# Triggering of Electronic Apparatus by a Percussion Instrument: Investigation of a Strain Gage Sensor as System Input Source

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***Abstract*—An electronic mechanism to translate a percussionist's strikes on a drum head to one or more TTL logic signals would allow for the triggering of a variety electronic or electrically-controlled apparatus. A strain gage sensor system was employed to detect deformations in the drum head surface. Sensor interface circuitry was used to translate analog signals from the strain gage to a TTL waveform. Tuning of various circuit elements provided triggering threshold control. Mechanical damping of the drum head controlled signal magnitude and suppression of reverberant head vibration and subsequent TTL signal bounce. The experiment concluded that the drum head dynamics were too complex to interpret by this method alone. Additional signal processing and alternate transduction methods were proposed as possible solutions.**

***Index Terms*—drum head, sensor, strain gage, musical instrument, triggering**

## I. Introduction

THIS project was pursued as an investigation of one potential method of translating drum head strikes into TTL signal transitions. The motivation for the project was to create a sensor mechanism and circuitry to provide the input stimulus from a drum head to control an electronic/electro-mechanical musical instrument comprised of a variety of sound-making devices. The mechanical battering of the drum head would need to generate a signal that could be interpreted by the control system which would subsequently trigger the acoustic devices to engage by switching electrical circuits and pneumatic actuators. The goal of the experiment was to determine whether one or more sensors could be used this way to trigger a single event from a strike on the head, or multiple different events selected by the location of impact where the drum head is struck.

The approach used in this experiment was to place a mechano-electrical transducer (strain gage) on the drum head and use electronic circuitry to translate the strain gage resistance dynamics into a varying voltage, and furthermore to a five-volt TTL waveform with variable triggering threshold.

The experiment succeeded in generating the analog electrical signal and associated logic transitions, but the dynamics of the drum head posed challenges. Post-impact reverberation of the head surface generated sustained vibration and subsequent logic triggers which were undesired. Various levels of mechanical damping were used to suppress these vibrations and improve the resulting signals.

Experimentation with this triggering method provided information helpful in evaluating whether this would be an effective solution to pursue and also generated some alternate ideas for other possible approaches to this problem. While the strain gage provided the expected signals, it generated bounce in the TTL signal. Mechanical damping methods posed a challenge, as did the inconsistency of head impact magnitude. These two parameters were difficult to control uniformly, which created difficulty in tuning the triggering level for consistent results. As such, this triggering method was called into question and some alternate possibilities were proposed.

NOTE: Some schematic diagrams and data plots too detailed for insertion into this two-column document format have been placed at the end of this report. References to these figures will be noted within the document as necessary.

## II. Experiment Design

### A. Mechanical Input Device

The fundamental mechanical component of this experiment was a ten-inch steel timbale drum fitted with a standard drum head which included some limited mechanical vibration damping in the form of an embedded concentric pinstripe ringing the perimeter of the head. Further damping was provided by an Evans Min-EMAD adjustable damping accessory. The drum was struck by hand with a standard oak wood-tipped drum stick.

### B. Mechano-Electrical Transducer

A Vishay strain gage was affixed with glue to the top of the drum head approximately one inch from the outer rim, just inside the pinstripe. The gage was pointed inward in an

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attempt to capture vibrations radiating from the center of the head toward the rim, as determined from manufacturer recommendations [1]. Prior to this installation, a pair of thirty-gage insulated wires were soldered to the strain gage to serve as conductors to the electronics. The wires were approximately two feet long and twisted together for noise suppression purposes as recommended by the manufacturer's technical documents [2].

The strain gage is a small pattern of conductive material embedded into a thin film substrate material. The nominal resistance of the gage at rest is 120 ohms in the case of the unit chosen for this experiment. This resistance changes by very small amounts when the gage is put under strain, namely if it is bent or deflected. The change in resistance is a function of the amount of deflection per unit length of the gage material. As such, it can be used as a transducer to convert mechanical deformation into an electrical signal [3].

### *C. Sensor Circuitry*

The sensor circuitry comprised of four main components: Wheatstone bridge, instrumentation amplifier, AC coupling capacitor, and trigger . For the complete schematic, please refer to Fig 4, located in Appendix A. Sub-circuits are included below in the sections where they are discussed.

#### *1) Wheatstone Bridge*

As shown in Fig 1 below, a Wheatstone bridge was constructed as the input interface to the circuitry.

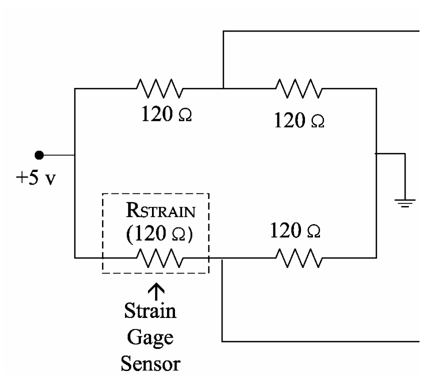


Fig. 1. Wheatstone bridge serving as strain gage input interface.

The strain gage comprises one of the four resistors in the network of the bridge. At a nominal resistance of 120 ohms, the other resistors are balanced such that with the five volt supply energized, a voltage of 0.0 v is observed at the output terminals (shown here as open wires pointing to the right of the diagram). Precision resistors eliminated the need for an additional balance control potentiometer which is sometimes used in similar bridge circuits. The excitation voltage chosen was 5 v, as determined using manufacturer's recommendation tables [4].

The bridge converts the small change in resistance (usually on the order of tens or hundreds of milliohms) into a change in voltage so that it can be measured, logged, and/or plotted on an oscilloscope. Since the resistance change is very small compared to the nominal 120 ohm system, the resulting voltage change is also extremely small, usually in the microvolt range or smaller. This tiny voltage change requires amplification for effective measurement. Therefore, the next stage of the circuit is an instrumentation amplifier.

#### *2) Instrumentation Amplifier*

Amplification of the small voltage change exhibited in the Wheatstone bridge is accomplished using a common instrumentation amplifier design. This design uses a common differential amplifier circuit with balanced inverting amplifiers at each input [5].

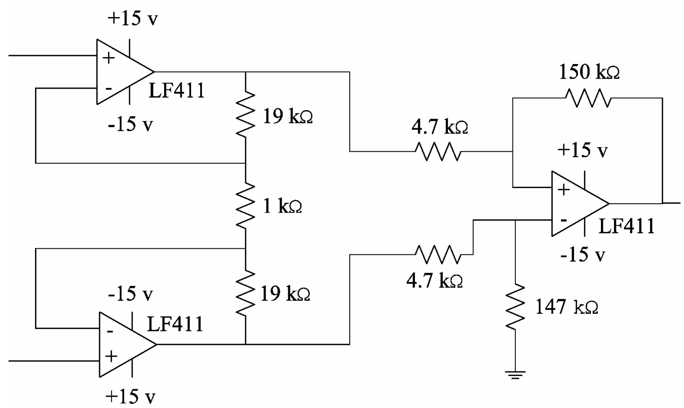


Fig. 2. Instrumentation Amplifier.

Outputs of the Wheatstone bridge stage connect to the inputs of this amplifier (shown here as the open wires extending to the left of the diagram). The first stage extracts the difference in voltage between the input terminals, while the second stage converts that from an arbitrary potential difference to a voltage with respect to ground. This amplifier was designed for an overall gain of approximately 600, which is enough to increase the magnitude of the voltage change from the Wheatstone bridge to a value that can be measured on the oscilloscope.

#### *3) AC Coupling Capacitor*

To ensure that only the magnitude of the voltage *change* is passed to the measurement instruments, the output of this amplifier (shown here as an open wire leading to the right of the diagram) is connected to an AC coupling capacitor in series before the next stage, which blocks the DC (unchanging) component of the signal. A 0.1 µF ceramic disc capacitor was used for this purpose. The LF411 was used for all operational amplifiers in the circuit.

The output of this capacitor was observed on the oscilloscope Channel 1 as the analog system output.

#### *4) Trigger Circuit*

A final stage of circuitry is designed to convert the changing voltage at the instrumentation amplifier output to a TTL waveform.

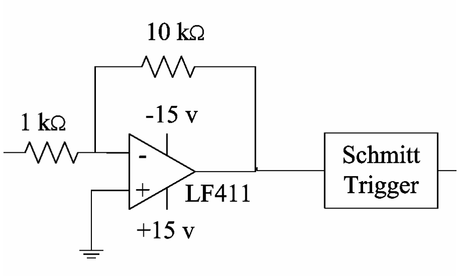


Fig. 3. TTL Trigger.

The triggering circuit includes two stages. The functional stage is the Schmitt trigger which toggles its TTL output state upon sufficient voltage at its input, then toggles back when that level drops below threshold again. A 74HC14 inverting Schmitt trigger was used.

However, the instrumentation amplifier signal output is too low to trigger the Schmitt device. Therefore, first, a preamplifier is used to increase the voltage change magnitude above the Schmitt trigger threshold level. This amplifier has a 10 kΩ potentiometer in the feedback channel which allows for precision tuning of the voltage to match the threshold level at the desired input magnitude. In this case, $V_{CC}$ for the Schmitt trigger was 5 v and it triggers on a rising signal at approximately 3.5 v. The instrumentation amplifier output was amplified by a gain of approximately 9 so that the Schmitt trigger would toggle when the instrumentation amplifier output was approximately 0.4 v rising. The preamp used another LF411 operational amplifier.

The Schmitt trigger output is the final stage of the system schematic and was observed on oscilloscope Channel 2 as the TTL system output.

*5) Other circuit considerations*

Not shown in the schematic are a number of 0.01 µF filter capacitors used on the op-amp power supply inputs (to ground). These were employed as low-pass filters for high frequency noise suppression from the power supply and associated wiring.

The circuit was built on a three-panel breadboard utilizing bus lines for $V_{CC}$, ground, and the +/- 15 v power supplies. As an additional noise suppression technique, the circuit was wired using the shortest direct leads possible. Aside from the power supply cables and the twisted-pair sensor wires described earlier, the longest wire lead in the circuit was approximately two inches.

### *D. Signal Observation and Data Collection*

The system performance was observed on a multi-channel digital oscilloscope capable of waveform storage. Signals were monitored in real time on the screen, with scope triggering set up to capture an 8 ms window of time surrounding a drum head strike. The results were saved for later analysis.

Two channels were recorded. Channel 1 captured the instrumentation amplifier output downstream of the AC coupling capacitor such that it only displayed changes in voltage of the amplified sensor output (analog system output waveform). Channel 2 captured the Schmitt trigger output (TTL system output waveform).

Captured data was plotted using Matlab and is presented in Appendix B as Fig 5 through Fig 9. Matlab code is included in Appendix C

## III. Experimentation

Experimentation with this system began with simple observations on the oscilloscope of the signals generated by striking the drum in the center of the head. In an effort to minimize the number of variables in the experiment, the head was always struck in the center. As such, the effect of the drum hit's location on the head was not thoroughly tested. Response was highly dynamic and inconsistent. Each drum strike generated a unique waveform. Furthermore, achieving consistent magnitude was nearly impossible due to the lack of precise control over the striking force.

The goal of the experiment was to determine if a drum head strike could generate a single TTL clock edge at the Schmitt trigger output, thus providing a single event trigger for the control system which could be connected to other equipment downstream. If this were successful, further experimentation would have been aimed at determining whether multiple sensors could be used to trigger different events depending on where on its surface the drum head was struck.

In general, the waveform was highly complex and spanned a much longer time than the strike itself. As anticipated, the drum head reverberated. Unexpected, however, was the magnitude of the post-strike vibrations. In general they were nearly as large, and in some cases larger, than the amplitude of the signal at the moment of impact.

Literature research supports this observation. In fact, specific mention of this phenomenon appears in a music synthesizer patent file [6]. Related references can also be found in several IEEE publications, notably one on robotic drumming from an IEEE Robotics and Automation conference proceedings [7]. A presumable advantage of that study was that they used a robotic arm to deliver drum beats of uniform force.

Even while utilizing the internal and accessory damping devices, the drum head was too susceptible to vibration for the data to be useful. The analog voltage was highly variant, and the TTL signal was triggering many times per strike, as one would expect to see from a non-debounced switch. Trigger threshold adjustment was somewhat helpful in eliminating some of the unwanted triggers, but not sufficient to create a single clock edge per strike.

The one effective solution was to provide extra mechanical damping on the drum head. This was done by hand since the required damping force had exceeded the capabilities of the manufactured damping devices. A large amount of pressure on the drum head, combined with a lighter strike was necessary to suppress the unwanted TTL bounces. Fairly consistent results were achievable with this method, although precise replication of any particular damping pressure or strike force was impossible to achieve by hand (as would also be the case in the real-world application of this system were it to be realized).

Despite this difficulty, some strike events were captured which demonstrated that the desired triggering was possible. However, given the narrow range of strike force and damping force required to achieve successful results, it is unlikely that this method could produce such successful results in a real-world drumming situation which would inherently entail a wide variance in striking force.

## IV. Data

A selection of the data collected has been plotted to demonstrate typical signals resulting from a variety of striking and damping situations. Please refer to Fig 5 through Fig 9 in Appendix B for the full-size plot diagrams. Five plots are provided. For the following discussion, all situations included maximum damping from the devices installed. From this point forward the term damping will refer to the amount of additional manual hand-damping that was provided by the percussionist. The top plot in each pair shows the analog system output, whereas the bottom plot shows the TTL output.

In general, it is notable that the signal-to-noise ratio of the plotted signals is quite high. This suggests that there may not have been significant noise in the system and/or the attempted noise suppression efforts were successful.

Also worth consideration are the lower-frequency oscillation waveforms that are apparent in each data set. At approximately 100 µs in period, these represent a frequency of approximately 10 kHz. This frequency is rather high to represent a fundamental musical tone from any standard musical instrument, so it is tempting to conclude these must represent harmonics. Since they appear in all of the plots it is likely that they are related to the resonant frequency of the drum. Perhaps the slight variations are related to the variances in damping pressure since drum head tension is related to the frequency of the tone it produces.

Figure 5 shows the a typical plot for the un-damped drumhead and a heavy drumstick hit. Note that there are many triggers of the TTL waveform, and that the 74HC14 used is a hex inverting Schmitt trigger so the TTL plots show a high signal in the un-triggered state and a low signal in the triggered state. This plot also reveals some of the complex harmonics evident in the drum head vibration characteristics. Also note the length of the waveform—it remains quite active at significant magnitude for the full 8 ms sample time and beyond. Clearly this is a poor TTL triggering situation since the objective is to achieve a single stable TTL transition for each stick strike.

Figure 6 shows that adding some manual damping reduces amplitude of the vibrations, but the complex reverberations can still be seen recurring long after the initial strike.

Figure 7 shows what a lighter hit looks like with approximately the same damping as the previous example. Nearly all of the head vibration energy is concentrated within 400 µs of the strike, a much shorter length of activity than previous examples. With only two TTL triggers, this example is getting much closer to the desired result.

Figure 8 appears to offer the perfect combination of damping and strike force. With the same damping as the previous two examples and a light strike, we see that a single TTL transition is triggered. We also see in this plot that the high frequency oscillations evident in the other plots are missing from this example. If this could be reproduced reliably then it may offer an effective solution to the triggering problem. However, as stated earlier, the drummers striking force will inevitably vary, most likely too much for this approach to work reliably.

Figure 9 uses the same damping again, but with an extremely light strike—in this case just a light tap with the stick. This strike response lacks sufficient magnitude to trigger the TTL signal.

## V. Analysis

The value of this experiment's results can be divided into two categories. The first consideration is what it revealed about the potential success of this system as a triggering method. Second, the resulting data can be used as system characterization that should help steer efforts toward alternate solutions.

Since this experiment was meant to test a possible solution to the triggering problem, it makes sense to consider this point first. As stated earlier, the dynamics of drum beats makes them difficult to administer with the degree of consistency necessary to trigger TTL transitions by this method. Mechanical damping offered some improvement, although it was at a cost of acoustic quality as well. The heavily damped drum head was crippled in its musicality and restricted the natural reverberations inherent to the desired sound of a drum. Considering these shortcomings, it would be sensible to pursue other options before using this design beyond the experimental stage, and reverting to this design only in the case of more significant problems with other possibilities.

One other option that was not explored significantly could be to research and/or attempt techniques of damping the signal electronically. Perhaps it would be sensible to try a low-pass filter of some kind, with a cutoff frequency low enough to attenuate the unwanted signal bounce, but high enough to accommodate the fastest possible drum beats—which should be less than 100 Hz, even for a drum roll by a highly skilled percussionist. This would be the next step taken if pursuit of the strain gage application were to continue. Since the frequency of the problematic bounces in this experiment were in the kilohertz range, it stands to reason that there is a wide enough transition band, between those high frequencies and the lower drum beat frequencies we would like to capture, to create an appropriate low pass filter. Some research of possible filter designs is likely necessary, as is some experimentation with filter placement in the circuit. Depending on the filter type and noise characteristics, one would need to determine whether it belongs at the sensor stage, in the amplifier stage, or between the analog amplifiers and the Schmitt trigger. Or as an alternative, possibly a digital filter could process the TTL output from the Schmitt trigger.

What was learned in this experiment would also be used to conjure other methods of creating the triggering signal.

Newer developments in optical sensors use deflection of fiber optic strands to detect and measure movement. These might be tunable to recognize drum head deflections of a certain magnitude.

Perhaps a pressure sensor could be used. The drum used in this experiment was open-backed—it has no head on the back side of the cylinder wall. In the case of a two-headed drum, the internal cavity is sealed in some cases. A pressure sensor measuring air pressure inside the drum may be more effective than a strain gage at distinguishing the initial stick impact from the resulting head vibrations which may move much less air than the initial strike.

Some two-headed drums have a small hole that vents internal pressure when the drum is struck. It therefore stands to reason that this air in motion could be sensed and translated into useful data by a number of possible sensor types.

## VI. Conclusion

While this experiment was useful in providing insight into the dynamics of a drum head, the signals it can generate using a strain gage sensor, and the circuitry that can be used to translate the physical vibrations into electrical signals, it did not produce a result that is ready for implementation. As proposed in the previous section, the next step with this experiment should be to research, design, and add a low-pass filter to this circuit. Further research is also necessary to determine if there is a better transducer or sensor system that could be used for this application by electronically quantifying other physical characteristics of the system by different means.

## Appendix A
## (Full System Schematic Diagram)

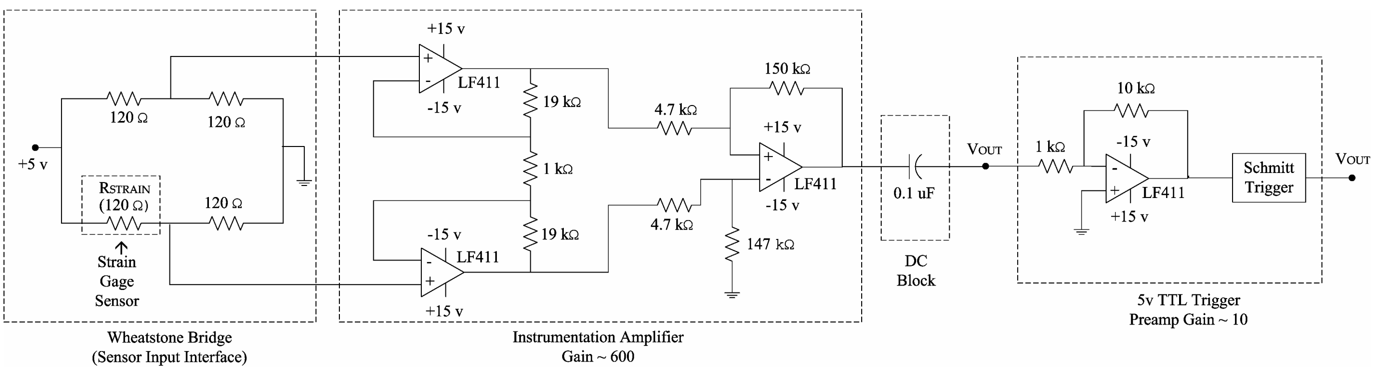


Fig. 4. Full circuit schematic.

# APPENDIX B
# (DATA PLOT FIGURES)

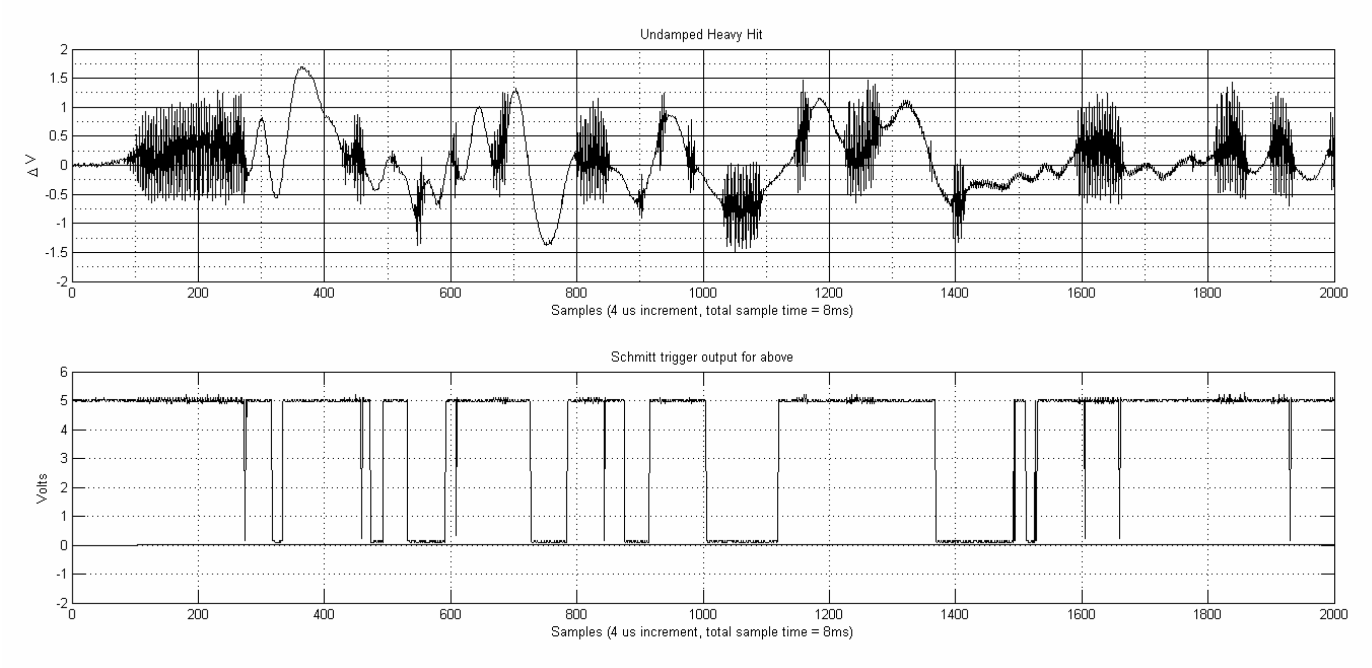


Fig. 5. Un-damped heavy hit.

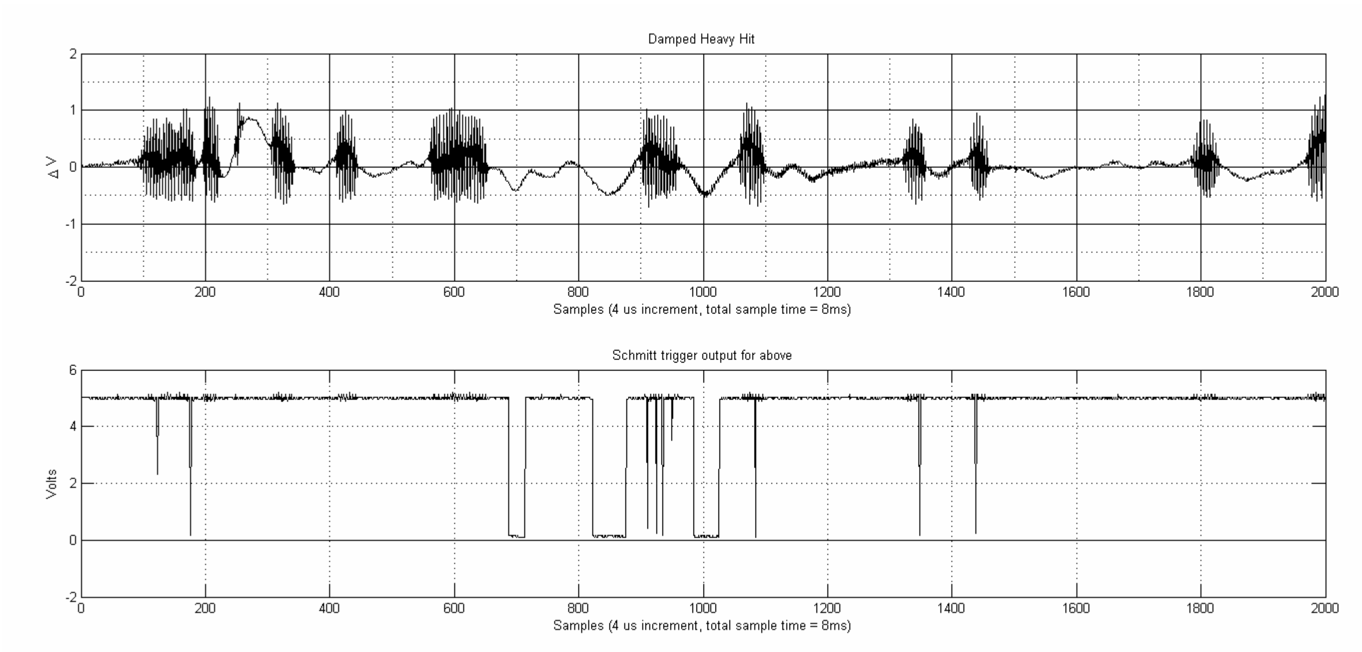


Fig. 6. Damped heavy hit.

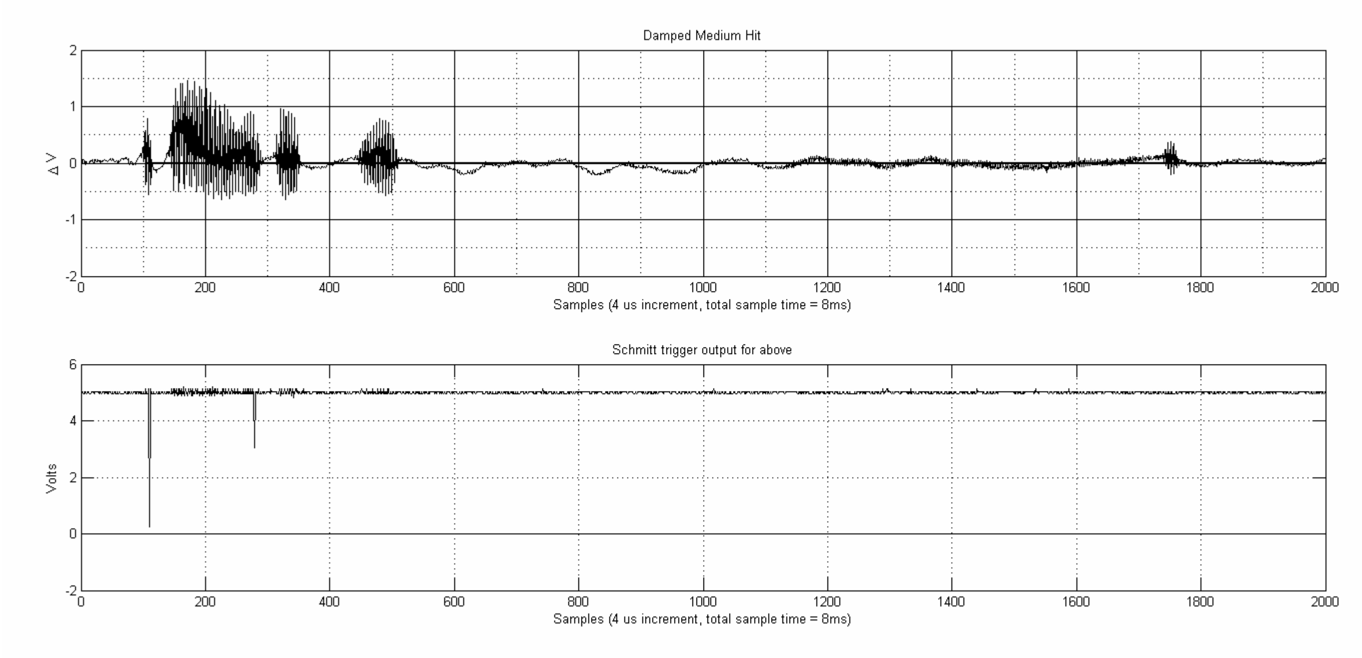


Fig. 7. Damped medium hit.

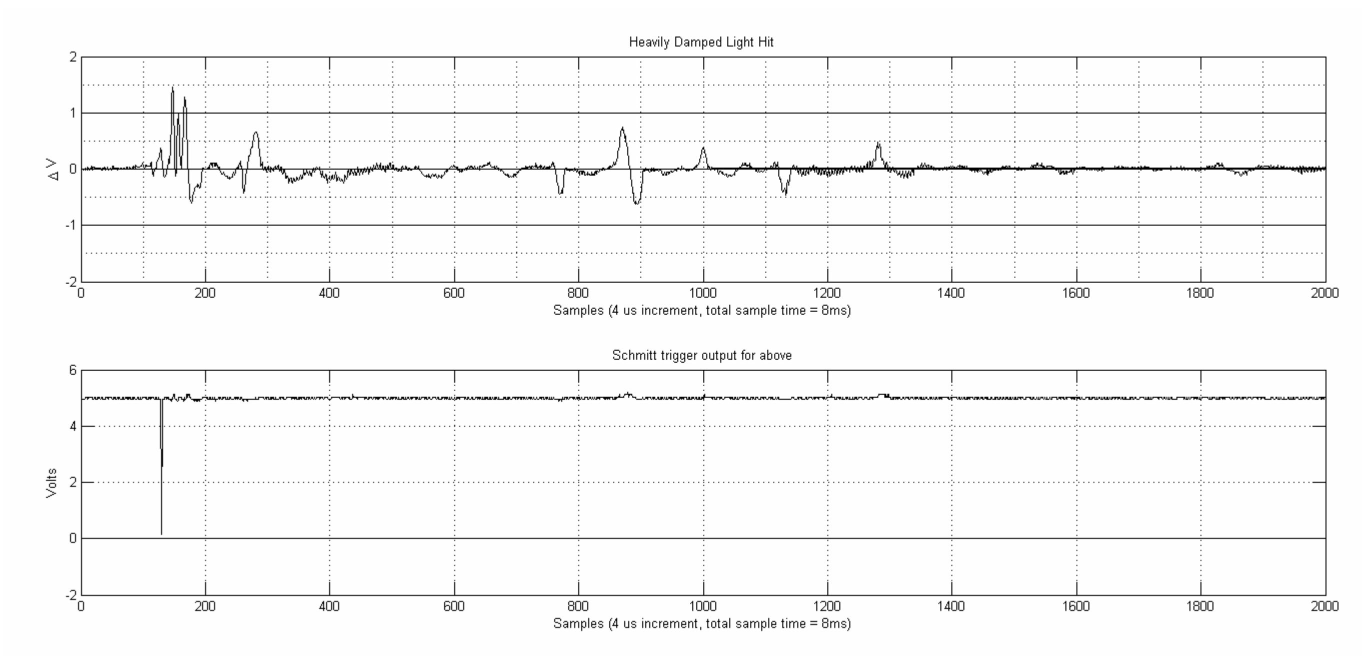


Fig. 8. Damped light hit.

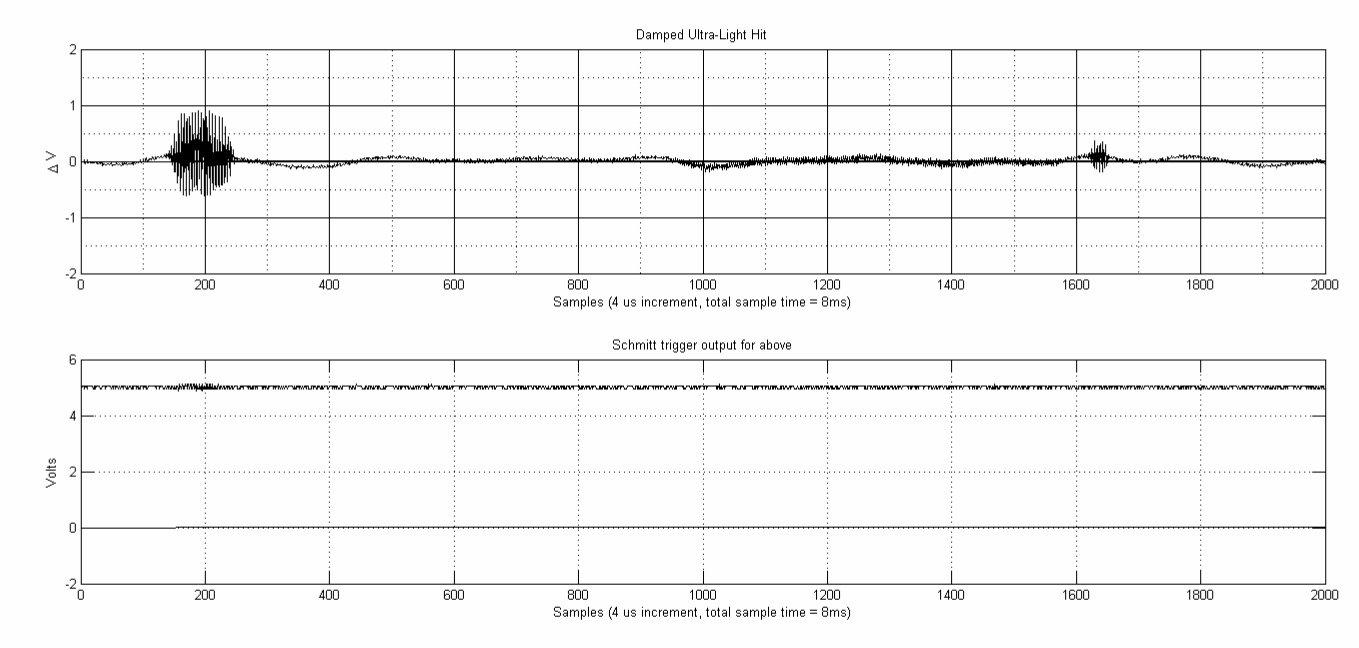


Fig. 9. Damped ultra-light hit.

## APPENDIX C
## (MATLAB CODE FOR DATA IMPORT AND PLOTS)

```
% Andrew Tubesing - DRUM HEAD STRAIN GAGE SENSOR - EE521 Fall2008

format short e

% Read data from CSV files
% Data size is RxC=2000x2, Sample interval = 4us, Sample Qty = 2000, Sample time = 8 ms

UH1=csvread('UndampedHeavyCH1.csv',499,3,[499 3 2499 4]);
UH2=csvread('UndampedHeavyCH2.csv',499,3,[499 3 2499 4]);

DH1=csvread('DampedHeavyCH1.csv',499,3,[499 3 2499 4]);
DH2=csvread('DampedHeavyCH2.csv',499,3,[499 3 2499 4]);

DM1=csvread('DampedMedCH1.csv',499,3,[499 3 2499 4]);
DM2=csvread('DampedMedCH2.csv',499,3,[499 3 2499 4]);

DL1=csvread('DampedLightCH1.csv',249,3,[249 3 2249 4]);
DL2=csvread('DampedLightCH2.csv',249,3,[249 3 2249 4]);

DU1=csvread('DampedUntriggeredCH1.csv',449,3,[449 3 2449 4]);
DU2=csvread('DampedUntriggeredCH2.csv',449,3,[449 3 2449 4]);

% Plot data arrays

figure('Name','Undamped Heavy Hit','NumberTitle','off')
subplot (2,1,1)
plot (UH1)
grid minor; xlim([0 2000]), ylim([-2 2])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('\Delta V'); title('Undamped Heavy Hit');

subplot (2,1,2)
plot (UH2)
grid on; xlim([0 2000]); ylim([-2 6])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('Volts'); title('Schmitt trigger output for above');

figure('Name','Damped Heavy Hit','NumberTitle','off')
subplot (2,1,1)
plot (DH1)
grid minor; xlim([0 2000]); ylim([-2 2])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('\Delta V'); title('Damped Heavy Hit');

subplot (2,1,2)
plot (DH2)
grid on; xlim([0 2000]); ylim([-2 6])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('Volts'); title('Schmitt trigger output for above');

figure('Name','Damped Medium Hit','NumberTitle','off')
subplot (2,1,1)
plot (DM1)
grid minor; xlim([0 2000]); ylim([-2 2])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('\Delta V'); title('Damped Medium Hit');

subplot (2,1,2)
plot (DM2)
grid on; xlim([0 2000]); ylim([-2 6])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('Volts'); title('Schmitt trigger output for above');

figure('Name','Heavily Damped Light Hit','NumberTitle','off')
subplot (2,1,1)
plot (DL1)
grid minor; xlim([0 2000]); ylim([-2 2])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('\Delta V'); title('Heavily Damped Light Hit');

subplot (2,1,2)
plot (DL2)
grid on; xlim([0 2000]); ylim([-2 6])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('Volts'); title('Schmitt trigger output for above');

figure('Name','Damped Ultra-Light Hit','NumberTitle','off')
subplot (2,1,1)
plot (DU1)
grid minor; xlim([0 2000]); ylim([-2 2])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('\Delta V'); title('Damped Ultra-Light Hit');

subplot (2,1,2)
plot (DU2)
grid on; xlim([0 2000]); ylim([-2 6])
xlabel('Samples (4 us increment, total sample time = 8ms)'); ylabel('Volts'); title('Schmitt trigger output for above');
```

## ACKNOWLEDGMENTS

The author would like to thank Dr. Ron Thomas, instructor of the EE321 Analog Electronics course that provided the author's experience with strain gages, instrumentation amplifiers, and other related topics. Dr. Aly El-Osery also deserves commendation as the instructor of the course for which this project was designed, and as a helpful advisor on the project.

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A generalist at heart, with diverse interests, the author has worked in broadcast engineering and communications contracting for eighteen years. He has published two books, one as a peace educator and another as a resource for inflammatory bowel disease. His foray into engineering is the result of a lifetime of wonderment and experimentation with apparatuses of all kinds—electrical, musical, whimsical, and otherwise, and is a key component to his career growth into product development, education, and further creative prowess.