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An Inter-university Extremely Low Frequency /Ultra Low Frequency Cooperative Project

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Abstract

Undergraduate students of Indiana University Southeast (IUS) and Purdue University collaborated to research the phenomena of natural occurring signals in the Extremely Low Frequency and Ultra Low Frequency ranges. Physics students of IUS fabricated coil antennas intended to receive signals from single hertz to approximately 100 hertz. The intent of the physics students research was to detect and analyze signals, especially those of terrestrial origin such as the Schumann resonances, lightning resonances, and the postulated electromagnetic signals that are pre-cursors to earthquake activity. Purdue Electrical Engineering Technology students designed amplification and active filter circuitry for the IUS physics students to use in their research. The Purdue students did this as a part of their RF and Power Electronics class. The relationship between these two universities respective programs proved to be mutually beneficial. The Purdue students had the experience of designing and fabricating a device which was put into immediate use. The IUS physics students supplied weekly feedback to the Purdue students on the signals that they had detected. The physics students gained a greater appreciation of electronics and the Purdue students an understanding of the physics under investigation. This project has proven to be interesting enough to continue on for three years and has received two grants from the Purdue Research Foundation. The present state of the research is briefly described.

Introduction

It has long been assumed that most of the interesting phenomena in the electromagnetic spectrum occur at frequencies above 3 kHz and indeed humans have made the greatest use of this part of the EM spectrum. However it is now known that a plethora of naturally occurring electromagnetic signals exist in the ranges of the EM spectrum called Extremely Low Frequency (ELF), 3 Hz to 3 KHz and Ultra Low Frequency (ULF) below 3 Hz. Many of these signals are of geophysical origin and because of a dearth of information existing on these phenomena, they merit further investigation. Known naturally occurring ELF/ULF signals encompass Schumann resonances, direct signals from lightning, and postulated electromagnetic precursors of earthquake. Manmade sources in these bands include the ubiquitous 60Hz power grid noise (50Hz in Europe) and secret submarine signals.

Following the suggestion of an article in Scientific American[1] a joint project was designed which involved students from a laboratory physics class (P309: Modern Physics Laboratory) at Indiana University Southeast (IUS) and students in the Purdue Electrical Engineering Technology program (located on the IUS campus) enrolled in an electronics course (EET 257: RF and Power Electronics). The IUS physics students constructed three antennas designed to be sensitive in the ULF/ELF frequency ranges. The Purdue students designed and constructed amplifying and filtering circuitry for the antennas as a part of their work in EET. The physics students were also responsible for recording and analyzing the data. To date the project has involved over 30 students and continues to be very effective in presenting meaningful research problems to students in both physics and EET programs.

The relevant science

Two electromagnetic phenomena are presently thought to exist in the frequency range below 3 KHz; Schumann resonances and low frequency electromagnetic earthquake pre-cursors. The Schumann resonances were discovered in 1952, have been investigated by many scientists and are still being examined by many experimenters around the globe[2]. The possibility that there may be low frequency earthquake pre-cursors in the electromagnetic spectrum is a more recent development which is still under debate.[3] One goal of the student project described in this paper was to investigate this latter possibility, as will be discussed below.

Schumann resonances

The ionosphere and the earth's surface are good conductors relative to air so that they can be thought of as two sides of a capacitor charged to approximately 260kV[4]. This creates a downward electric field of 100 to 300 Volts per meter in regions where there is no storm activity. This results in a discharge (leakage current) of the ionosphere/surface capacitor in fair weather of approximately 1 kAmps on average between the entire earth's surface and the ionosphere[5]. Three mechanisms are known which charge this capacitor: 1. Charge going to the ionosphere from the tops of thunderstorms (by far the most important) 2. Solar wind interacting with the earth's magnetic field and 3. Atmospheric tides in the thermosphere (a region of the atmosphere just above the ionosphere). The exact mechanism of cloud electrification is still not well understood[6] but it is this mechanism acting in thunderstorms which does most of the work in charging the earth/ionosphere capacitor.

In addition to the fair weather return current, cloud to ground lightning strokes also return charge to the earth (in effect short circuiting the thunderstorm current generator). Most lightning is cloud to cloud (and is difficult to examine) and does not contribute to the global circuit. The most common form of cloud to ground

lightning starts with a series of faint (detectable only by high speed camera) downward flows of negative charge called a stepped leader. This stepped leader apparently creates a channel for charge flow. A large amount of current (up to 30 kAmps) called the return stroke then flows out of the channel starting from the bottom part of the channel first and then from higher regions. A shockwave moving upward at speeds of approximately 1.1×10^8 m/s forms at the leading edge (furthest from earth) of the downward moving charge and it is this shockwave which we perceive as lightning. Although there are return strokes starting from the cloud and traveling downward, most return strokes travel upward. The high speed of the shockwave and amount of visible light given off and the persistence of human vision make it nearly impossible to determine which direction the shockwave is moving without using cameras or other equipment[3].
Lightning is broad band, giving off all frequencies in the electromagnetic spectrum although there is usually a peak in emission amplitudes around 10kHz. The exact frequencies emitted depend on temperature, pressure and number of electrons in the return stroke. Because of the broad band nature of the electromagnetic spectrum given off by lightning it might be thought that detectors far from a thunderstorm would record white noise with no particular signature frequencies. And in fact recordings of spectrums near lightning strikes do show a broad spectrum. The space between the ionosphere and the earth, however, form a resonance cavity so that in much the same way that only certain wavelengths will fit on a string at a given tension, only certain wavelengths of the electromagnetic spectrum will 'fit' in the earth/ionosphere cavity. The longest of these wavelengths is on the order of the earth's circumference. Because the height of the ionosphere changes from day to night due to heating and expansion of the atmosphere and from location to location around the world, the wavelength of these standing waves changes slightly on a daily basis and also depend somewhat on the location of the detector.

The result on broad band electromagnetic spectrum coming from lightning strikes due to the resonance and wave guide effects of the earth/ionosphere cavity is that low frequency electromagnetic waves are found in the earth's atmosphere at 8, 15, 20, Hz with two smaller amplitude signals at 27 and 32Hz. These are called the Schumann resonances[4,7]. Typically they are determined from Fourier transforms applied to ten minutes or more of measurements of the electric or magnetic field changes at the surface of the earth.

The laboratory

Because of the predominance of 60 hertz signals a laboratory was constructed in a remote barn on the campus. The barn has aluminum siding which is contiguous throughout. The siding was connected on two sides to an eight foot copper ground rod to shield the laboratory instruments from any signals generated outside of the lab. The two antennas were placed into the earth approximately 75 meters from the barn housing the lab.

The computers and other equipment of the ELF/ULF project. The lab was built without cost to the researchers by the university physical plant.

The antennas are fed with coax and then amplified before being fed to an analog to digital conversion board connected to the 486 computer (such outdated computers are good for mundane tasks such as data logging and can be had for free). The software used on the computer allows for Fast Fourier Transform conversion of the signal and for long term data logging of these signals so that a week or more of data can be compiled at once and analyzed. The data is transformed into a frequency domain format with specified time slices for analysis by the student researchers. Both long and short term data reception can be transformed into the frequency domain via Fast Fourier Transforms. Short time slices, such as ten minutes, are useful looking for events such as lightning. Longer compiled data up to months in time is useful for examining the Schumann resonances.

The antennas

Each antenna was wound around a very high permeability core with an approximate relative permeability of 60,000. These high mu cores are one-half inch in diameter and two feet in length and have about 6,000 feet of AWG 30 teflon coated wire in 30,000 turns wound on them. Like any multi-turn receiving loop, this antenna was designed to receive the magnetic field rather than the electric field as in the case of the dipole antenna [8]. Each antenna was encased in a piece of 2 inch PVC pipe and capped at each end to seal it hermetically. The antennas were then buried in the ground.

The physics students wound the antennas with the use of a 3/8” drill and a great deal of labor. Each antenna had approximately 30,000 turns of 30 AWG wire on them. The salient word in the previous is *approximately*. By winding the antennas by hand the results for each as a receive antenna varied considerably. One antenna showed approximately 6 decibels of sensitivity compared to the other antenna. The students and the faculty were both introduced to the very involved science of coil-winding. The research team is seeking funding or a benevolent coil manufacturer to wind new antennas at present.

Two antennas are used for reception. One antenna is horizontal pointing East-West, the second antenna is vertical. The antennas are buried next to each other in a remote site outside of the barn used to house the ELF/ULF laboratory. The purpose of the cross polarized antennas was to attempt to determine the polarity of detected signals.

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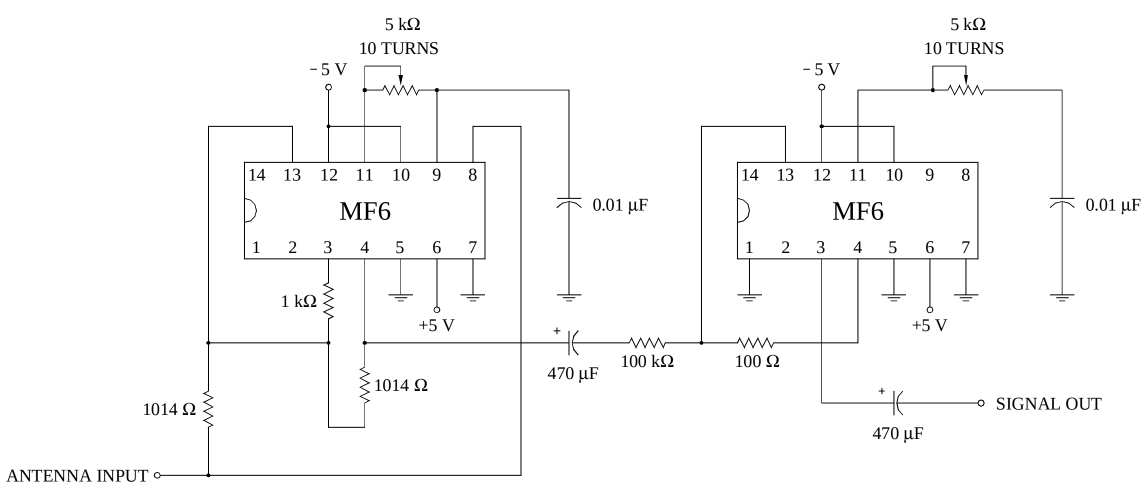
The electronics

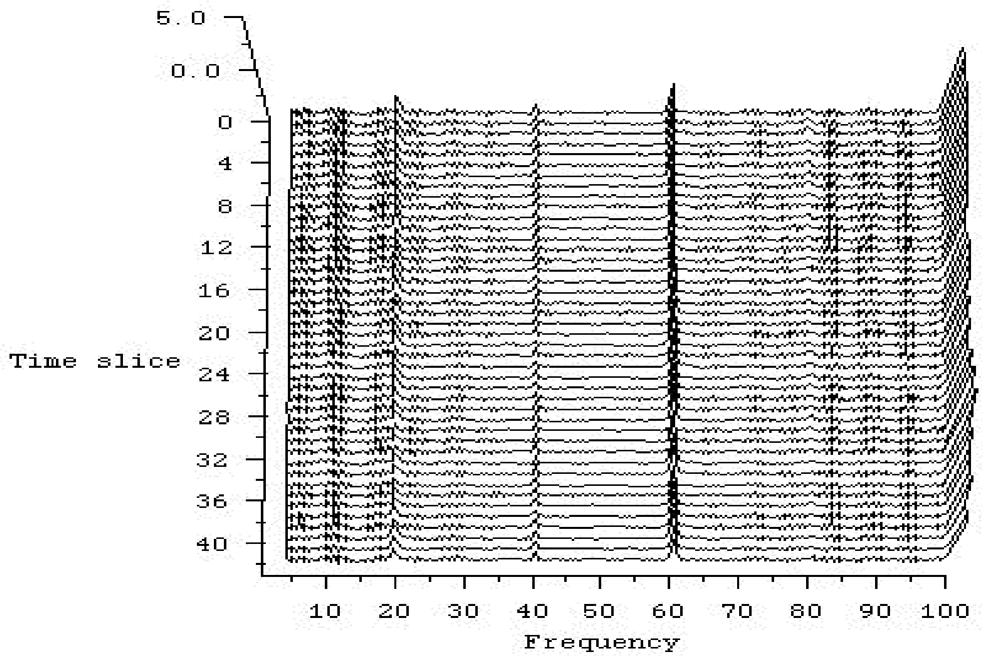
The EET students of Purdue designed an amplification and active filter circuit for use in this project. Several versions of this circuit have been made. The EET 257, Power and RF Electronics class of Purdue EET students designed a circuit that utilized a MF6 filter and its on-board operational amplifiers to achieve gain and to notch out the annoying and ever present 60 hertz. The class worked in teams and each team came up with a design of their own. A representative from each team presented their design to the remainder of the class and after all designs were presented, the class collectively chose one of the designs. This design was then laid out on a printed circuit board and the board was fabricated by a local manufacturer pro bono (it did not hurt that the owner’s son was a student in this class). The circuit was then completed with inserting components, soldering and testing. The circuit the students designed is shown below.



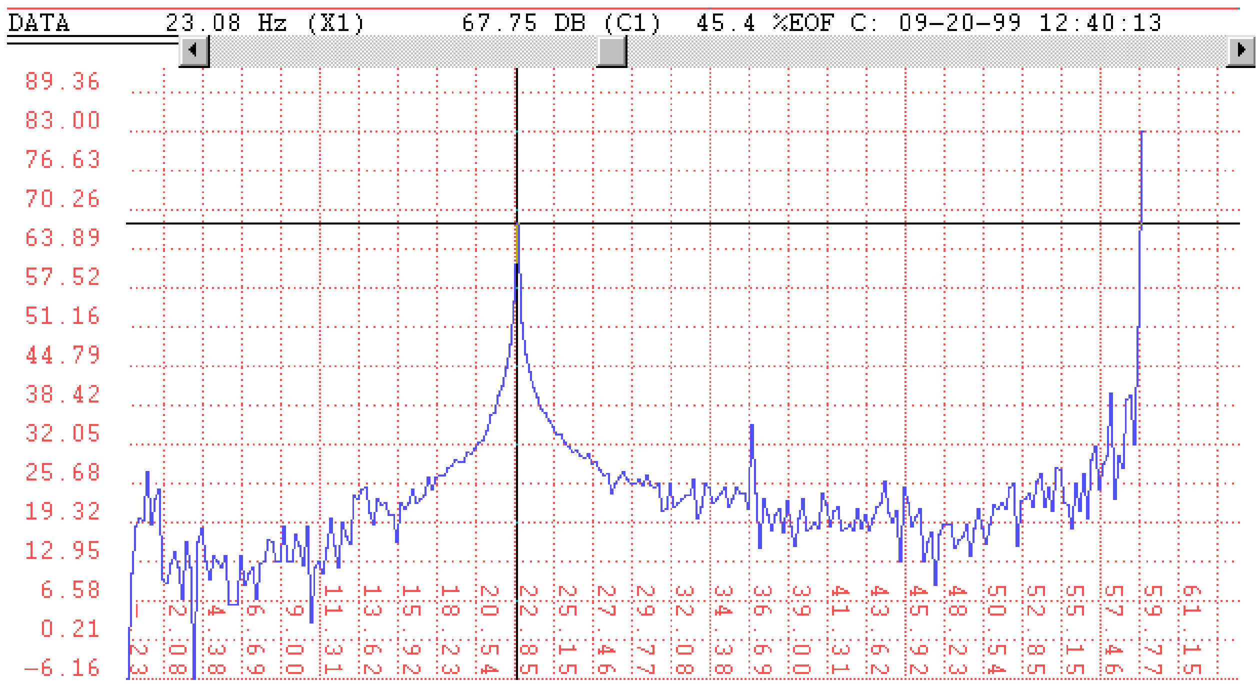
This circuit was used successfully in the early stage of the project. Since that time eight different versions of amplifiers have been made. When the project was moved to the barn location, the necessity for a 60 hertz notch was passe. A need for much greater gain was determined necessary and recent versions show that change. The circuit in use now has 148 dB of gain with no filtering.

Discoveries

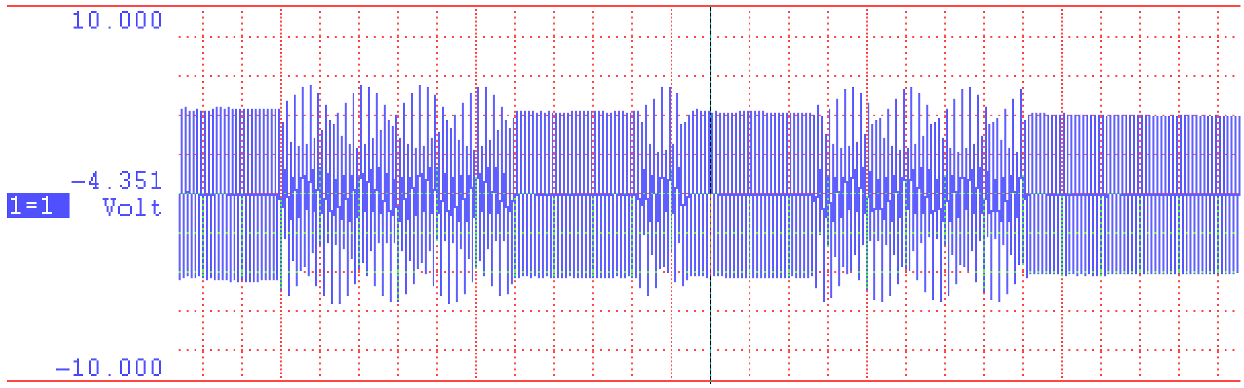
The research team has learned a great deal about ULF and ELF detection and analysis, yet certainly no scientific breakthroughs have yet been made. It is noteworthy however that the detection of what are apparently the Schumann resonances is shown in the following frequency domain analysis. The display below is a compilation of many days of data gathered and that data was then converted to frequency domain by Fast Fourier Transform. The Schumann resonances are below 25 hertz. Of course the ubiquitous 60 hertz is clearly visible.



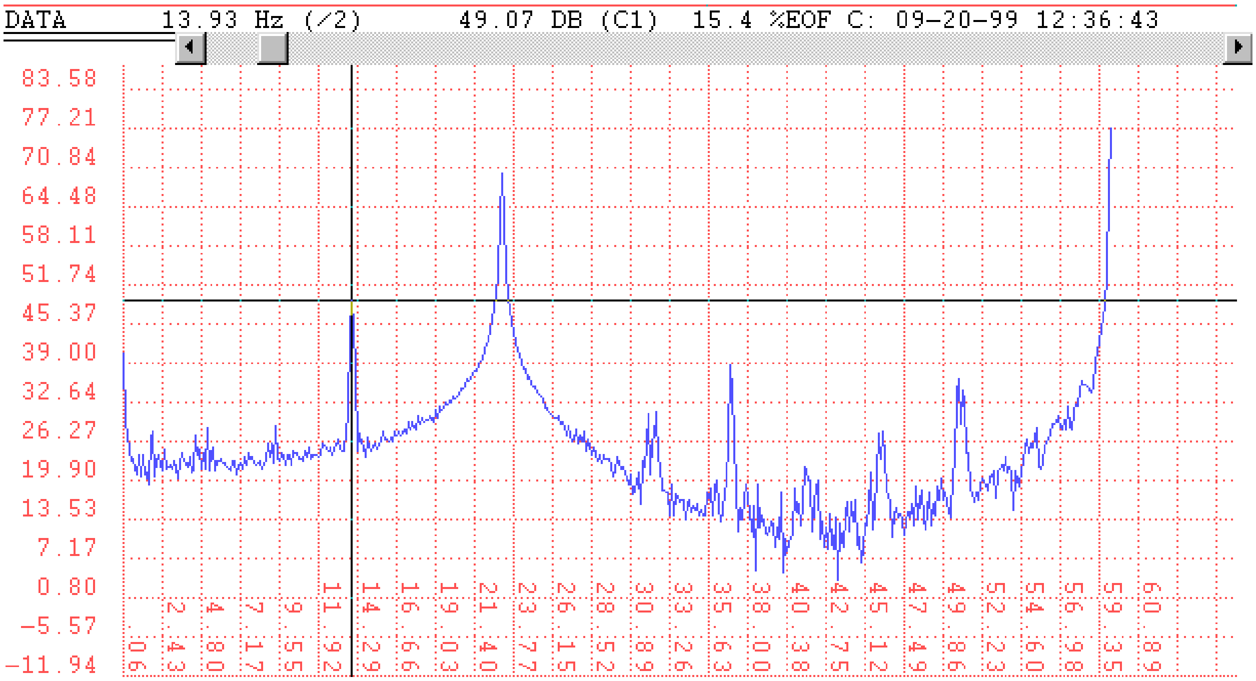
Additionally many other phenomena have been noted that piqued the curiosity of both student and faculty researchers. One noteworthy observation is the presence of several notably large ELF signals. A second is the fact that the further the test transmit antenna is moved away the greater the signal is distorted. And last is the fact that the second harmonic of the test signal showed to be stronger than its fundamental when transmitted from the test antenna on two different occasions. Some of these observations are shown below.



This display is of a close range test signal demonstrating that circuitry clearly detects the 23 hertz test signal. The test signal was injected into an antenna similar to the receive antennas and laid on the earth approximately 20 feet from the receive antennas in this instance.



This display shows the oscilloscope display of the personal computer while logging the data. This display illustrates the ability to communicate at these frequencies, the long-short-long modulation shown above is the letter 'K' in morse code. In previous displays it is this display that is then converted to frequency domain via Fourier Transform.



This display shows the test signal of 23 Hz. as the dominant peak. A 14 Hz.signal is marked for its amplitude of 71.9 dB and it frequency. The presence of a 37 hertz and 50 hertz peak can be clearly seen. The 37 Hz. Signal is the difference between the 23 Hz. test signal and the 60 Hz. Power grid. The origin of the 50 Hz is unknown. This effect of additional signals being detected while transmitting a test signal has generally been noted in cases where the test signal is further away from the receive antennas as is the case with this display.

Conclusion

This project has been a tremendous aid to the undergraduate students of both programs involved. The physics students gained a greater appreciation of the difficulty of the electronics in use and the EET students learned a great deal about the physics of ULF/ELF electromagnetic signals. Each group showed considerably improved motivation in pursuing an original research project such as this. Student enthusiasm has spurned continued involvement beyond the two classes which were originally involved. Several students have volunteered their time over the past three years.

Future directions for this project include the ability to send data via the internet in real time so that it can be monitored from anywhere there is a computer and a modem and improved antennas which will be professionally wound (the researchers learned a great deal about the science of coil winding, but are yet novices for it is indeed an involved and complicated art). The author also hopes to communicate in the ELF range possibly breaking the amateur record for lowest frequency communication. One of the displays demonstrates that it is feasible to do so via morse code visually displayed.

Overall, the project was a boon to student morale and learning. This project was a fortunate meeting between two universities and their respective departments that continues today. The possibilities are nearly endless and the author looks forward to the future of this endeavor.

References:

1) S. Carlson; The Amateur Scientist, Scientific American May 1996, p98.
2) D. R. MacGorman and W. D. Rust; The Electrical Nature of Storms, pp114-117. 1998 Oxford University Press, Oxford.
3) G. Stavrakakis and P. Varotosos. "Claims of Success in Using Geoelectrical Precursors to Predict Earthquakes Are Criticized- and Defended." Letters, Physics Today, June 1998 p 15.
4) D. D. Sentman. 1982: Schumann resonances. In CRC Handbook of Atmospherics, Vol. 1, H. Volland, ed. CRC Press, Boca Raton, FL, pp.111-78.
5) Bering, E. A. , Few, A. A. and Benbrook, J. R. ; The Global Electric Circuit; Physics Today, October, 1998; pp24-30.
6) R. A. Black and J. Hallett; The Mystery of Cloud Electrification American Scientist, Vol 86 Nov-Dec. 1998 pp526-534.
7) Polk, C. 1985: Schumann resonances. In CRC Handbook of Atmospheric Electrodynamics , H. Volland, ed. CRC Press, Boca Raton, FL, pp.111-78.
8) Payne, W. E. (March 1997) Sensitivity of Multi Turn Receiving Loops [online] Available:http://www.lwca.org/library/articles/ywk/loopetheo.htm. (November 2, 1999)

Author's Biography

Terrence P. O'Connor is an Associate Professor of Electrical Engineering Technology for Purdue University. He teaches at the New Albany site where he has taught all but one of the courses in the two year degree offered there. He is primarily interested in ELF/ULF signal detection in the area of research, but also has delved into engineering ethics. He is a graduate of Northern Arizona University where he received a B.S. in Engineering Technology. He received his Master of Science degree in Engineering Technology from West Texas State University. He can be reached at : toconnor@purdue.edu