase,fname,nstack,source,phones,nSP,
350:  sx,rx);
351:
352: // write plot files (channel numbers 0 to 7).  Move above WriteSEG2 to show mean
353:  for (chnl = 0; chnl < nchannels; chnl ++) {
354:  saveplot (s1,nmax,nchannels,ndt,chnl,BIAS);
355:  } //next chnl
356:
357: //   read(serialfd,&c,1);
358:    close(serialfd);
359:    free(s1);
360:     return 0;
361: } //end main
362:
363:
364: float Time(int *sendcount, int nchannels, int ndt, int *tmod, int *tcount)
365:         {
366:   float stime;
367:   *sendcount = *sendcount + 1;
368:   *tmod = *sendcount % nchannels;
369:   if (*tmod == 0)
370:  {*tcount=*tcount + 1 ;}
371:          stime=((float) (*tcount-1) * ndt)/1E6; // time (seconds)
```

```
372:   return(stime);
373:  }  //end Time
374:
375:
376:
377: //------------SETPROP FUNCTION-----------------------------------
378: int setprop(int serialfd, struct termios attribs, short debug)
379: {
380:  speed_t speed;
381:
382:
383: /* Check that serialfd points to a TTY device */
384:  if(!isatty(serialfd)) {
385:  fprintf(stderr,"ABORT, not TTY\n");
386:  return(1); } //endif
387:
388: /* get the current settings */
389:  if(tcgetattr(serialfd, &attribs) < 0) {
390:  fprintf(stderr,"ABORT, can not get configuration\n");
391:  return(1);} //endif
392:
393: if(debug !=0 ) {
394: // debug print structure
395:  fprintf(stderr,"GET TERMIOS STRUCTURE\n");
396:  fprintf(stderr,"c_iflag: %08x \n",attribs.c_iflag);
397:  fprintf(stderr,"c_oflag: %08x \n",attribs.c_oflag);
398:  fprintf(stderr,"c_cflag: %08x \n",attribs.c_cflag);
399:  fprintf(stderr,"c_lflag: %08x \n",attribs.c_lflag);
400:  fprintf(stderr,"c_cc[NCCS]: %08x \n",attribs.c_cc[NCCS]);
401:  } //endif
402:
403:
404: // turn off input processing
405:  attribs.c_iflag &= ~(IGNBRK | BRKINT | ICRNL |
406:  INLCR | PARMRK | INPCK | ISTRIP | IXON);
407:
408: // No line processing
409:  attribs.c_lflag &= ~(ECHO | ECHONL | ICANON | IEXTEN | ISIG);
410:
411: // Turn off character processing
412:  attribs.c_cflag &= ~(CSIZE | PARENB);
413:  attribs.c_cflag |= CS8;
414:
415: // One byte is enought to return from read
416:  attribs.c_cc[VMIN] = 1;
417:  attribs.c_cc[VTIME] = 0;
418:
419: /* set the baudrate */
420: cfsetospeed(&attribs, B115200); /* outut baudrate */
421: cfsetispeed(&attribs, B115200); /* input baudrate */
422: //cfsetospeed(&attribs, 4096); /* outut baudrate */
423: //cfsetispeed(&attribs, 4096); /* input baudrate */
424:
425: if(debug !=0 ) {
426: // debug print structure
427:  fprintf(stderr,"\nSETTING TERMIOS STRUCTURE\n");
428:  fprintf(stderr,"c_iflag: %08x \n",attribs.c_iflag);
429:  fprintf(stderr,"c_oflag: %08x \n",attribs.c_oflag);
430:  fprintf(stderr,"c_cflag: %08x \n",attribs.c_cflag);
```

```
431:  fprintf(stderr,"c_lflag: %08x \n",attribs.c_lflag);
432:  fprintf(stderr,"c_cc[NCCS]: %08x \n",attribs.c_cc[NCCS]);
433:  } //endif
434:
435:
436: /* if there is need for it, set other settings here */
437:
438: /* eventually apply everything for your serialfd descriptor */
439: //if (tcsetattr(serialfd, TCSANOW, &attribs) < 0)
440: if (tcsetattr(serialfd, TCSANOW, &attribs) < 0)
441: {
442:         perror("stdin");
443:         return(1) ;
444:     }
445:
446: if(debug !=0 ) {
447:  speed = cfgetispeed(&attribs);
448:  fprintf(stderr,"input speed: %lu\n", (unsigned long) speed);
449:  speed = cfgetospeed(&attribs);
450:  fprintf(stderr,"output speed: %lu\n", (unsigned long) speed);
451:  puts("---------------\n");
452:  } //endif
453:
454:
455:   return(0);
456: }  //end setprop
457: //-----------------------------------------------------------------
458:
459: /* Function to check ndt > overhead, optimization 3 on arduino */
460:  int  CheckDTnchan(int ndt, int nchannels)
461:  {
462:  switch (nchannels) {
463:  case 1 :
464:  if (ndt < 1000) return(1000); else return(ndt);
465:  break;
466:  case 2 :
467:  if (ndt < 2000) return(2000); else return(ndt);
468:  break;
469:  case 3 :
470:  if (ndt < 2000) return(2000); else return(ndt);
471:  break;
472:  case 4 :
473:  if (ndt < 3000) return(3000); else return(ndt);
474:  break;
475:  case 5 :
476:  if (ndt < 3000) return(3000); else return(ndt);
477:  break;
478:  case 6 :
479:  if (ndt < 4000) return(4000); else return(ndt);
480:  break;
481:  case 7 :
482:  if (ndt < 4000) return(4000); else return(ndt);
483:  break;
484:  case 8 :
485:  if (ndt < 5000) return(5000); else return(ndt);
486:  default :
487:  return (0);
488:  } //endswitch
489:
```

```
490:  } //end CheckDTnchan
491:
492:  int getparm(int argc, char *argv[],
493:      int *nsamp, int *ndt, int *nchannels, int *nstack, int *fnum,
494:  char source[], char phones[], short *nSP, float *sx,
495:  float rx[])
496:  {
497:  int i;
498:
499:  if (argc == 1 ) {
500:  fprintf(stderr,"USAGE: %s nsamp ndt nchannels nstack file source phones SP SX RX \n",
501:  argv[0]);
502:  puts("Ex: SEIS16v2 1000 5000 8 1 0 H VRTVRTVV 0 5 1 2 3 4 5 6 7 8");
503:  puts("source: H=hammer W=weight_drop D=dynamite G=gun V=vibrator");
504:  puts("phones: V=vertical R=radial T=transverse (8 channels)");
505:  puts("SP: Shot point number, SX Shot point X-coord");
506:  puts("RX: Array of X-coordinates geophones");
507:  return(1); }
508:  else {
509:  if (argc >=2) *nsamp = atoi(argv[1]); else *nsamp = 1000;
510:  if (argc >=3) *ndt = atoi(argv[2]); else *ndt = 1000;
511:  if (argc >=4) *nchannels = atoi(argv[3]); else *nchannels = 1;
512:  if (argc >=5) *nstack = atoi(argv[4]); else *nstack =1;
513:  if (argc >=6 ) *fnum = atoi(argv[5]); else *fnum = 0;
514:  if (argc >= 7) strncpy(source,argv[6],1);
515:  if (argc >= 8) strncpy(phones,argv[7],8);
516:  if (argc >=9) *nSP = atoi(argv[8]); else *nSP = 0;
517:  if (argc >=10 ) *sx = atof(argv[9]); else *sx = 0;
518:  for ( i = 11; i<19; i++) {
519:  if (argc >=i ) rx[i-11] = atof(argv[i-1]); else rx[i-11] = 0;
520:  } //next i
521:  } //end else
522:  return(0);
523:  }  //end getparm
524:
525: // SAVE PLOT-----------------------------------------------------------------
526:  int  saveplot (int y[], int npts, int nchannels, int ndt, int chnl, int BIAS )
527:  {
528:  //y[] is in microvolts
529:  int tmod;
530:  int tcount;
531:  int sendcount;
532:  float stime;
533:  int itrace;
534:  char XL[9]="Time (s)";
535:  char    YL[23]="Amplitude (millivolts)";
536:  char Xwin[4]="png";
537:  char ofile[10];
538:  int   ybase =  0;
539:  int   dscale = 1;
540:  if (BIAS != 0 ) {dscale =1000;}
541:  sendcount = -1;
542:  ybase = meanval(y,npts,sendcount,nchannels,chnl,BIAS)/1000; // mv
543:  sprintf(ofile,"plot%1.1d.png",chnl);
544:  itrace = chnl;
545:  int FG; //fixed gain variable
546:  int DSFI; //descale factor inverse
547: /* Hardwired Gain is 19dbv (the 1000 microvolts to mv in gnuplot pipe) */
548:  FG = 19;
```

```
549:     DSFI = round ( (pow((double) 10., (double) ((float) FG)/20.0)));
550:
551:
552: /*
553:  FILE *h2;
554: //...open output file
555:         if( (h2=fopen(ofile,"w"))==NULL ) {
556:           fprintf(stderr,"\n ABORT !! Error opening file %s",ofile);
557:           return(1); }
558: */
559:
560: //  PIPE VERSION
561:  FILE *h2 =popen("gnuplot ","w");
562:
563:    fprintf(h2,"set grid \n");
564:    fprintf(h2,"set output \"%s\" \n",ofile);
565:    fprintf(h2,"set terminal %s size 640,240  \n",Xwin);
566:    fprintf(h2,"set key left \n");
567:    fprintf(h2,"set xlabel \" %s \" \n",XL);
568:    fprintf(h2,"set ylabel \" %s \" \n",YL);
569: // fprintf(h2,"set yrange [-500:500] \n");
570:  //note plot in mv ($2/1000) and data writen below corrected for k-gain DSFI
571:    fprintf(h2," plot '-' u ($1):($2/1000):($3) lc 'black' w filledc above t '' ,");
572:  fprintf(h2," '' u ($1):($2/1000) lc 'black' w l t \"  Trace %d \" \n",itrace+1);
573:    int j;
574:  tmod =0;
575:  tcount = 0;
576:  sendcount = -1;
577:    for(j=0;j<npts;j++) {
578:  stime=Time(&sendcount,nchannels,ndt,&tmod,&tcount);
579:  //Select chnl
580:  tmod = sendcount % nchannels;
581:  if (tmod == chnl) {
582:      fprintf(h2,"%f %d %d \n",stime,y[j]/DSFI,ybase/dscale);
583:  } //endif
584:    } //next j
585:    fprintf(h2,"e\n");  //this is required when std in - plot
586:  tmod =0;
587:  tcount = 0;
588:  sendcount = -1;
589:   for(j=0;j<npts;j++) {
590:  stime=Time(&sendcount,nchannels,ndt,&tmod,&tcount);
591:  //Select chnl
592:  tmod = sendcount % nchannels;
593:  if (tmod == chnl) {
594:      fprintf(h2,"%f %d %d \n",stime,y[j]/DSFI,ybase/dscale);
595:  } //endif
596:    } //next j
597:    fprintf(h2,"e\n");  //this is required when std in - plot
598:  fclose(h2);
599:  return(0);
600: //...close pipe
601:  fflush(h2);
602:  pclose(h2);
603:  } //end saveplot
604:
605: //COMPUTE MEAN============
606:  int meanval(int y[],int nmax, int sendcount,int nchannels,int chnl, int BIAS) {
607:  int i;
```

```
608:  long sum = 0;  //even though a sample fits, 1000's of samples gets big
609:  int average;
610:  int tmod;
611:  if (BIAS == 0 ) {
612:  for (i=0; i<nmax; i++) {
613:  sendcount = sendcount +1;
614:  tmod = sendcount % nchannels;
615:  if (tmod == chnl) {
616:  sum = sum + y[i];
617:  } //endif
618:  } //next i
619:  average = sum / (nmax/nchannels);
620:  } else {
621:  average = BIAS; }
622:  return(average);
623:  } //end meanval
624:
625: //========================WriteSEG2=============================================
626: int WriteSEG2(int npts, int nchnl, float fsamin, int s1[],
627:   int ybase[],char rawrecord[], int stack, char source[], char phones[],
628:  short nSP, float sx, float rx[])
629: {
630: //...declare variables
631:  time_t            start;
632:  struct tm        *ptr;
633:  char TIME[40], DATE[40];
634: //C++ requires char const, not just char
635:  char const *mon[12]={"Jan","Feb","Mar","Apr","May","Jun",
636:         "Jul","Aug","Sep","Oct","Nov","Dec"};
637:
638:  FILE    *h1;
639:  char ofile[12] ;
640:  int i, k;
641:  unsigned short int ID = 0x3a55;   //bytes 0 1
642:  unsigned short int REV = 1; //bytes 2 3
643:  /* Note: 8 channel recorder, but allow max 10 channels for pointers space
644:  This will permit some zeros for buffer to free format section */
645:  unsigned short int M ;  // size of trace point block NCH*4  //bytes 4 5
646:  unsigned short int NCH   ; // number of channels  //bytes 6 7
647:  char LENST = 0x01; // length of string terminator  (bytes) //byte  8
648:  char ST = 0; //string terminator byte //bytes 9 10
649:  char LT = 0x01; //length of line terminator character (bytes) //byte  11
650:  char LTC = 0x0a; // line terminator //byte  12
651:  char RES = 0x00; //reserved byte //bytes 14-31
652:  int ZERO4 = 0;   //4 byte zero
653:  short int ZERO2 = 0;   //2 byte zero
654:  unsigned short int TDBID = 0x4422;
655:  unsigned long int TPB, LOC1, LOC2, EFDB, EDB;
656:  int CHNL ;
657: // int stack ;
658:  char STRING[40];
659:  int FG; //fixed gain variable
660:  double DSF; //descale factor
661:
662:
663: //...set parameters
664:  char lineid[] = "0001";
665:  sprintf(ofile,"%s",rawrecord);
666:  float ry = 0.0,
```

```
667:  rz = 0.0;
668:  float  sy = 0.0,
669:  sz = 0.0;
670: // stack = 1;
671: // nchnl = 8;
672:
673:  char typerecvr[30];
674:  char typesrc[30];
675: // char source = 'H';
676:  switch (source[0]) {
677:  case 'H':
678:  sprintf(typesrc,"HAMMER");
679:  break;
680:  case 'W':
681:  sprintf(typesrc,"WEIGHT_DROP");
682:  break;
683:  case 'D':
684:  sprintf(typesrc,"DYNAMITE");
685:  break;
686:  case 'G':
687:  sprintf(typesrc,"GUN");
688:  break;
689:  case 'V':
690:  sprintf(typesrc,"VIBRATOR");
691:  break;
692:  default:
693:  sprintf(typesrc,"HAMMER");
694:  }
695:
696:  NCH = nchnl;
697:  CHNL = 0;
698:  M=32;  // NCH * 4 if NCH max = 8
699:
700:  for (i=0; i<40; i++) {
701:  TIME[i] = '\0';
702:  DATE[i] = '\0'; }
703:
704:
705: //...open output file
706:         if( (h1=fopen(ofile,"wb"))==NULL )
707:  {
708:  fprintf(stderr,"\n ABORT !! Error opening file %s",ofile);
709:  return(1);
710:  }
711:
712: //...GET TIME AND DATE
713:       time(&start);
714:       ptr=localtime(&start);
715:       sprintf(TIME,"  ACQUISITION_TIME %2.2u:%2.2u:%2.2u  ",
716:          (*ptr).tm_hour,(*ptr).tm_min,(*ptr).tm_sec);
717:       sprintf(DATE,"  ACQUISITION_DATE %2.2d/%3s/%4.4d  ",
718:          (*ptr).tm_mday,mon[(*ptr).tm_mon],(*ptr).tm_year+1900);
719:
720: //...FILE DESCRIPTOR BLOCK
721:  fwrite(&ID,sizeof(short int),1,h1); //bytes 0,1 ID
722:  fwrite(&REV,sizeof(short int),1,h1); //bytes 2,3 revision number
723:  fwrite(&M,sizeof(short int),1,h1);//bytes 4,5 size trace pointer block
724:  fwrite(&NCH,sizeof(short int),1,h1); //bytes 6,7 number of channels
725:  fwrite(&LENST,sizeof(char),1,h1);  // byte 8 size of ST
```

```
726:  fwrite(&ST,sizeof(char),1,h1); //byte 9   string term char used
727:  fwrite(&ST,sizeof(char),1,h1); //byte 10  2nd string term char
728:  fwrite(&LT,sizeof(char),1,h1); //byte 11  size LTC
729:  fwrite(&LTC,sizeof(char),1,h1); //byte 12 line term char
730:  fwrite(&ST,sizeof(char),1,h1); //byte 13 2nd line term char not used
731:  for (i=14; i<32; i++) {
732:  fwrite(&RES,sizeof(char),1,h1); }
733:
734: //...TRACEPOINTER SUBBLOCK
735: // TPB = ftell(h1);    //capture start of block to come back to later
736:  TPB = (long int) 0x20;
737:  for (i=0; i<8; i++) {
738:  fwrite(&ZERO4,sizeof(int),1,h1);} //zero out pointers to start
739:
740: //...Write Date of acquisition
741:  LOC1=ftell(h1);
742:  writestring(DATE,RES,LTC,h1);
743:
744: //...Write Time of acquisition
745:  writestring(TIME,RES,LTC,h1);
746:
747: //...Write Instrument
748:  sprintf(STRING,"  INSTRUMENT PM_Arduino Mayhew_A/D 01  ");
749:  writestring(STRING,RES,LTC,h1);
750:
751: //...Write Instrument
752:  char UNITS[40];
753:  sprintf(UNITS,"  UNITS METERS  ");
754:  writestring(UNITS,RES,LTC,h1);
755:
756: //...capture end of free format location
757:  EFDB=ftell(h1) - 1 ;
758: // printf("location end of FDB = %0lx \n",EFDB);
759:
760:  EDB = EFDB ;  //not really end of data block first time
761:  // EDB is also start of TDB later on
762:
763: /* START OF TRACE DESCRIPTOR BLOCK ==================================== */
764:
765:  for (k=0; k<nchnl; k++) {
766:
767: //return to trace pointer block start and write LOC2
768:  fseek(h1,TPB+k*4,SEEK_SET);
769:  LOC2= EDB + 1 ;  // add one to point beyond end of FDB or EDB
770:  fwrite(&LOC2,sizeof(int),1,h1);
771:
772:
773: //...Write Trace Descriptor block
774:  fseek(h1,LOC2,SEEK_SET);  //return to start of trace descriptor block
775: //printf("%08lx \n",LOC2);
776:  fwrite(&TDBID,sizeof(short int),1,h1);  //write ID code for TDB
777:
778:  LOC1=ftell(h1);  //start of trace descriptor block just after ID
779:  short int TDBS = ZERO2;
780:  fwrite(&TDBS,sizeof(short int),1,h1); //write zero temporary for block size
781:  int SB = 4*npts; //size of data block in bytes
782:  fwrite(&SB,sizeof(int),1,h1); //size of data block in bytes
783:  int NS = npts;  // number of samples in a data block
784:  fwrite(&NS,sizeof(int),1,h1); //number of samples in data block
```

```
785:  char DFC = 0x02; // Data Format Code for 32 bit integer
786:  fwrite(&DFC,sizeof(char),1,h1);
787:  /* Reserved */
788:
789: /* NOTE Strings must start with 2 spaces to allow offset to next replacement int
790:         and must end with 2 spaces to allow for \0 and \0a replacement (eofs eofl) */
791:  for (i=13; i<32; i++) {
792:  fwrite(&RES,sizeof(char),1,h1);
793:   }
794:  sprintf(STRING ,"  CHANNEL_NUMBER %d  ",CHNL+k);
795:  writestring(STRING ,RES,LTC,h1);
796:
797:  sprintf(STRING,"  ALIAS_FILTER %d %d  ",100,6);
798:  writestring(STRING,RES,LTC,h1);
799:
800:  sprintf(STRING,"  HIGH_CUT_FILTER %d %d  ",100,6);
801:  writestring(STRING,RES,LTC,h1);
802:
803:  FG = 19;  //gain in dBv (change if your instrument different)
804:  sprintf(STRING,"  FIXED_GAIN %d  ",FG);
805:  writestring(STRING,RES,LTC,h1);
806:
807:  sprintf(STRING,"  DELAY %.2f  ",0.);
808:  writestring(STRING,RES,LTC,h1);
809:
810:  sprintf(STRING,"  LINE_ID %s  ",lineid);
811:  writestring(STRING,RES,LTC,h1);
812:
813:  sprintf(STRING,"  RAW_RECORD %s  ",rawrecord);
814:  writestring(STRING,RES,LTC,h1);
815:
816:  switch (phones[k]) {
817:  case 'V':
818:  sprintf(typerecvr,"VERTICAL_GEOPHONE");
819:  break;
820:  case 'T':
821:  sprintf(typerecvr,"T_HORIZONTAL_GEOPHONE");
822:  break;
823:  case 'R':
824:  sprintf(typerecvr,"R_HORIZONTAL_GEOPHONE");
825:  break;
826:  default:
827:  sprintf(typerecvr,"VERTICAL_GEOPHONE");
828:  }
829:
830:  sprintf(STRING,"  RECEIVER %s  ",typerecvr);
831:  writestring(STRING,RES,LTC,h1);
832:
833:  sprintf(STRING,"  SOURCE %s  ",typesrc);
834:  writestring(STRING,RES,LTC,h1);
835:
836:  sprintf(STRING,"  SOURCE_STATION_NUMBER %4.4d  ",nSP);
837:  writestring(STRING,RES,LTC,h1);
838:
839:  sprintf(STRING,"  RECEIVER_LOCATION %.2f %.2f %.2f  ",rx[k],ry,rz);
840:  writestring(STRING,RES,LTC,h1);
841:
842:  sprintf(STRING,"  SOURCE_LOCATION %.2f %.2f %.2f  ",sx,sy,sz);
843:  writestring(STRING,RES,LTC,h1);
```

```
844:
845:  sprintf(STRING,"  SAMPLE_INTERVAL %.6f  ",fsamin);
846:  /* Arduino A/D -->SEIS16v2 s1[] is in microvolts, SEG-2 Standard
847:  requires a descaling factor applied to the SEG-2 data which will
848:  yield mvolts */
849:  writestring(STRING,RES,LTC,h1);
850:
851:     DSF = 1.000 / (1000. * pow((double) 10., (double) ((float) FG)/20.0));
852:  sprintf(STRING,"  DESCALING_FACTOR %14.7E  ",DSF);
853:  writestring(STRING,RES,LTC,h1);
854:
855:  sprintf(STRING,"  STACK %d  ",stack);
856:  writestring(STRING,RES,LTC,h1);
857:
858:  LOC2 = ftell(h1);
859:  TDBS = LOC2 - LOC1 + 2 ;  // add 2 bytes to include ID 0x4422
860:
861: //determine padding if needed for Trace Descriptor Block TDB
862: //...Size, TDBS must be divisible by 4
863:  int pad,p1;
864:  p1=TDBS % 4;
865:  if ( p1 != 0) {
866:  pad = 4-p1;
867:  TDBS = TDBS + pad;
868:  } //endif
869: //printf("pad = %d \n",pad);
870: // printf("Trace Descriptor Block Size (bytes) %d \n",TDBS);
871:  fseek(h1,LOC1,SEEK_SET);
872:  fwrite(&TDBS,sizeof(short int),1,h1); //write block size
873:  fseek(h1,LOC2,SEEK_SET);
874:
875:  if ( p1 != 0) {
876:  for (i=0; i<pad; i++) fwrite(&ST,sizeof(char),1,h1);
877:  }
878: // long LOC3;
879: // LOC3=ftell(h1);
880: // printf("LOC3 = %8lx \n",LOC3);
881:
882: //...WRITE DATA
883:  int *pr;
884:  pr = &s1[0] + k;
885:  /*NOTE: DC level is removed from data since pr changes signal
886:   on exit:  *pr = *pr - ybase[k] changes s1, a pointer */
887:  for (i=0; i<npts; i=i+1) {
888:  *pr = *pr - ybase[k];
889:  fwrite(pr,sizeof(int),1,h1);
890:  pr = pr + nchnl;
891:  } //end of data write
892:
893: //...save end of data block
894:  EDB = ftell(h1) - 1; //the last byte of 4byte integer
895:
896:  } // next k chanl
897:  fclose(h1);
898:  return(0);
899: } //end WriteSEG2
900:
901: void writestring(char STRING[], char RES, char LTC,FILE *h1)
902: {
```

```
903:  int nbytes, nbytesf;
904:  nbytes = fprintf(h1,"%s",STRING);
905:  fseek(h1,-nbytes,SEEK_CUR);
906:  nbytesf = nbytes + 1  ;  //replace 2 blanks at begin with stringlength
907: // printf("bytes %d \n",(int) nbytes);
908:  fwrite(&nbytesf,sizeof(short int),1,h1); //write number of bytes forward
909:  //to next 2byte forward of next
910:  fseek(h1,nbytes-3,SEEK_CUR);
911:  fwrite(&RES,sizeof(char),1,h1); //replace 2nd last char with \0 endofstring
912:  fwrite(&LTC,sizeof(char),1,h1); //replace last char with 0xa endofstring
913: }
```

8 GNU General Public License

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Version 3, 29 June 2007

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