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The Georgia Tech High School Field Mill Project

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Abstract

The Severe Storms Research Center (SSRC) at the Georgia Tech Research Institute (GTRI) has mentored high school students from a local magnet high school for the last several years. Three students have contributed to the development of a low cost, easily constructed atmospheric electric field mill. The students researched the subject, selected a plan, modified that plan, and have constructed three versions of the mill.

Lessons learned in the construction and operation of an initial 'alpha' version of the mill were applied to produce two 'beta' versions. A PSPICE simulation of the current 'beta' mill was used to educate the student on circuit fundamentals as well as to troubleshoot the design. The current 'beta' version consists of several stock printed circuit boards (PCBs) that were laid out by one of the students, along with a standard list of parts. Both the 'alpha' and 'beta' versions of the mill were operated alongside a Vaisala EFM-II commercial mill and compared favorably.

It is hoped that, after a few more optimizations and modifications, a low-cost mill design will be available that can be distributed to leading high school science programs in Georgia. These mills may be used to investigate local electric field effects, as well as to create a large scale electric field measurement array with a potential to investigate lightning initiation and cessation prediction.

Introduction

One of the purposes of the Severe Storms Research Center (SSRC) is to enhance scientific outreach to students in the state of Georgia. Another aim is to enhance the ability of researchers to predict, detect and analyze severe storms over the state. Both of these aims are met in the high school field mill program. In the program, high school students from a local magnet high school are mentored over a semester. The goal of the program for the students is to involve them in some ‘real world’ science and have them, in a very self-directed manner, produce reportable scientific progress in a presentation setting by the end of the semester.

To this end, three students have been involved in the construction, evaluation and refinement of an atmospheric electric field mill. Initial potential plans were identified during a literature and internet search, from which a single promising design was selected. This design was evaluated and an 'alpha' version of the 'student field mill' was produced by the first mentee. The alpha version was compared with a commercial field mill, the Vaisala EFM-II. After analysis of the results of this initial comparison, the second student made some incremental improvements to the student mill electronics. Another aspect of this students work was the development of methods to both calibrate reponse and measure enhancement factors for field mills. A third student was involved in transitioning the beta version of the student mill from hand-crafted printed circuit boards (PCB) to 'professionally' laid out boards. This third student also performed a side by side comparison of the student mill with the EFM-II.

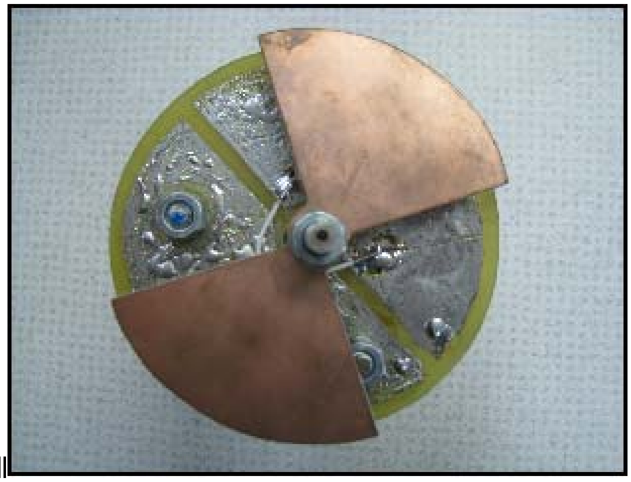
The development of an atmospheric electric field mill was chosen as a trial project for several reasons. The deployment of an inexpensive array of field mills is an element a long range goal of the SSRC to investigate lightning initiation and cessation prediction methods . To that end, there are numerous plans in various media that describe relatively simple plans for the construction of field mills [*Carlson*, 1999] [*Chubb*, 2007] [*Kneifel*, 2005] [*Trostel*, 1983].The detail of these plans are generally on the level that can be accomplished by well mentored high school students. The SSRC also already operates a commercial field mill and therefore has a 'gold standard' against which the student mill may be compared.

Alpha Version

The initial literature research identified several potential plans which could be used as a basis for construction of the student mill. In the end, the on-line plans by Stefan Kneifel [*Kneifel*, 2005] were chosen due to the simplicity of design, the common materials used in construction of the device (including a coffee can), and the conveniently small size of the finished device. One difficulty in the use of these plans was that the language of the description was german.

The main components of the alpha version of the student mill were constructed from six hand made PCBs fastened together with three bolts and a circuit hand wired on a piece of 'perf' board, all fit inside a small coffee can. The outside can provides both physical and electrostatic shielding for the electrics within. The main sensing elements of the alpha mill consists on a circular plate divided into four conductive quadrants. The two opposing quadrants are wired together and insulated from the other pair of quadrants. Above the sensing element, a single conductive, grounded 'chopper blade' was constructed which is attached to a small DC motor. The arrangement of the sensing elements and the chopper blade can be seen in Figure 1. As the chopper blade spins above the sensing elements, alternating positive and negative charges are induced on the commonly wired sensing elements due to the ambient electric field. Below the sensing elements PCB is a small replica of the upper chopper blade. This lower chopper interrupts the signal through an optical coupler and, by this means, allows the position of the upper chopper blade to be known and the AC signal from the sensing elements can be recitified.

Figure 1. Top view of alpha version of student field mill



The motor is attached to a similar circular PCB located below the sensing elements. Two other circular boards are used for structural support and electrical shielding below the motor support. The arrangement of these elements can be seen below in Figure 2. The top PCB contains the sensing elements. Below this can be seen the optical coupler surrounding the small replica chopper blade. Immediately below the replica chopper is the motor mount PCB. Below the motor mount are two additional PCBs used for both mechanical stability and to electrically isolate the 'perf' board circuitry that is mounted vertically just above the bottom PCB.

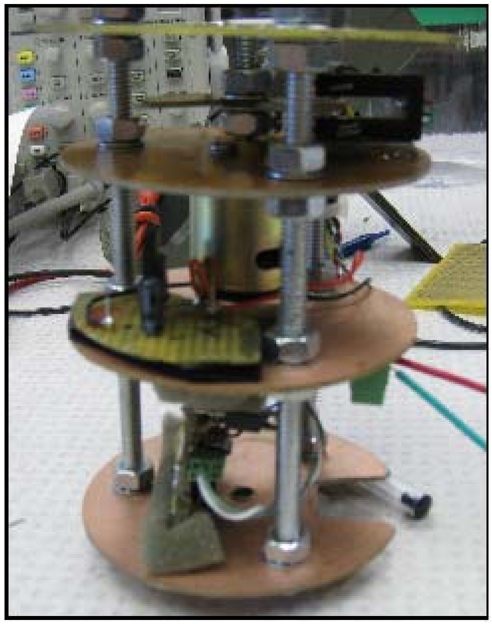


Figure 2. Side view of first beta version of student field mill

All five connected PCBs are then fastened inside a small coffee can and, typically, mounted with the sensing elements facing downwards to protect the circuitry from rainfall. The assembled mill, on a stand is shown in Figure 3.

Figure 3. Fully assembled student field mill

Once the first, alpha version of the student mill had been assembled in the laboratory, it was moved to the roof of the SSRC. The roof houses a Vasaila EFM-II field mill. The EFM-II is a high quality commercial mill that has been in continuous operation on the SSRC roof for over five years and is well suited as a comparison device for the student mill. The two mills were operated for several hours at horizontal separation of about 20 feet. This allowed them to measure very similar fields while not interfering with each others measurements. After gain and offset adjustments, the uncalibrated reading from the alpha version of the student mill compared very favorably with the reading from the commercial mill. The two mills reading are shown in Figure 4. The student mill, labeled 'DMB Mill', follow closely the trends and short term changes indicated by the 'commercial' EFM-II.

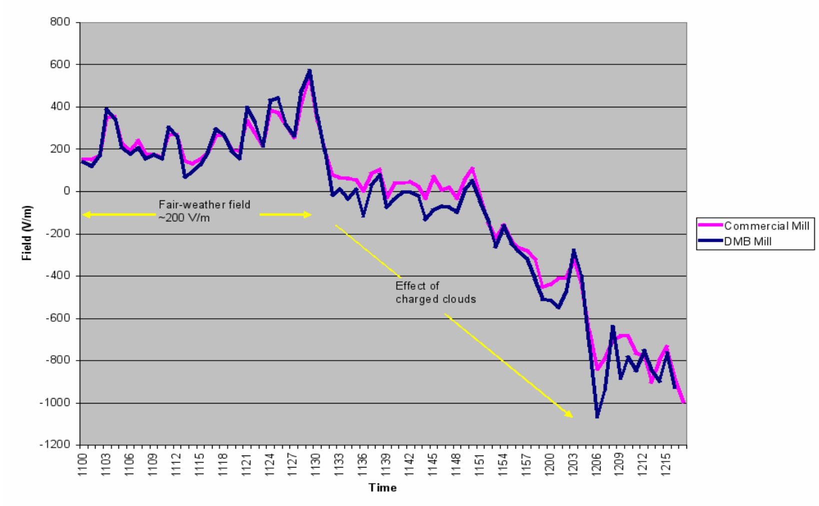


Figure 4. Side by Side Comparison of Alpha Student Field Mill and Vaisala EFM-II

First Beta Version

After completion of the successful comparison of the alpha version of the mill with the EFM-II, the second student undertook several initiatives to both improve the functionality of the mill and to develop calibration methods.

The rotation rate of the mill is important in the determination of the electric field, as the output of the mill has a component due to the shielding frequency of the sensors as well as a component due to the ambient field. The original student mill fed the DC motor directly from the output of the battery pack. It was determined that, as the battery weakened, the voltage delivered to the motor decreased and the rotation rate slowed. A voltage regulator circuit was designed and built by the student to provide the motor with a constant voltage, regardless of the supply voltage from the battery. This ensured that, as long as the battery remained above a critical level, the motor would always be driven by the same supply voltage and the rotation rate would be more stable.

Another effort undertaken by this student was the development of calibration procedures. The basic setup was to place the student mill between two very large (10' by 10') charged capacitor plates. The plates could be charged to different potential differences using a high voltage power supply, therefore allowing field values similar to those experienced in the free atmosphere to be produced. The basic setup, shown in Figure 5, consisted of the upper plate set to various potentials and the lower plate set to earth ground. The mill top was inserted through a small circular hole into the space between the two plates. With a plate spacing typically on the order of 0.3 meters, fields between +10kV m^{-1} and -10kV m^{-1} were produced. A photograph of the setup is shown in Figure 6.

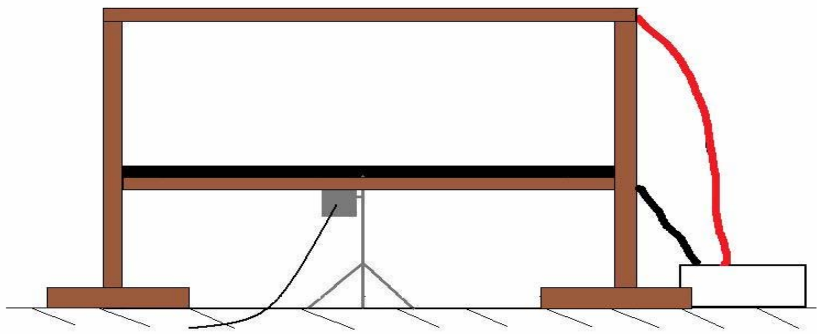


Figure 5. Calibration between two large plates

Figure 6. Calibration setup on roof of SSRC

The response of the first beta version of the student mill to these large fields is shown in Figure 7. It can be seen that, over this large range of external fields, the response is linear and consistent. The calibration setup allowed the smaller, fair weather level field response to also be examined. As the calibration results in Figure 8 show, the response is not single-valued in the region near zero applied field. The results showed an area between +/- 75 V m^{-1} where calibrated operations were not possible.

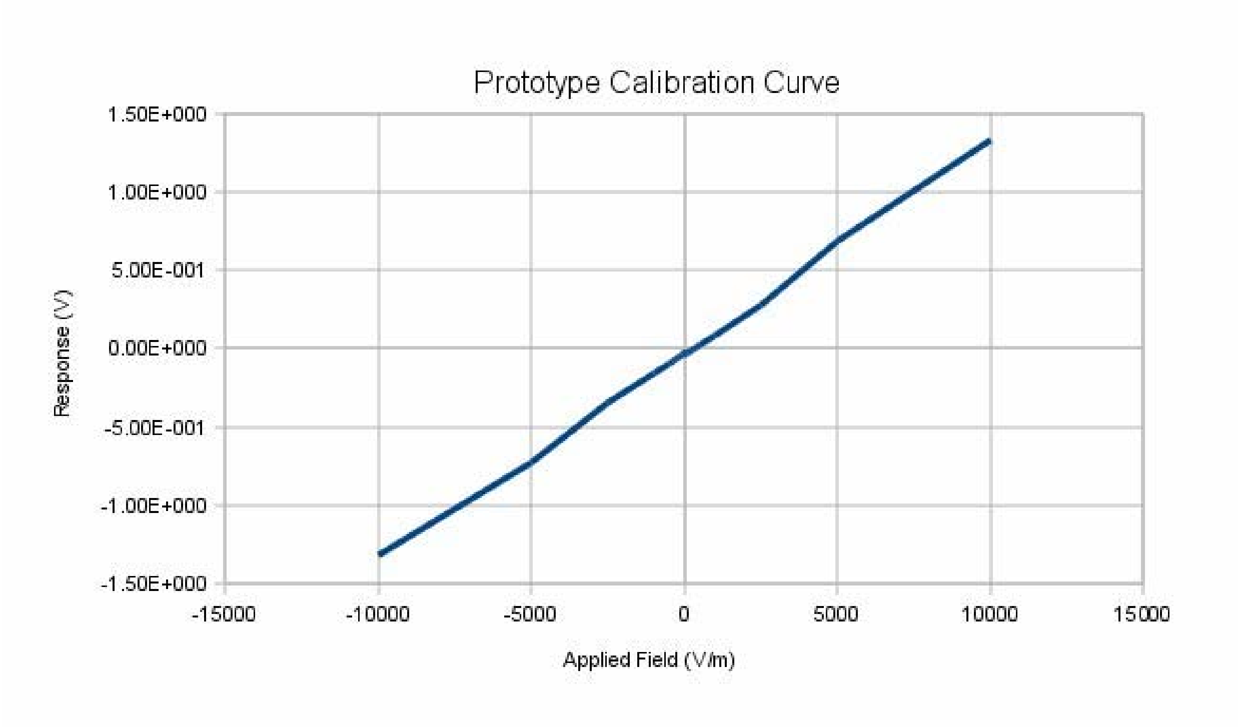


Figure 7. Large scale calibration of first beta version of student mill

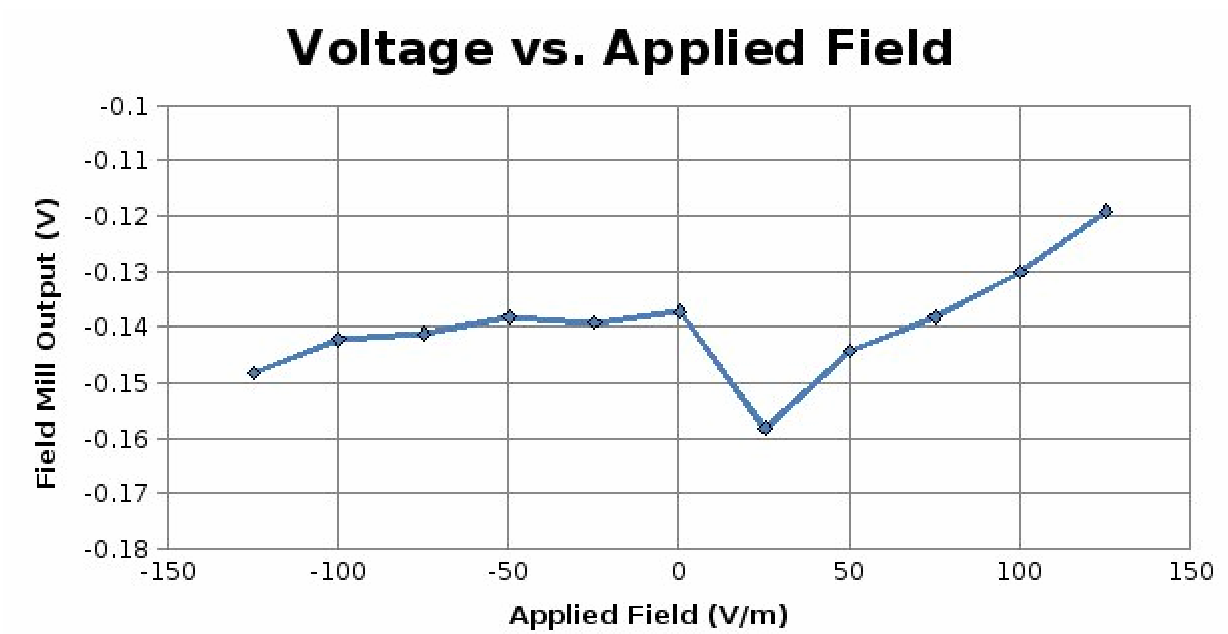


Figure 8. Calibration anomaly noted near zero applied field for first beta version of student mill

The calibration plates had also been designed to support the investigation of the enhancement factor of the elevated, stand-based field mill setup. The field lines tend to be enhanced over the top of projected surfaces as is illustrated in Figure 9 below. In addition, the mills sensing elements are faced downwards in typical operations to protect against rainwater. These orientation changes affect the mills output.

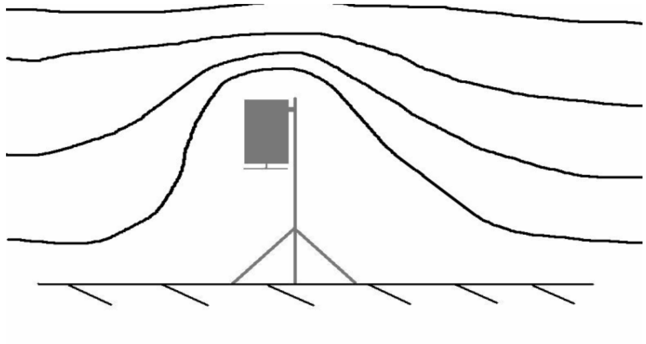


Figure 9. Enhancement of field over extended object

A measurement to determine the stands enhancement effect was planned as shown in Figure 10. In this arrangement, the top, high potential, plate of the calibration setup is removed. The mill is placed so that it projects through the hole in the surface of the lower, ground plane. This large ground plane acts to remove the enhancement effect and allows the ambient field to be measured by direct comparison to calibration experiment output. If a companion, pre-calibrated mill on a stand is used, or if the mill orientation is quickly modified to the standard mode shown in Figure 9 during a period of calm, slowly changing fair weather fields, the enhancement factor may be determined. Unfortunately, the lack of single-valued response at low, fair weather fields precluded this test.

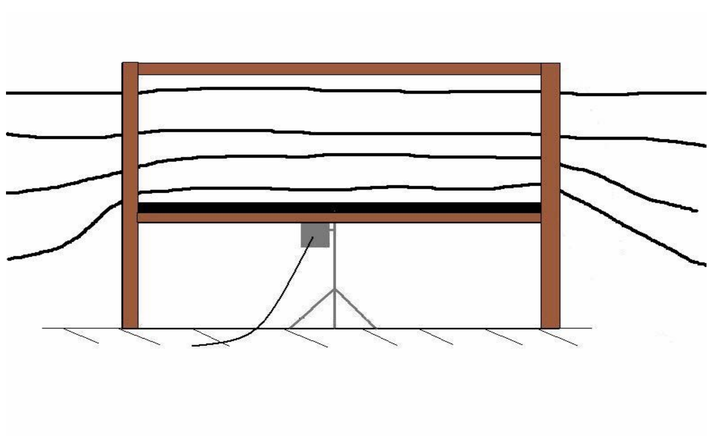
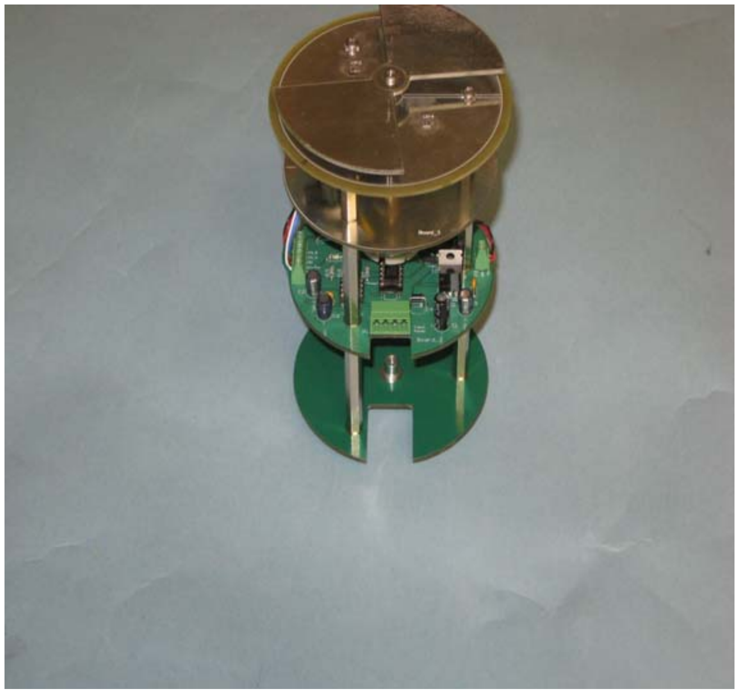


Figure 10. Use of lower ground plane in ambient field measurement

Second Beta Version of Student Mill

The latest student mentored in program has enhanced the mill design in two very significant ways. The PCBs that are used to construct the mill have now been laid out using professional design tools and sent to an outside PCB fabrication shop for production. The results are twofold. The fit and finish of the main components of the



mill are far superior, as can be seen in Figure 11, below.

Figure 11. PCB (beta 2) version of student field mill

Improvements have been made in all the components of the mill, including the use of standoffs and the integration of the circuitry onto the middle PCB. Operation of the mill is now much smoother.

A secondary benefit of the layout using professional tools was the integration of this layout and electrical design with the use of PSPICE for circuit simulation. An examination of the signals within the simulation discovered a component error that could potentially impact the low field readings. The circuit used with the second beta version is shown in Figure 12.

This version of the mill was also run along side the professional EFM-II device for comparison. The results, shown in Figure 13, demonstrate very good correspondence between the two mills outputs. One deviation seen in the student mill is a slow increase in output over time. The main spindle on which the upper chopper blade was fixed was seen to be rubbing on the penetration hole in the sensing plate during this experiment. Over the course of the comparison, the friction rubbed substantial material from the penetration hole, and may have allowed the chopper blade to spin more freely later in the experiment. A simple bearing inserted in the sensing plate that supports the chopper blade spindle would address this concern.

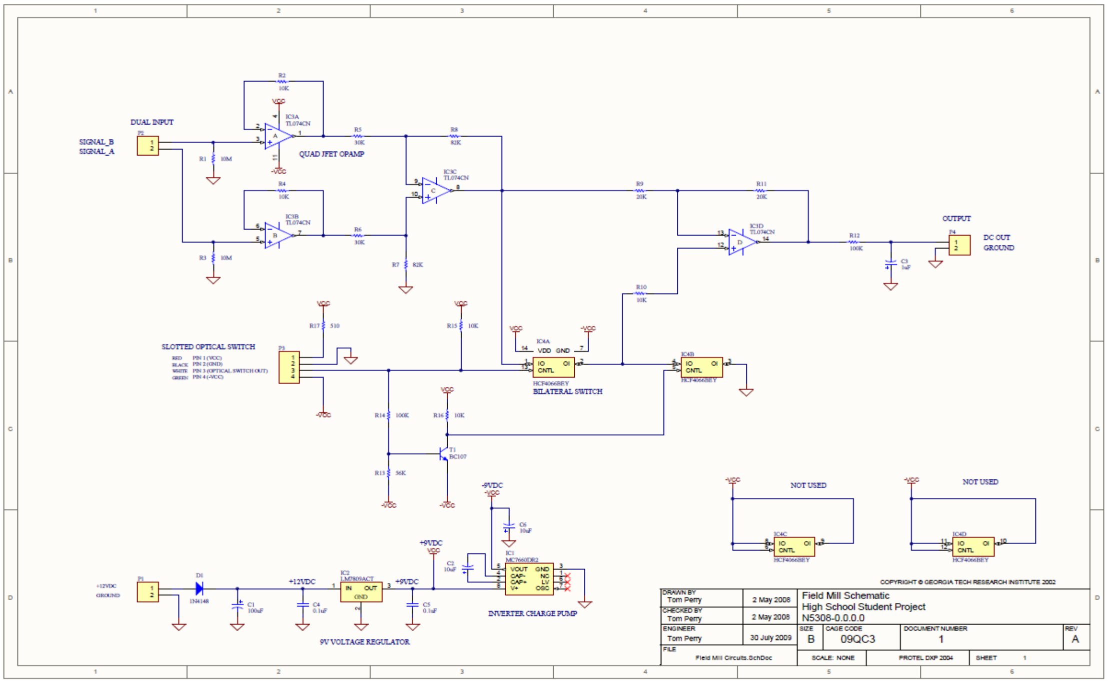


Figure 12. Beta 2 Student Field Mill Circuit Diagram

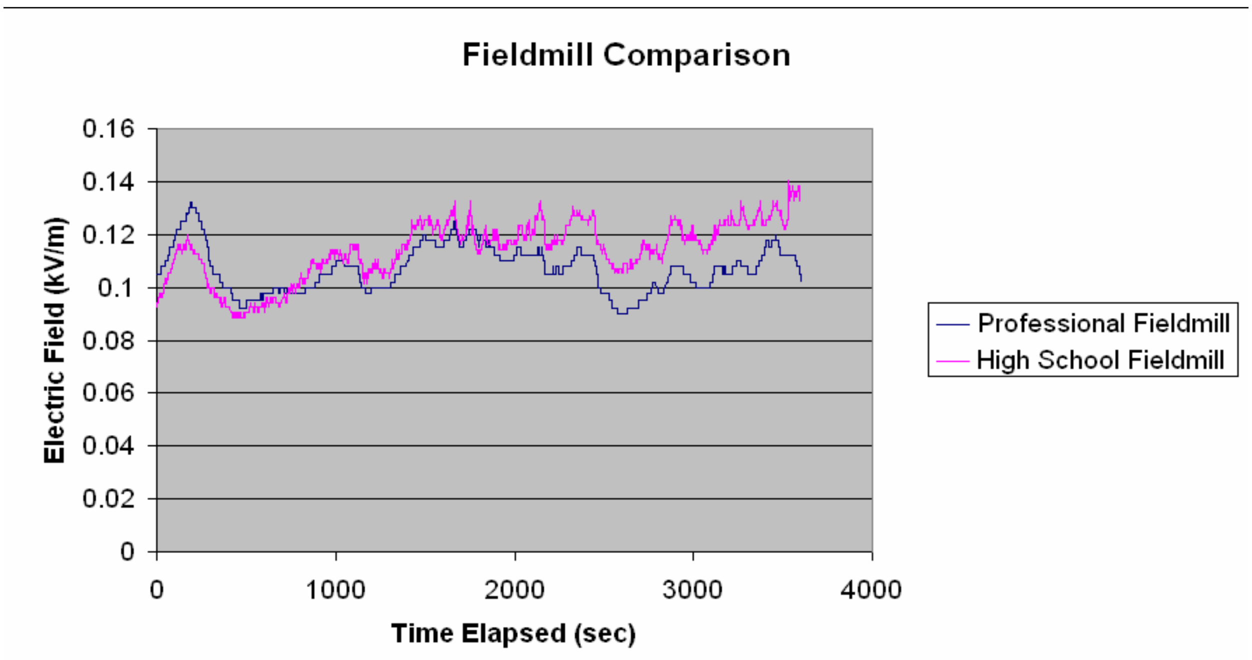


Figure 13. Comparison of second beta version of student mill with EFM-II

Future Plans

Future plans for the student mills include revisiting the calibration procedures using the improved PCB design, inclusion of the support bearing in the sensing PCB, and the development of display and networking options in advance of array development.

It is hoped to push a simple, yet accurate mill design out to leading high schools across the state of Georgia. The deployment of an array of electric field mills could then be used to investigate the development thunderstorm and other severe storms across the state. Arrays of mills have shown promise as part of the solution to predict both lightning initiation and cessation [*Kimball and Gallagher*, 2009] [*Murphy et al.*, 2008]. The combination of the output of the student mill arrays with other existing instrumentation, such as the North Alabama Lightning Mapping Array [*Buechler et al.*, 2009] and the NEXRAD radar operated by the NWS in Peachtree City, GA could prove very useful.

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