Triggering Device for Acoustical Monitoring of Lightning

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Executive Summary

Acoustic research of thunderstorms in the Magdalena Mountains of New Mexico is currently being performed by Dr. Rene Arechiga. The current system continuously records the thunder data. This continuous recording results in large quantities of data which must be stored and processed. The space required to store this data and the time it takes to process it are problematic. The purpose of this project is to design, fabricate, and test a device that will detect lightning events, produce a trigger corresponding to these events, and use these triggers to store valid thunder data. This device will be used to retrofit the current system to help solve the continuous recording problems. Audio data is considered valid when it occurs around a lightning event. In order to detect the lightning event a slow antenna is used. Two techniques were utilized to recognize a lightning event from the slow antenna. The two techniques were: an Analog Threshold Detector and a Digital Differential Detector. The Analog Threshold Detector indicates an event when the output exceeds a set point, and the Digital Differential Detector indicates an event when consecutive samples differ excessively. Both systems will create a controlled pulse in the event of lightning. These pulses may be used to start audio data storage in the currently implemented data logger system. When this pulse is fed into the current system the audio data will be recognized as valid and stored to the SD card. The current system will be adjusted to ensure that audio data will be recorded before and after a lightning event. This allows for the researchers to follow the audio changes over the course of a lightning event. Currently, the Analog Threshold Detector has been designed, implemented, and tested. This testing includes both the lightning detection and triggering circuits. The Digital Differential Detector has been designed but still needs to be implemented and tested. The adjustments to the current system which stores the audio data have begun but still need to be completed and finally tested. Lastly, the triggering devices need to be integrated to the data recording system. However, both triggering systems have been designed to have the same outputs. This allows both systems to have the same integration solutions.

Signatures

Kalyn Jones	Date
Ryan Steinbach	Date
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Dr. Rene Arechiga Customer	Date
Dr. William Rison Faculty Advisor	Date

I. INTRODUCTION

Professors in New Mexico Tech's Electrical Engineering Department perform research to measure and record propagation characteristics of lightning using both electromagnetic and acoustic measurement systems [1]. The acoustic system currently in use for lightning research continuously detects and records audio data. This continuous recording results in large quantities of data to be stored. This paper describes the design and testing process used in implementing a triggering device that may be interfaced with the current recording system so that data is only stored when lightning and thunder are occurring in the immediate area of the acoustic sensor. The addition of this device to the acoustic thunder monitoring system would allow for the continued expansion and improvement of the lightning measurement abilities.

II. BACKGROUND

A. Current System Limitations

Dr. Rene Arechiga is currently performing acoustic recording of thunder in the Magdalena Mountains of New Mexico. Acoustic pressure sensors can detect thunder caused by a given lightning strike and use time of arrival information for spatially distinct microphones to triangulate the location of the source lightning event. Additionally, these acoustic sensors can measure the infrasonic signals produced by the electrostatic field changes that occur in lightning discharges.

The current acoustic lightning monitoring system continuously stores GPS time-stamped acoustic records. The continuous recording in the acoustic measurement system creates large datasets. This, in turn, increases the frequency with which researchers must travel to the remote sites and rotate removable SD card storage devices. Additionally, the large quantities of stored data make it difficult to locate valid thunder data for post-processing.

B. Triggering System Improvements

To increase the amount of time that the same SD card can be used to store data from the acoustic monitoring system and simplify the post-processing techniques, a triggering system that will enable the system to only record data in the presence of a valid lightning discharge event can be designed and implemented. Such an addition to the system could potentially allow for the further expansion of the acoustic lightning data being recorded at New Mexico Tech.

III. CURRENT SYSTEM OPERATION

The current audio recording system uses a microphone to convert acoustic waveforms present in the area of deployment of the audio sensor into electrical signals. Each signal is then filtered to reduce ambient system noise, enhance the quality of the recorded audio information, and ensure that sampling the signal does not result in aliasing. The filtered signal is then amplified to enhance the resolution with which the audio signal can later be sampled. The input audio waveforms that have been converted into electrical signals are then sampled using an analog-to-digital converter (ADC). The ADC converts the signal into a digital form where it can be manipulated and stored by a microprocessor. The microprocessor groups and stores a fixed amount of information in temporary memory. When the allocated temporary memory has been filled, the microprocessor sends the whole section of information to the SD card. This grouping of data before writing to the SD card increases the data storage speed. The temporary memory is cleared as the microprocessor begins to collect information to fill another buffer. Each time a buffer fills, the information is written to the SD card. The current audio data-logger system is separated into two different subsystems: an audio digitizing board and a data-logger storage board.

A. Audio Digitizing Board

The audio circuit board takes in the microphone signals and performs the filtering, amplifying, and digitizing of the input audio signals. Fig. 1 shows the PCB for the audio portion of the currently implemented system. Fig. 2 shows a simple block diagram for the function accomplished in the audio board.

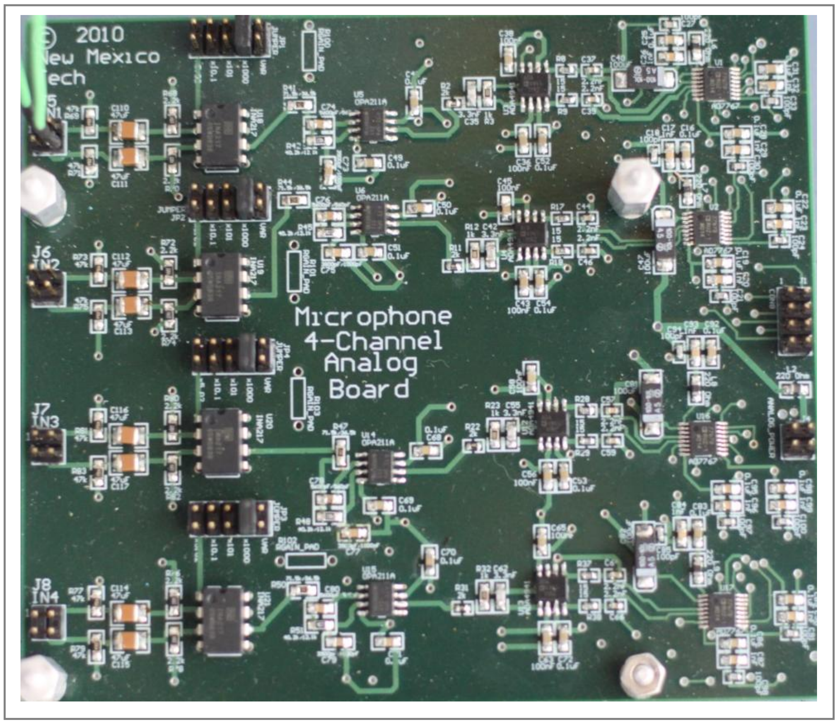


Fig. 1: Audio recording PCB.

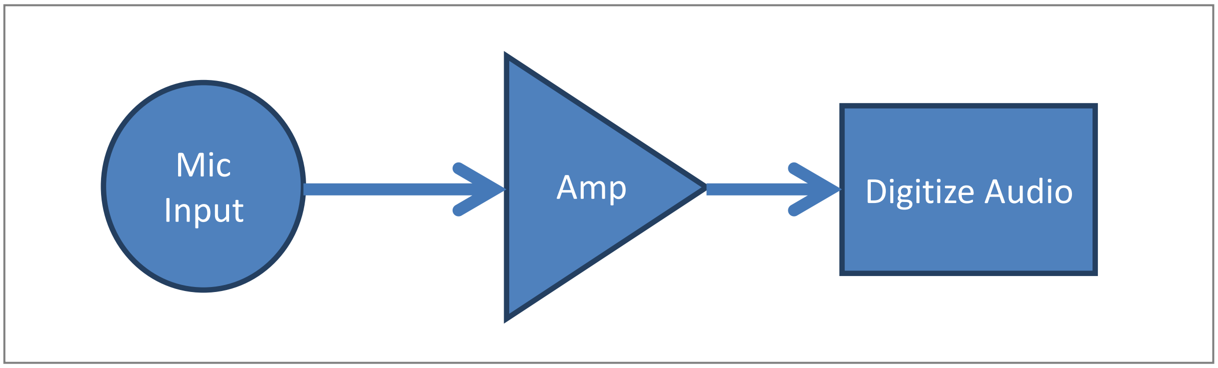


Fig. 2: Audio recording functional diagram.

B. Data-Logger Board

The data-logger board of the currently implemented system reads in the digitized data from the audio digitizing board, groups the data as it places it in temporary memory, and then writes the grouped data to the SD card. The implemented data-logger board is shown in Fig. 3. Also, a simple block diagram for the data-logger board can be seen in Fig. 4.

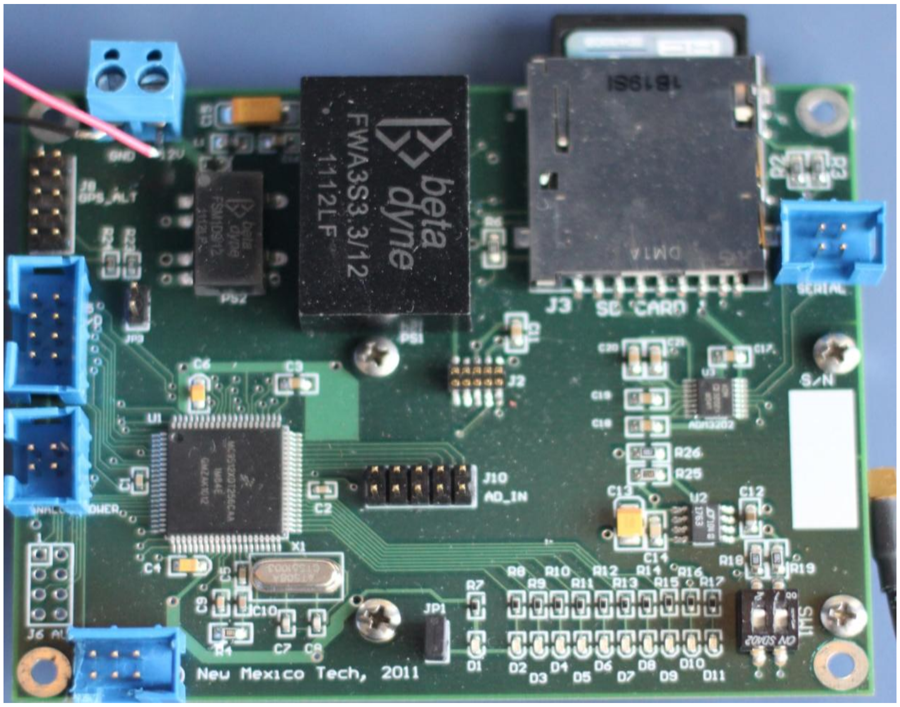


Fig. 3: Data-logger PCB.

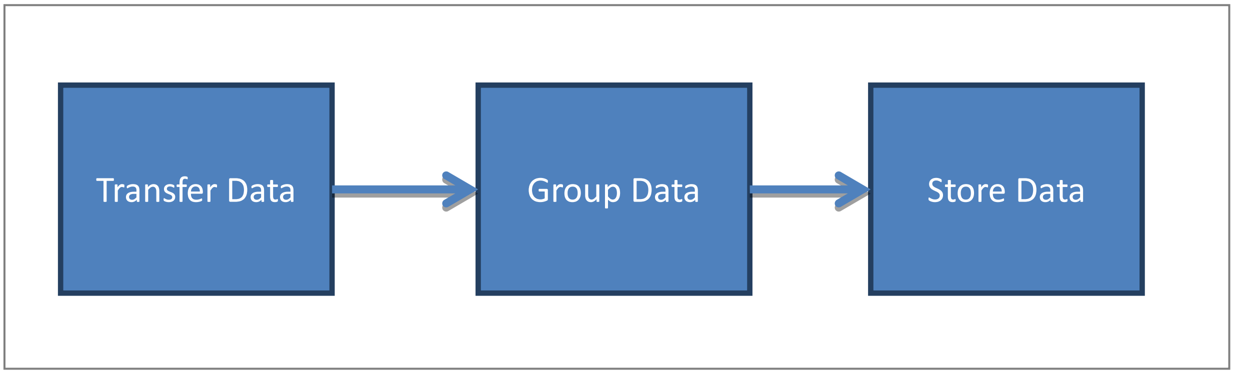


Fig. 4: Data-logger functionality.

IV. DESIRED OPERATION

Because of the large quantities of acoustic thunder data being created and stored, triggered data storage would be preferable to the continuous data-logging of the current system. In such a system, the audio conversion and sampling would occur in the same way that they do in the currently implemented system. The digital signal would then be grouped and stored in the data logging system as before. The difference in this desired system is in the criteria for when the information, stored in the circular buffers, is written to the SD card.

In the triggered data-logger system, data should be continuously recorded but only stored to the SD card under certain conditions. Data storage should only occur when a lightning event is detected within a predetermined radius of the sensor array. This radius of detection should be easily selectable as either 5km, 10km, 15km, 20km, or 30km.

In order to accomplish this triggered data storage, a system must first be implemented to detect lightning events and create a pulse that the data-logger system can use to initialize transfer of the audio information from temporary storage in the buffer to the SD card.

Additionally, the firmware that controls SD card storage must be modified to detect this trigger pulse and use the trigger to begin storage. It is useful to analyze audio data both before and after the lightning flash. In order to obtain audio data before the lightning flash, pre-triggering will be employed. The duration of both the pre-triggering and post-flash recording should be easily configurable by simply changing variables in the firmware source code prior to reloading of the firmware onto the data-logger. This will allow for modifications to the data storage technique as the focus of future thunder research varies.

V. TRIGGERING SYSTEM DESIGN REQUIREMENTS

A. Budget

The design, implementation, and testing of the triggering system must be completed for less than $1000.

Emphasis should be placed during the design process on reducing the cost of replicating the final triggering system. Upon completion of the design process, a number of the currently implemented acoustic monitoring systems may be retrofitted to include triggered data storage. Minimizing cost of reproduction will minimize the financial burden of performing such a system upgrade.

B. Power Supply

The implemented triggering system must run off of a single 12VDC battery. This design consideration is due to the availability of the currently deployed system’s power supply.

C. Interfacing

The implemented triggering system must support integration to the current data-logger. The trigger pulse output should be electrically isolated to ensure that noise and crosstalk are minimized. Additionally, the trigger output should be produced at the logic levels of the data-logger.

VI. LIGHTNING DETECTION THEORY

Selective data storage of valid thunder data requires knowing when thunder might occur. Arguably, the easiest way of detecting the possibility of thunder is to detect the lightning discharges that create the acoustic signal. Lightning is caused when charges are separated within a cumulonimbus cloud. This charge separation occurs when freezing ice particles in the middle of a cumulonimbus cloud collide with any dust particles present in the cloud [2]. Both objects become charged and charge separation is created. The negatively charged particles tend to fall to the bottom of the cloud; the positive charge tends to accumulate at the top of the cloud with a small distribution of positive charges on the bottom surface of the cloud [3]. The most common charge distribution in thunderclouds, a tripole, can be seen in Fig. 5.

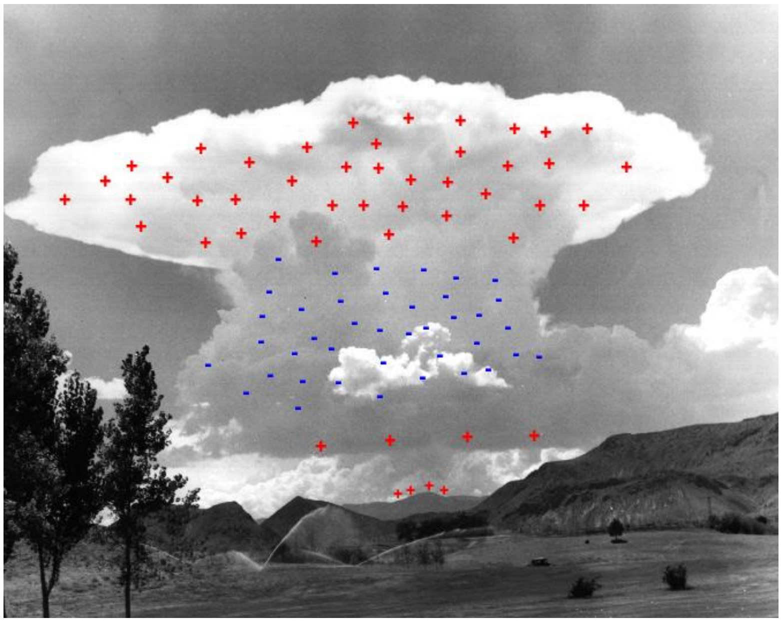


Fig. 5: Thundercloud charge distribution.

This separation of charges in the cloud induces electric fields. When the electric fields become large, air may ionize allowing for the transfer of charges in the form of a lightning strike. Either positive or negative charges may be transferred to the Earth's surface. Fig. 6 shows the different types of lightning discharges that may occur.

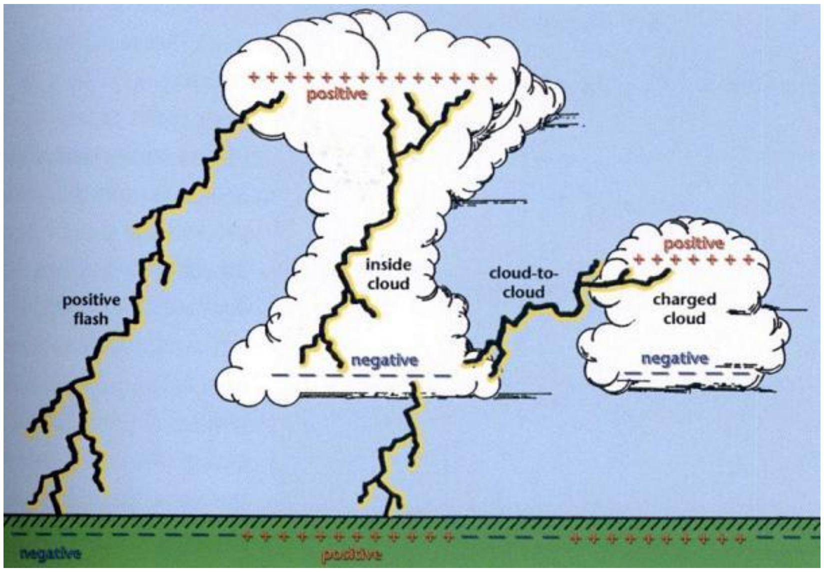


Fig. 6: Lightning discharges.

Upon recommedation of our faculty advisor, a slow antenna will be used to detect lightning events.

VII. Slow Antenna Theory and Design

A. Basic Theory

Slow antennas work by measuring changes in Earth’s charge distribution caused by changing electric fields during lightning events. Large changes in the charge detected by the slow antenna can be related to lightning strikes. The following sections describe the subsystems used in a slow antenna. Fig. 7 shows the basic functionality of a slow antenna.

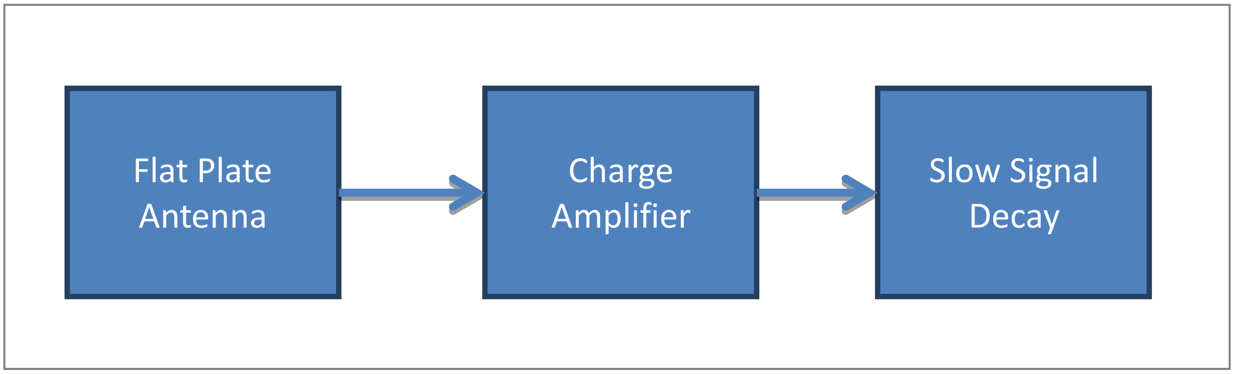


Fig. 7: Slow antenna block diagram.

1) Flat Plate Antenna

In a slow antenna, the physical antenna is a circular, metal, flat plate antenna [3]. Fig. 8 shows a slow antenna often used in research at Langmuir Laboratories.

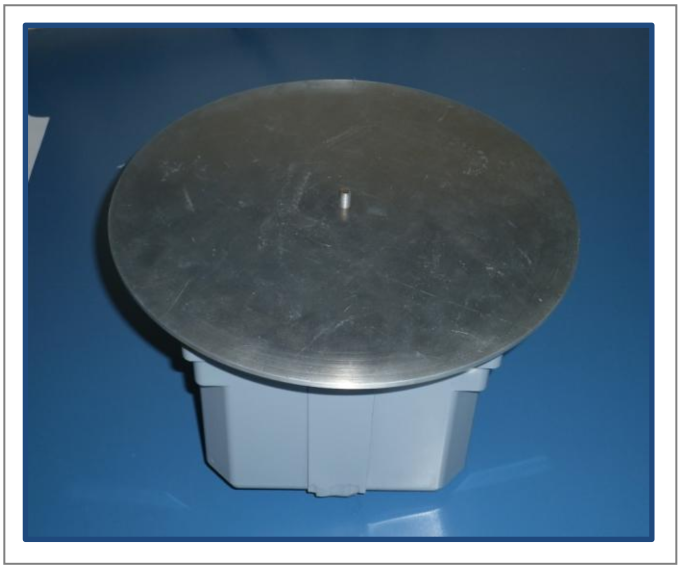


Fig. 8: Flat plate slow antenna.

When the antenna is placed parallel to Earth’s surface, the charge is moved onto the antenna’s plate. In the ideal case, the charge density present on the flat plate antenna is exactly equivalent to that on Earth’s surface where the plate is located [5]. This charge density on Earth’s surface is caused by the electric field present due to the separation of charge caused in thunderclouds [2]. The flat plate antenna available for the design of the lightning detector for this triggering system is an aluminum disk 6 inches in diameter.

2) Operational Amplifier Integrator

The feed to the flat plate antenna is then connected to the input of an operational amplifier integrator circuit, acting as a charge amplifier. This circuit consists of a capacitor in the negative feedback path. Fig. 9 shows the circuit diagram for the ideal op-amp integrator connected to an antenna [6].

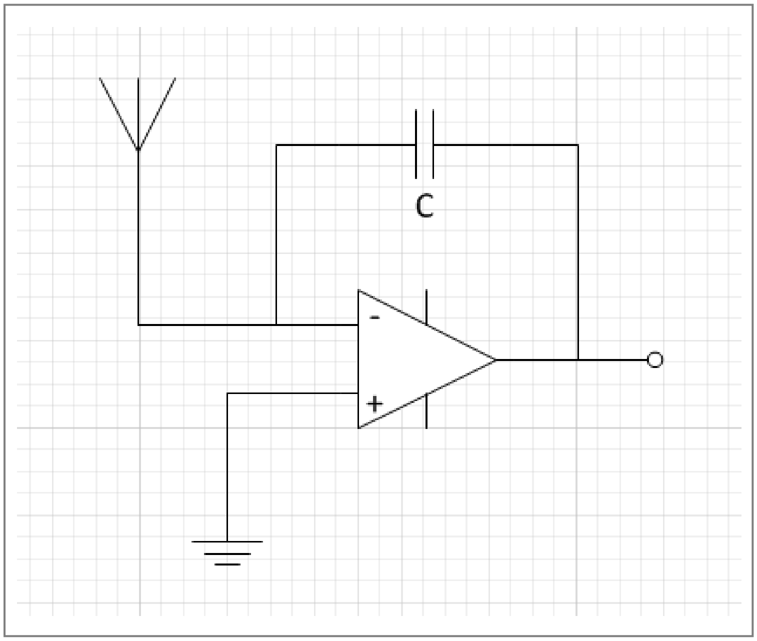


Fig 9: Ideal op-amp integrator.

This results in a voltage at the output of the op-amp that is directly proportional to the charge input from the antenna. In this circuit, lightning will cause sudden changes in Earth's surface charge distribution; this change in charge causes changes in voltage at the output of the op-amp. These changes in voltage can be used to detect the lightning events. In this circuit, the size of the capacitor should be chosen so the maximum field expected would lead to the maximum output of the op-amp.

3) Practical Circuit Design

Due to bias currents, the ideal op-amp integrator cannot be implemented because the output of the op-amp will saturate at one of the power supply rails [7]. While this issue can partly be alleviated using op-amps designed to have ultra low bias currents, this alone will not be a sufficient solution.

In order to rid the slow antenna circuitry of this flaw, a resistor can be added in parallel with the charge amplifying capacitor in the feedback path as shown in Fig 10. The addition of this resistor would allow the bias current another path to flow through [6]. If the bias current flows through the feedback resistor, the op-amp will not saturate. Instead, the output will have an offset voltage determined by the bias current and the value of the feedback resistor used [7].

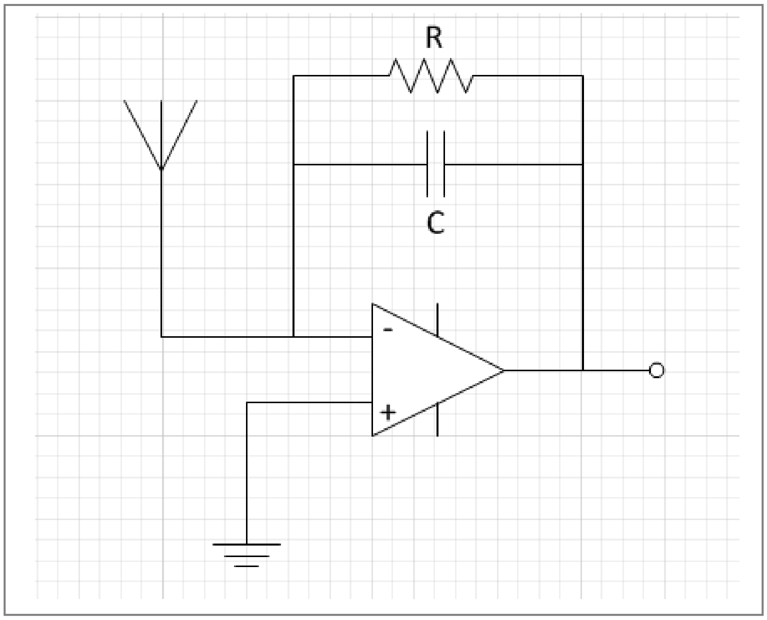


Fig. 10: Slow antenna integrator with RC feedback.

While the addition of a feedback resistor will fix the bias current saturation problem, it also changes the overall behavior of the circuit. The circuit now displays resistor-capacitor (RC) charge and discharge behavior.

Because of this behavior, steady-state values for the field on Earth's surface will not produce any output response, regardless of the magnitude of the electric field caused by the thundercloud's charge separation. Sudden jumps in field due to lightning discharge will still appear at the output of the op-amp. However, they will decay at a rate defined by the RC time constant determined by the values of feedback resistor and capacitor. In slow antennas, the RC time constant is chosen such that the decay is "slow;" the time constant should be on the order of seconds [4]. In this type of circuit, components should be chosen based not on the maximum field value expected, but rather on the maximum change in electric field expected [3].

B. Circuit Design/Component Selection

Now that the basic circuit for the slow antenna has been determined, components and their values can be selected to give the desired behavior.

1) Charge Amplifying Capacitor

The feedback capacitor should be chosen such that the output of the op-amp reaches its maximum level when a large magnitude lightning strike occurs directly overhead of the flat plate antenna. Such a scenario can be modeled as a single charge moving from a typical lightning discharge height of 4km to the ground plane of Earth's surface [5]. Additionally, in performing the calculations to select a component value for the charge amplifying capacitor in the feedback path of the slow antenna, it is important to consider that the mounting of the flat plate antenna in the configuration selected for this lightning detector improves the sensitivity of the charge detector by a factor of 5 [4].

The electric field change created when a charge, Q, moves to the ground from height, H, directly overhead can be found using equation (1). Then, the voltage drop across a capacitor, C, can be calculated using equation (2) when an antenna of area, A, is in the presence of an electric field, E [5].

$$\mathrm{E} = \frac{2\mathrm{Q}}{4\pi\varepsilon_0 H^2} \tag{1}$$

$$\mathrm{V} = \frac{\varepsilon_0 EA}{C} \tag{2}$$

Combining and evaluating the equations above, it is found that for a typical lightning discharge, which moves between 7C and 10C of charge to the Earth's surface from an average height of 4km, the slow antenna will output its maximum value for an overhead lightning strike if the capacitor value is 1500pF. This value also takes into account the added sensitivity due to the mounting gain.

2) Discharge Resistor

The value of the discharge capacitor is then selected to give an RC time constant, τ, for the slow antenna of 6s [4]. The RC time constant can be calculated using equation (3) [6].

$$\tau = \mathrm{RC} \tag{3}$$

Given the capacitor value selected for appropriate maximum values, the slow antenna feedback resistor is found to be 4GΩ.

3) Operational Amplifier

As mentioned previously, the op-amp selected for this design must have a low intrinsic bias current. Using this design constraint and knowing that ±5V supply rails will be available to power the op-amp, the OPA129 ultra-low bias current operational amplifier was selected. The OPA129 has a typical bias current of 100fA.

4) Guard Ring

When placing all selected component footprints in the printed circuit board (PCB) design, an additional measure was taken to ensure the correct operation of the slow antenna. A guard ring, surrounding the input terminals of the op-amp was connected to the ground (0V) potential.

This guard prevents stray currents from traveling through the insulator in the PCB [8]. Given the high impedances of all components in the slow antenna circuitry, something as seemingly minor as a fingerprint on the surface of the PCB can allow currents to flow. Even the smallest currents can cause a significant voltage at the output of the op-amp due to the large feedback resistor. Fig. 11 shows the placement of the guard ring.

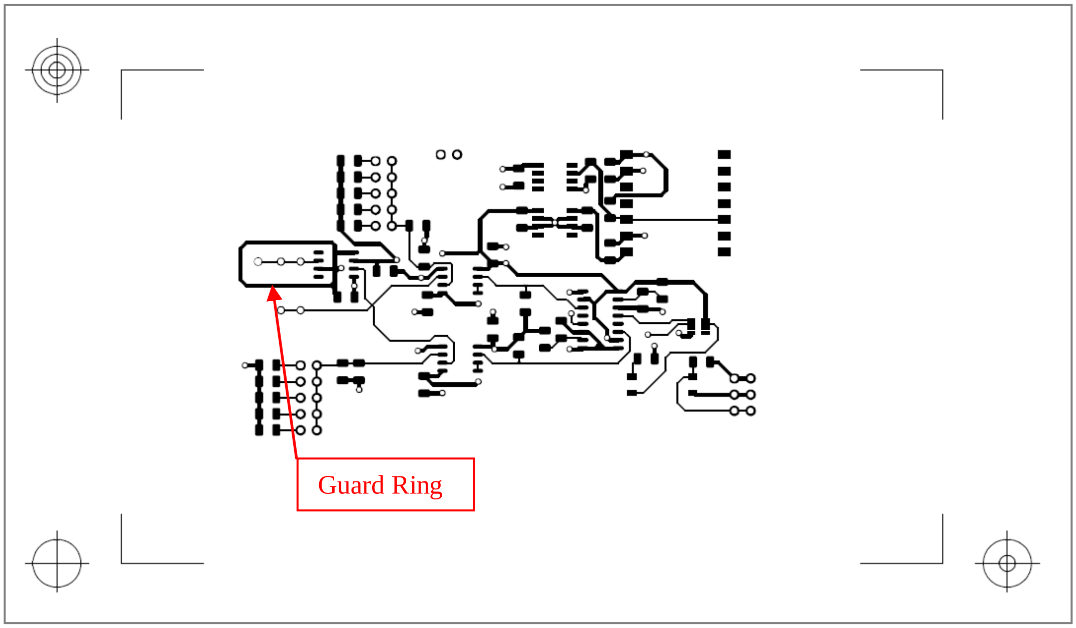


Fig. 11: Analog trigger PCB layout.

VIII. TRIGGER DESIGN APPROACH

Following the design of the slow antenna circuitry, lightning events can be detected by the voltage spikes at the output of the slow antenna. The triggering system implemented should detect these voltage spikes and create a stable, fixed-duration pulse that can be used to trigger data storage.

Two potential triggering systems are considered as design alternatives for a triggering system. A threshold detector can be used to detect the lightning discharge. When the slow antenna output crosses a specified threshold a controlled pulse will be outputted. This system is referred to as an Analog Threshold Detector. A differential detector will also be considered to detect the lightning discharge. The output of the slow antenna will be digitized and consecutive samples are compared for a large difference. This large difference will result in a controlled output pulse. The system is referred to as a Digital Differential Detector.

It was decided that both design alternatives will be implemented so a comparison can be made between the two systems. Each system should be designed to create the same positive pulse trigger signal so that the later integration of the trigger input with the data-logger does not depend on the type of trigger system being utilized.

IX. ANALOG THRESHOLD DETECTOR

A. Desired Operation

The analog threshold detector designed should detect lightning events within a selected radius of the audio recording system station. In the event of a detected lightning discharge, the system should create a positive square pulse at the logic levels used in the data-logger system. The pulse should be stable at a high logic level for a fixed period of time before falling back to a low logic level. The period of this high signal should be sufficient for the microprocessor, used in the data-logger system, to detect the positive level so triggered data storage can begin. The data-logger's onboard microprocessor is Freescale's HCS12X. At the clock speed of 40MHz used on this chip, a signal duration of 1.0ms was selected as being sufficiently long for detection.

B. System-Level Design

In order to implement the desired behavior of the analog triggering circuitry, the following systems were utilized. Fig. 12 shows the system-level design selected for the analog triggering system.

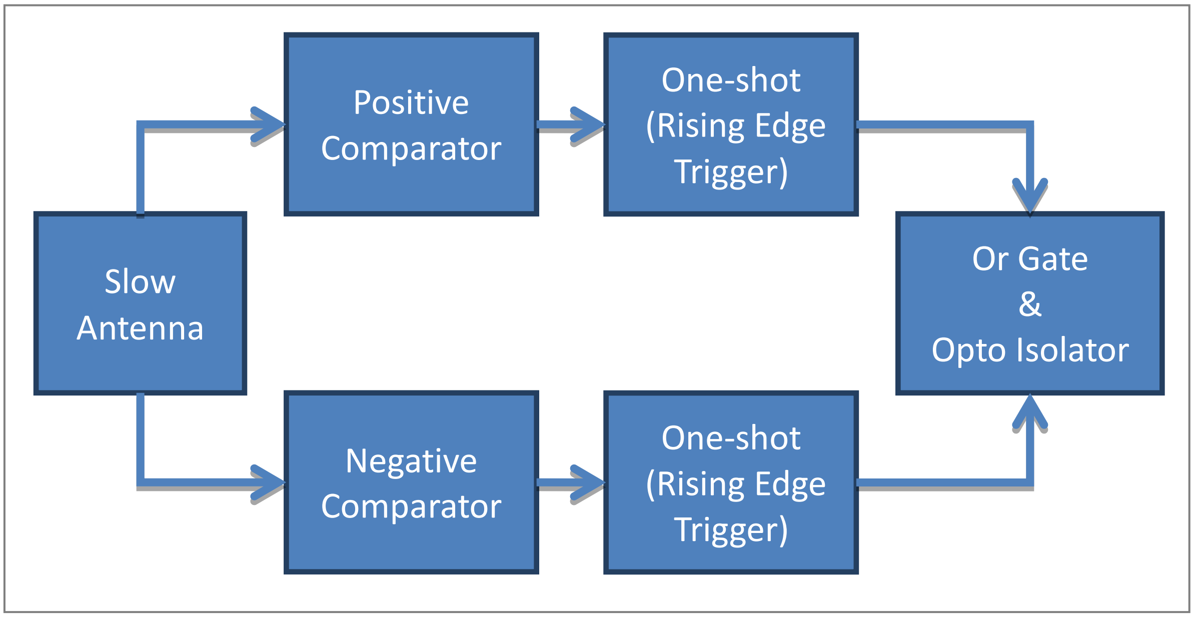


Fig. 12: Analog-triggering system block diagram.

1) Comparators

The voltage output from the slow antenna is fed into two comparators. This ensures that triggering will occur on both positive and negative lightning events. The comparators detect when the magnitude of the electric field change, represented by the change in slow antenna voltage, exceeds a selectable reference level. These reference level selections relate directly to the desired detection radii. The electric field detected at a distance of R from the lightning event by moving a charge, Q, from height, H, can be calculated using equation (4). This magnitude of electric field will then create the voltage drop, V, across the capacitor as determined in equation (2).

$$E = \frac{2Q}{4\pi\varepsilon_0(H^2 + R^2)} \tag{4}$$

Lightning at larger distances will create smaller values of electric field at the detector. Therefore, to detect distant lightning events, lower triggering thresholds must be used. Table I shows the reference voltage needed for each detection radius.

TABLE I
THRESHOLD VOLTAGES FOR INCREASING RADII

Radius of Detection	*Threshold Voltage*
5 km	±0.885V
10 km	±0.186V
15 km	±0.0630V
20 km	±0.0273V
30 km	±0.00840V

When the slow antenna output voltage exceeds the threshold magnitude, the output of the comparator will transition from a low to a high logic level.

2) One-Shots

The one-shots used in this circuit detect the low-to-high transition made when the comparator thresholds are exceeded. When this transition occurs, the one-shot outputs a 5V pulse. The duration of the output pulse is determined by external components. After the pulse is completed, the one-shot waits for the next rising edge of the comparator.

3) Or-Gate

The or-gate used in this circuit combines the outputs of the two one-shots. Because it is desired to detect all lightning events, it is not necessary to distinguish between the positive and negative lightning events detected by the two signal pathways in the analog circuit. The or-gate makes the overall signal output of the triggering system a positive pulse in the case of either positive or negative lightning.

4) Optical Isolator

Optical isolation of the triggering signal output provides the necessary noise and crosstalk, reduction. Additionally, using an optical isolator allows the signal levels to be shifted to the data-logger logic levels.

C. Component Selection

After the functional circuit design had been completed, it was necessary to select components that would function together and give the desired output for each step of the analog triggering system. In addition to desired functionality requirements of each component, it is necessary to consider the ±5V supply rails that are available to power components.

1) Comparators

The comparator selected was the LM311 differential comparator. The LM311 is beneficial for our purposes because it produces a positive output voltage for both positive and negative events. This is important because the input to the one-shots must be positive.

2) One-Shot

The one-shot selected was the SN74AHCT123A. This chip has two independently controlled one-shot elements. This one-shot has external resistors and capacitors that determine the length of the pulse. The pulse duration can be calculated from the external component values using equation (5).

$$t_w = \mathrm{R_T C_T} \tag{5}$$

Designing for a pulse duration of 1.0ms, component values for the external timing components were found. The external timing resistor had a value of 100kΩ. The capacitor value was calculated to be 0.01uF.

3) *Or-Gate*

The or-gate used was the 74V2G32. It was selected for its larger than average physical footprint and quick propagation delay.

4) *Optical Isolator*

The optical isolator used in this circuit was the TCLT1002. This optical isolator had a current transfer ratio between 63% and 125%. This determined the value of external components used to isolate and change the signal levels of the trigger. The biggest concern here was that the output resistor had to be large enough such that the current allowed to pass through the output side of the optical isolator would create an adequately sized voltage drop to indicate a low logic level.

D. *Final Design*

The final pieces of the design process for the analog triggering system were to include peripheral components such as decoupling capacitors on the power lines and pull-up or pull-down resistors to maintain steady-state outputs. The overall circuit diagram for the analog triggering system is shown in Fig. 13.

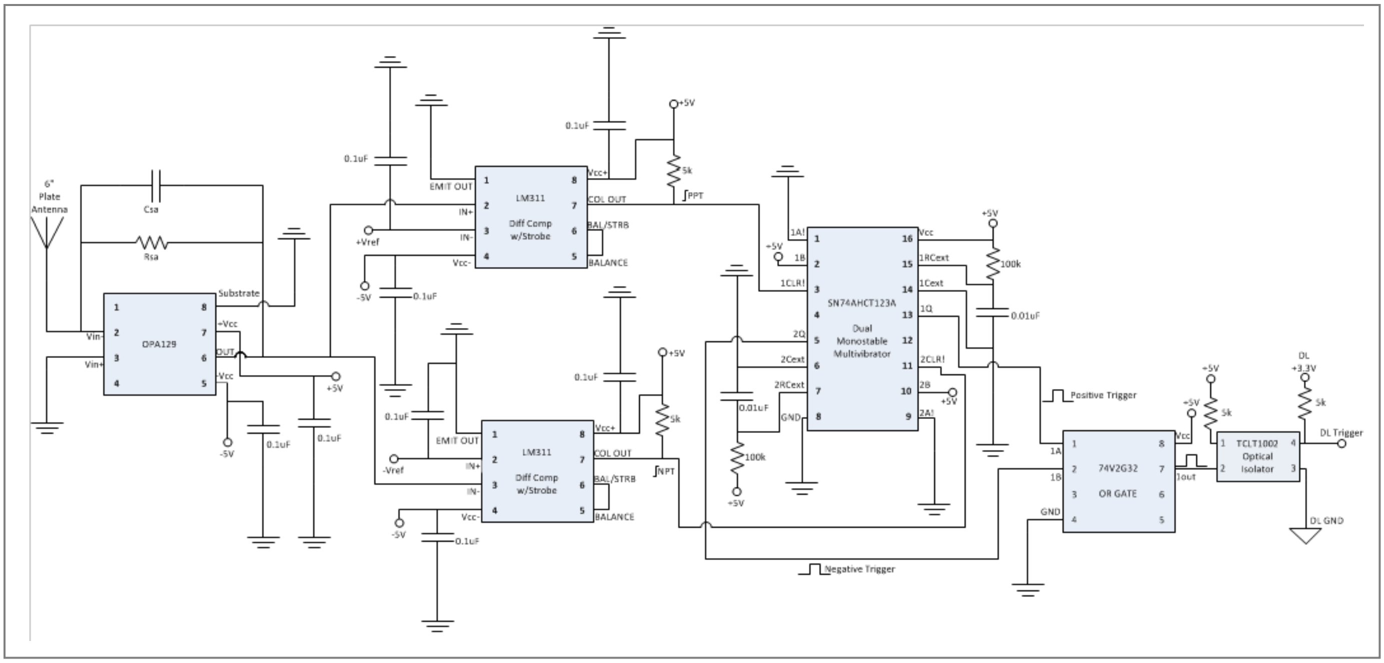


Fig. 13: Analog triggering system circuit diagram.

X. DIGITAL DIFFERENTIAL DETECTOR

A. *Desired Operation*

The digital triggering system can be implemented on a separate microprocessor board sampling the slow antenna output. Upon detection of a sudden lightning caused spike, this system should create a 1.0ms duration 5V pulse output.

B. *System-Level Design*

The digital triggering system should digitize the signal output from the slow antenna. The difference should be taken between consecutive signal measurements. When there is a significant change in the slow antenna voltage between the two samples, a lightning event has likely been detected. In this event, a fixed length trigger output should be generated. This functionality is shown in Fig. 14.

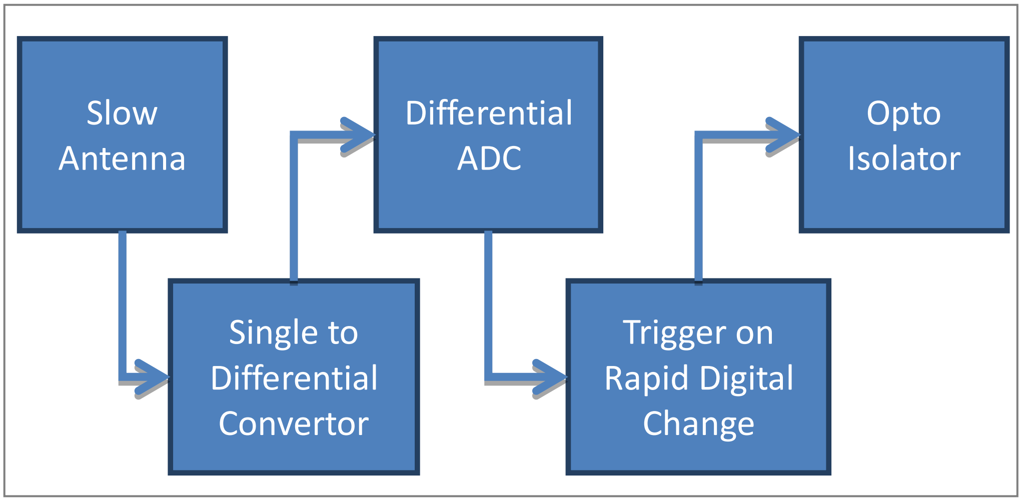


Fig. 14: Digital triggering system block diagram.

C. *Program Flow*

Fig. 15 shows the theoretical detection of a lightning event in the Digital Differential Detector.

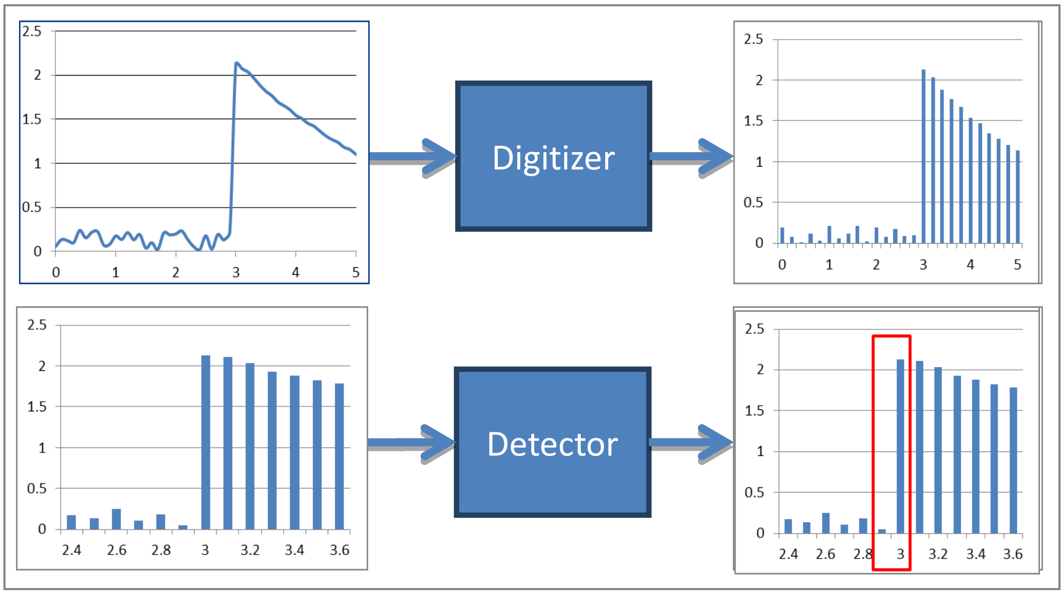


Fig. 15: Digital differential detector.

The slow antenna output voltage is sampled and digitized. Consecutive samples are then compared. Large differences between these consecutive samples indicate the occurrence of a lightning event. A trigger pulse is then created.

D. Optical Isolator

The produced trigger must be electrically isolated from the data-logger system. A separate PCB must be designed to perform this isolation using the same theory as that of the optical isolator in the analog triggering system.

XI. TRIGGERED DATA STORAGE

Integration of the triggering output to the data-logger system is the same in both the analog and digital systems. This is achieved due to the design of equivalent output trigger specifications..

A. Trigger Input to Data-Logger

The 1.0ms trigger output that was generated is read in using input capture in the HCS12X. Input capture detects the rising edge transition of the trigger pulse and uses the time of this event to begin data storage.

B. SD Storage Criteria

Audio data is constantly being recorded using the microphone and saved using a circular buffer. When a trigger is detected, the circular buffer is written into the SD card. Writing the contents of the buffer when the pulse is detected yields pre-trigger recording of a time length equal to the amount of information that can be stored into the circular buffer. After the trigger occurs, the circular buffer will refill and again store the audio thunder data a set number of times. Adjusting the number of times which the buffer is written to the SD card controls the recording time following a lightning event.

C. Multiple Trigger Events

One potential problem that might arise with such a triggered recording system is if a second trigger event occurs while data is still being recorded and written from a previous trigger event. If this were to occur, data storage would continue for the specified recording length after the second trigger. The circular buffer will be written to the SD card, the fixed number of times specified in the firmware, after each trigger event. Recording will continue until there has not been a trigger within the last recording period. With this setup, it is possible to have a period of time with near continuous data storage if new triggers consistently occur while the previous trigger's data storage is still in progress.

XII. TESTING

A. Slow Antenna

Although the operation of slow antennas has been proven successful in the past, the system was tested to prove that it worked as expected. To test the slow antenna, a secondary plate was put over the flat plate antenna (controlled separation was achieved through a nylon spacer). A voltage was then applied to the secondary antenna to produce an electric field. To simulate a lightning event, a pulsed voltage can be applied to the top plate of the spaced pair. This pulsed voltage creates a large fast change in the electric field between the two plates, similar to field changes that occur during lightning. The results of the electric field slow antenna test can be seen in Fig. 16. The output of the slow antenna was as expected. A large voltage change occurs when the electric field first changes. The output then decays exponentially as defined by the RC time constant of 6s.

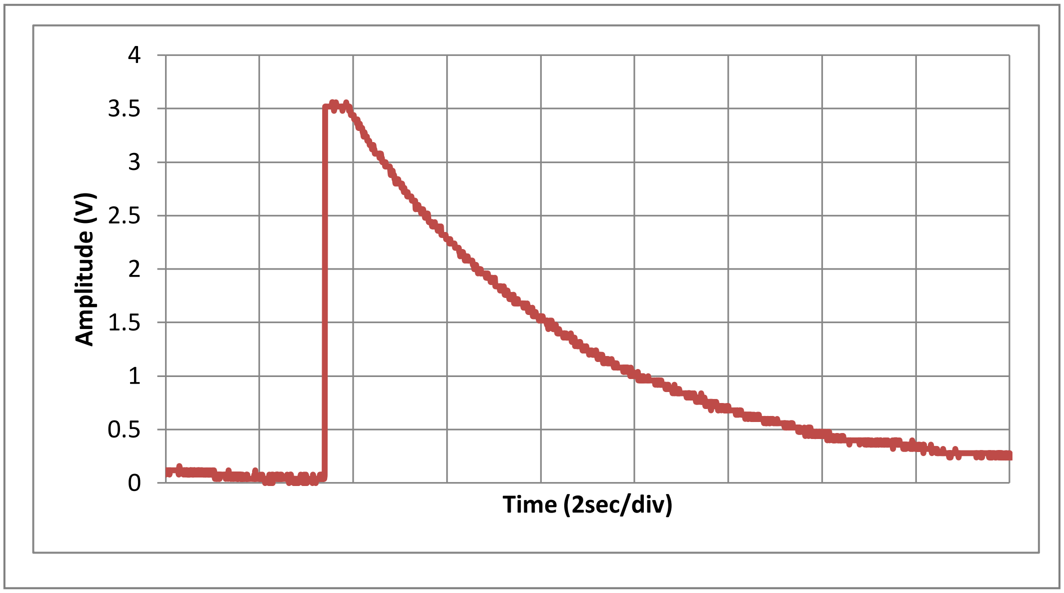


Fig. 16: Slow antenna electric field testing.

B. Analog Trigger

A test signal, created using a signal generator, was inputted in place of the slow antenna signal. The behavior of the triggering system was confirmed. A 1.0ms positive pulse was generated every time that the input signal crossed either of the selected reference voltages. The recorded data is shown in Fig. 17.

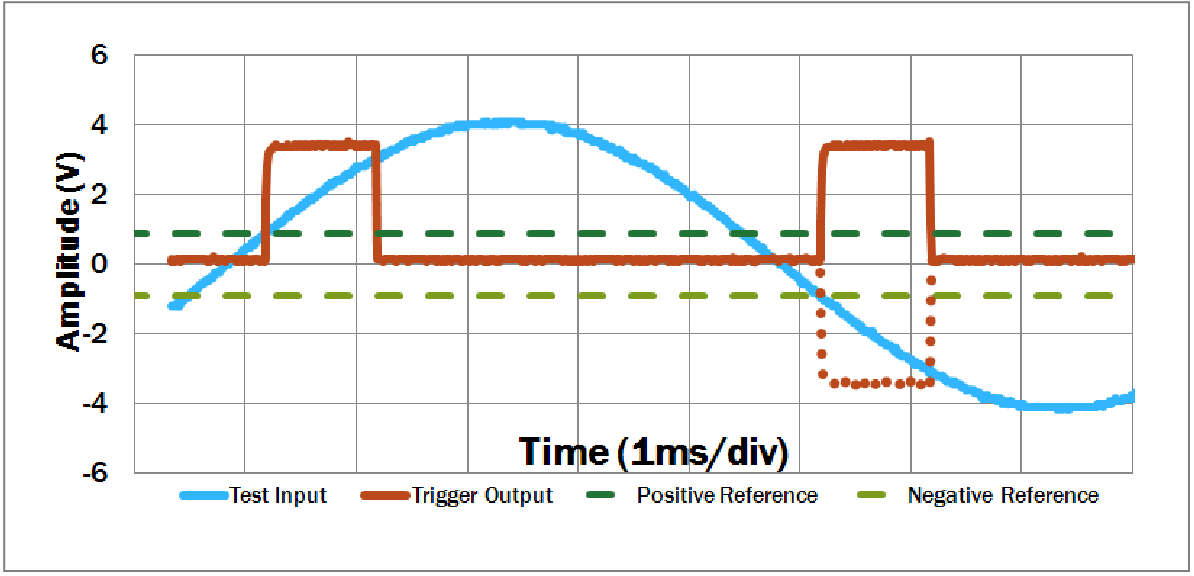


Fig. 17: Analog trigger testing.

C. Analog Trigger with Slow Antenna Input

With the slow antenna circuitry working, the whole analog threshold detector was tested. As seen in Fig. 18 a) and b), when the slow antenna output crossed the threshold a 1.0ms pulse was created.

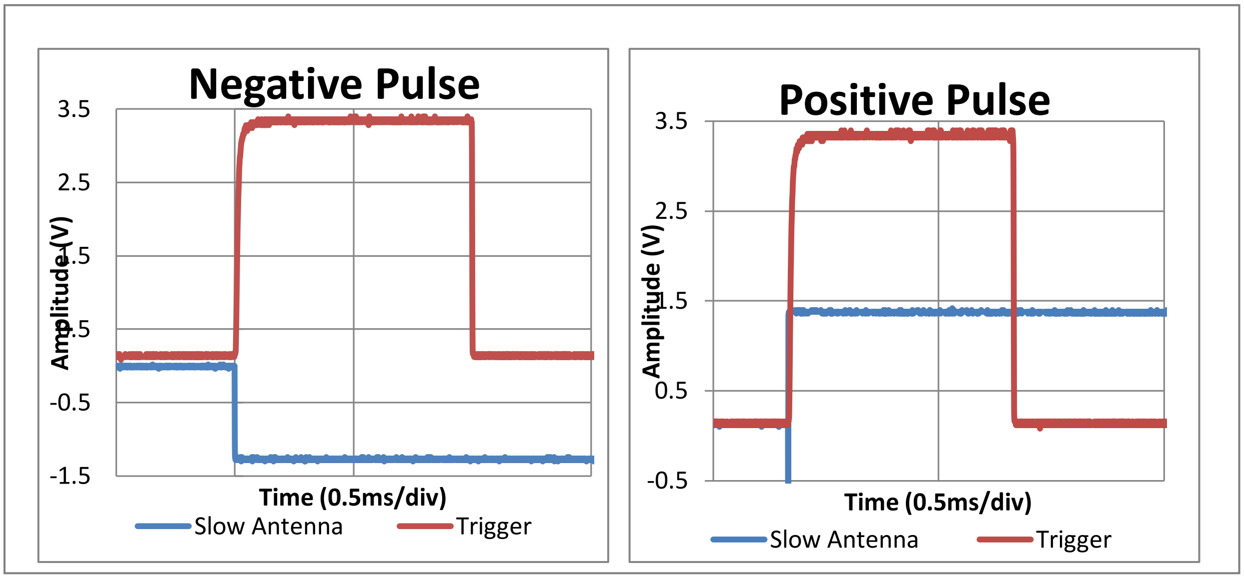


Fig 18: a) Negative pulse electric field triggering.

Fig 18: b) Positive pulse electric field triggering.

D. Optical Isolator

The trigger output was put through the optical isolator with the output of the optical isolator powered by 3.3V, used on the data-logger board. The trigger output shape was maintained across the optical isolator and the logic levels were shifted appropriately. On the trigger system side of the isolation, a high logic level of 5V was attained; on the data-logger side of the optical isolator a 3.3V logic level was observed. The 3.3V logic level can be seen in Fig. 17.

XIII. PROJECT STATUS

A. Slow Antenna

The slow antenna has been designed and prototyped. The circuitry is physically implemented on the analog triggering system PCB. The slow antenna was successfully tested using created electric fields.

B. Analog System

The analog system has been designed, implemented and tested. Circuit behavior is as designed. Trigger pulses are created at the appropriate times and durations. The completed analog triggering PCB is shown in Fig. 19. The complete analog system has successfully been tested with created electric fields.

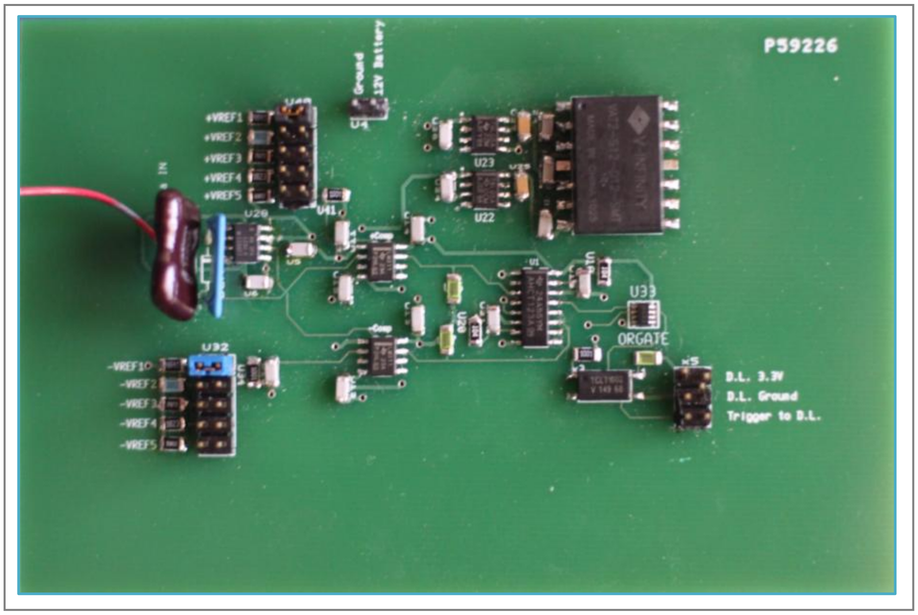


Fig. 19: Analog triggering system PCB.

C. *Digital System*

Conceptual design of the digital triggering system has been completed.

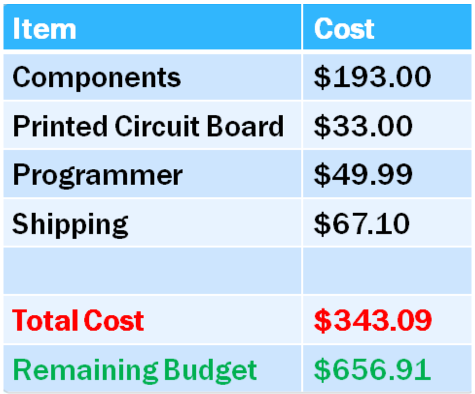
D. *Trigger Integration*

Program flow for triggered data storage in the current data-logger system has been completed. Modifications to the existing code are in progress.

XIV. BUDGET

The provided budget was $1,000. Table II shows the budget spent during the design process as well as the funds remaining.

TABLE II
TRIGGERING SYSTEM BUDGET BREAKDOWN



Item	Cost
Components	$193.00
Printed Circuit Board	$33.00
Programmer	$49.99
Shipping	$67.10
Total Cost	$343.09
Remaining Budget	$656.91

Several data-logger systems will need to be retrofitted with the designed triggering system. Therefore, it was important that the triggering system be relatively inexpensive to manufacture. The analog triggering system can be replicated for $162.57. At this cost, a future system upgrade is feasible.

XV. FUTURE WORK

While much of the preliminary design work has been completed, some implementation and testing of concepts still needs to be completed.

A. Digital System

Total system implementation and testing is still required. The coding will be relatively simple to complete due to a preexisting system that already has the slow antenna and digitizing systems in place. The implementation of a new independent system will take much longer because parts must be selected and a printed circuit board must be created. This delay can be mitigated if the preexisting system can be obtained from Dr. William Rison. The integration of the digital system should be trivial due to the similarity in trigger outputs between the analog and digital systems.

B. Triggered Data Storage

Modifications to existing code must be completed. An algorithm for circular buffering and storage must be tested. The overall system must be tested to prove functionality with no data loss.

C. Field Testing

Complete system testing may be completed when the system is deployed in the Magdalena Mountains in the summer 2013 thunderstorm season. Real lightning events can be detected and the thunder data may be stored in the SD card. Successful triggered data storage will then confirm the overall functionality of the triggering system implementation.

A full comparison of the Digital Differential Detector and the Analog Threshold Detector can be completed during the field testing. This testing will provide an answer to the question of which detector works better. To complete this comparison a digital and analog detector will have to be deployed. The detections of these two systems will then need to be compared to Langmuir’s lightning mapping array to test for best detection.

D. Differentiation of Lightning Types

If differentiation between positive and negative lightning events becomes desired, the combination of the positive and negative event, through the or-gate, will still work. In order to distinguish the two types of events the pulse lengths can be set to different values. For example, the duration of the positive one-shot pulse could be increased to 2.0ms and the duration of the negative one-shot pulse could remain 1.0ms. This modification will be simple and only involve exchanging a single resistor on the positive trigger one-shot.

XVI. CONCLUSIONS

Because the digital triggering system has not yet been successfully implemented, a comparison of the two system design concepts cannot be performed. However, the performance of the analog triggering system has been confirmed. Using the analog triggering design, it is possible to implement a trigger pulse in the event of a lightning discharge event. This pulse can then be used to implement triggered data-storage.

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FIGURE SOURCES

Fig. 5 courtesy of P. Krehbiel. NMT Physics Department
Fig. 6 from: http://www.crondallweather.co.uk/lightning.html#.UWHzPJNlnW8