Development of a Fuzzy Model for Deteriorating Engine Oil— The U.S. Army is poised to introduce Condition Based Maintenance (CBM) across its land-based vehicle fleet. CBM is expected to increase the vehicles’ readiness and operational availability and reduce the soldiers’ maintenance burden. This research will be a (currently unfunded) follow-up project to one of the topics that was funded by the U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC) through CAViDS in 2008-2011. Janos Grantner and Claudia Fajardo, of the MAE Dept. will be working on this research.

Development of Fuzzy Automata for Robot Control Applications – In this project a new version of Grantner’s fuzzy automaton model will be developed using Dombi-operators for fuzzy model building and inference. Then the research will be focusing on potential applications in the area of remotely operated surgical robots. In this currently unfunded project Janos Grantner, Jozsef Dombi, of University of Szeged, Hungary and Tamás Haidegger, Obuda University, Hungary, will be the primary investigators.

Nonlinear Circuits and Systems Laboratory
Room A-209
http://homepages.wmich.edu/~miller/NonlinearCircuitsAndSystems.html

This laboratory continues to explore electronic implementations of chaotic systems under the direction of Dr. Miller, in collaboration with Dr. Giuseppe Grassi of the University of Salento and ECE faculty.

Mechanical engineering undergraduate student Ben VanDyken is continuing his work on a NASA Michigan Space Grant Consortium Undergraduate Research Fellowship to implement a discrete time chaotic system described in the 2012 article “Dead-beat full state hybrid projective synchronization for chaotic maps using a scalar synchronizing signal” by Dr. Grassi and Dr. Miller in the journal Communications in Nonlinear Science and Numerical Simulation. Ben is building on the work of previous and current students in the lab, including David Kirklewski and Donovan Squires.

Undergraduate student Nate Noffsinger has designed an anti-aliasing low pass filter to support testing a continuous time coupled chaotic oscillator initially designed by a 2007 senior design group (Chris Bommarito, Paul Kokney, and Donovan Squires). That project was inspired by the 2008 article "Generation of a four-wing chaotic attractor by two weakly-coupled Lorenz systems” in the International Journal of Bifurcation and Chaos by Dr. Grassi, Dr. Severance, Emil Mashev, and Dr. Miller.
The Neurobiology Engineering Laboratory investigates the principles and mechanisms of information processing and knowledge representation in biological neurons and neuronal networks. This research is truly an interdisciplinary effort, requiring close collaboration between faculty and students in biology, electrical engineering, and mathematics. Drs. Miller and Severance direct this lab.

Doctoral student Michael Ellinger is investigating experimental validation of theoretical concepts in the soon-to-be published ASME Journal of Dynamic Systems, Measurement, and Control article “Current Stimuli That Provide Membrane Voltage Tracking in a Six Dimensional Neuron Model” by Dr. Melinda Koelling (Math Department), Dr. Miller, Mike, Dr. Severance, and Faculty Specialist John Stahl. Drs. John Jellies and Cindy Linn of Biological Sciences have worked closely with Mike in their labs to conduct the needed electrophysiology experiments. The technique should allow use of optimal control to find reduced energy currents that enable a neuron to produce a desired output signal. Doctoral student Jason Anyalebechi and Drs. Koelling and Miller are in the final stages of preparing an article that describes application of this method to neuron phase models.

One area of continued focus is the development of instrumentation to support experiments in neurophysiology, and in particular the measurement and stimulation of neuron electrical activity. Master of Science students Donovan Squires (CpE) and Kyle Batzer (EE) are currently writing their theses on their completed neuron stimulation and measurement system. Donovan has produced a printed circuit board implementation that features A/D and D/A converters and slots for up to eight pre-amp/stimulator cards designed by John Stahl. Kyle developed a FPGA based solution for transfer of data between the system and a PC via a USB interface. Dr. Bazuin provided his expertise throughout the development process. The design of this system is based in part on work by previous senior design groups and was presented at the annual 2012 MSGC conference in Ann Arbor. Both John and Kyle secured NASA Michigan Space Grant Consortium support for this work.

Neurons can be extracted from snails (these are in the Neurobiology Engineering Lab) for experimental studies. Photo credit: M. Ellinger

Instrumentation developed by Donovan Squires and Kyle Batzer used in an earthworm electrophysiology experiment. Photo credit: D. Squires (from draft thesis)
The laboratory is perfecting cell culture protocols that could be applied to the culture of biological neurons for experimental studies. Under the direction of Michael Ellinger, undergraduate students Shannon Kloha and Matt Wolfe studied effects of surface coatings on cell growth. Shannon was awarded a NASA MSGC Undergraduate Research Fellowship and a WMU Seibert Undergraduate Research and Creative Activities Award to support this research. Shannon and Matt presented their work at the annual 2012 MSGC conference in Ann Arbor.

Shannon Kloha and Matt Wolfe at the annual 2012 Michigan Space Grant Consortium Conference displaying their work in studying the effects of different coatings on cell growth.

Donovan Squires presenting his and Kyle Batzer’s work on electrophysiology instrumentation at the 2012 Michigan Space Grant Consortium Conference

Dr. Miller is supporting ongoing work by Biological Sciences Ph.D. student Sr. John-Mary Vianney and her advisor Dr. John Spitsbergen to study effects of electrical stimulation on cell cultures. This support has included the construction of electrophysiology equipment by undergraduate mechanical engineering student Ben VanDyken.

**Tau Beta Pi**

[http://www.rso.wmich.edu/taubetapi/](http://www.rso.wmich.edu/taubetapi/)

One mission of Tau Beta Pi is to recognize “distinguished scholarship and exemplary character” [tbp.org] among undergraduate engineering students. Undergraduate students invited to be considered for membership must be in the top eighth of the junior class and top fifth of the senior class in eligible engineering programs. The WMU Michigan Kappa Chapter of Tau Beta Pi initiates elected students each fall and spring semester. Our chapter serves the community and college through active volunteerism. Chapter advisors are Dr. John Cameron (Chemical Engineering), Barry Frost (Lead CAE Analyst, Johnson Controls), Provost Tim Greene, Vice President for Research Dan Litynski, Dr. Miller (Chief Advisor), and Dr. Bob White (Industrial and Manufacturing Engineering). Current officers are Mikkhael O’Dell, Casey Kick, Andrew Biscupski, Lauren Fromm, Thomas Wheeler, and Colin Haire.
The Michigan Kappa Chapter garnered five awards at the 2012 National Convention, including a Chapter Project Award, an Honorable Mention for the R. C. Matthews Outstanding Chapter Award, and an Honorable Mention for the R. H. Nagel Most Improved Chapter Award.

Spring 2013 Tau Beta Pi Initiation

Construction of a Wheelchair Ramp in Southwest Michigan

**Center for Advanced of Smart Sensors and Structures (CASSS)**

Sensors provide a link between the digital world of computers, modern communications systems and the “real” or analogue world in which we live in, making it possible for us to obtain real time information about our surroundings, especially in inaccessible and inhospitable environments. In present-day biotechnological applications, the analysis of biochemical products is of utmost importance. The complexity of interfacing a biochemical environment directly to an electronic device needs to be overcome as smaller and faster devices are highly desired for replacing time-consuming laboratory-analyses. The attractive properties of biochemical sensors such as high sensitivity and high selectivity along with low detection limits are extremely promising for biochemical sensing applications. Researchers in this interdisciplinary program work towards: (a) understanding the cellular and molecular biology/chemistry of binding proteins at the sensor surface, (Bio/Chem); (b) develop tools, techniques and protocols to non-intrusively collect relevant bio/chemical information using an array of micro/nano probes, sensors and analysis protocols (Micro/Nano); (c) characterize the electrical parameters, choose appropriate materials for sensors and develop better models to understand the interface between sensors and bio/chemical (Bio/Micro/Modeling/Materials/Chem); (d) design and develop microelectronic integrated circuits for sensor control at the local level and processing at local and remote levels with wireless communication and distributed computing capabilities (VLSI/INFO). The Center for Advanced Smart Sensors and Structures is dedicated to performing research in wide variety of areas related to smart sensors and structures. This center forms the nucleus for cross-disciplinary research and provides a mentoring source for doctoral and masters level students. Some of the interdisciplinary research activities are as follows:

a) **Printed Wireless Humidity Sensors On Flexible Substrates**

In this research work, a wireless humidity sensor was inkjet printed on a flexible polyethylene terephthalate (PET) substrate film using silver (Ag) nanoparticle based ink. The printed sensor consisted of an interdigitated capacitor (IDC) and an inductive coil pair in planar form. The IDC of the LC resonant circuit was spin coated with a humidity sensitive polymer poly (2-hydroxyethylmethacrylate) (pHEMA) and placed inside a Caron 6030 humidity chamber. It was observed that the capacitance of the IDC was directly proportional to the relative humidity. This change in capacitance resulted in a shift in the resonant frequency of the LC sensor which was remotely measured through an inductive detection coil. This project is overseen by Drs. **Massood Atashbar, Brad Bazuin**, ECE Professors and...
**b) Impedance Based Electrochemical Biochemical Sensor**

An efficient electrochemical biosensor for the detection of various chemical and biological species was successfully fabricated by incorporating gold (Au) interdigitated electrodes (IDE), with 5 µm width and spacing, on a glass substrate, using photolithography technique. Gold was chosen as the electrode material for this work due to its inertness and because of its known affinity for biomolecules, especially for its ability to bind to proteins. Also a flow cell, with inlet and outlet ports for the microfluidic chamber, was fabricated using an acrylic material with a reservoir volume of 78 µl. Analysis of the impedance based response of the two-terminal device successfully demonstrated the feasibility of the biosensor to distinguish among various concentrations of chemical substances like potassium chloride (KCl), lead sulphide (PbS), mercury sulphide (HgS) and cadmium sulphide (CdS) as well as some biological proteins such as mouse monoclonal IgG, sarcosine and D - proline at pico molar (pM) concentration levels. This project is overseen by Dr. Massood Atashbar, ECE Professor.

**c) Printed Electrochemical Biochemical Sensors on Flexible Substrates**

This project addresses the challenges of fabricating miniaturized, low-cost, flexible sensors via high - throughput techniques which are expected to be used for applications in chemical and biological detection. The researchers aim at printing (Gravure, Inkjet and Screen), characterization and testing of carbon nanotubes, graphite and silver inks as electrodes for interdigitated electrodes on paper, glass and polyethyleneterephthalate (PET) substrates. An efficient electrochemical biosensor was successfully printed on a flexible PET substrate film using silver (Ag) nanoparticle based ink. The electrochemical impedance spectroscopy (EIS) response of the printed sensor for detecting low concentrations of biochemical species revealed a very high sensitivity at pico molar (pM) concentration levels of potassium chloride (KCl), lead sulphide (PbS), mercury sulphide (HgS), cadmium sulphide (CdS), sarcosine and D - proline. Fabricating arrays of organic thin film transistor (OTFT) structures on flexible substrates using traditional printing techniques are also part of this research study. This project is overseen by Drs. Massood Atashbar, Brad Bazuin, ECE Professors and Margaret Joyce, PCI Professor.

**d) Printed Capacitive Based Humidity Sensors on Flexible Substrates**

A capacitive type humidity sensor (Inter Digitated Capacitor (IDC)) was successfully printed on a polyethyleneterephthalate (PET) substrate by means of rotogravure printing using silver (Ag) nanoparticle based ink as metallization with dimensions of 200 µm electrode finger width and spacing. The fabricated device was spin coated with humidity sensitive hydrophilic polymer (Poly Methyl Methacrylate (PMMA)). The capacitive response of sensor towards Relative Humidity (%RH) was measured in the range of 40% RH to 80% RH. The capacitive response of the printed sensor towards humidity showed a maximum hysteresis of 8 % at 60% RH. The sensor showed a variation of only 0.8 % from the average value at 70% RH and 25°C. This project is overseen by Drs. Massood Atashbar, Brad Bazuin, ECE Professors and Margaret Joyce, PCI Professor.

**e) Three Dimensional Localization using a Passive Wireless SAW Transponder**

The aim of this project is to develop a real-time sensing system based on wireless SAW technology. This sensing system can be used to identify and track SAW tags in an indoor environment. A finite element analysis was employed to analyze the second order effects of a passive surface acoustic wave (SAW) transponder. The second order effects, which occur due to the electrode perturbation and wave reflection, were analyzed using a two-
dimensional finite element analysis method. A 31-bit Pseudo Random (PN) code sequence was implemented to demonstrate the second order effects on different configurations of the SAW transponder. This project is overseen by Drs. Massood Atashbar ECE Professor, and Kapseong Ro, MAE Professor.

f) Fully Printed Wireless LC sensor for Heavy Metal Detection
This research project focused on the successful development of a fully printed wireless LC sensor for the detection of toxic heavy metals. The sensor, consisting of an inductor, detection coil and interdigitated electrodes (IDE) in planar form, was fabricated using screen and gravure printing technologies on a flexible polyethyleneterephthalate (PET) substrate with silver (Ag) based ink as metallization. The capability of the printed LC sensor for detecting very low concentrations of toxic heavy metals was demonstrated. The wireless response of the printed LC sensor revealed a very high sensitivity at picomolar levels of cadmium sulphide (CdS) and lead sulphide (PbS). This project is overseen by Drs. Massood Atashbar, ECE Professor and Margaret Joyce, PCI Professor.

g) Novel flexible strain gauge sensor fabricated using screen printing
A flexible strain gauge sensor was successfully designed and fabricated using screen printing on polyethylene terephthalate (PET) substrate using silver (Ag) based ink as metallization. The electromechanical characteristics of the printed strain gauge sensor were examined by subjecting the sensor to a 3-point bend test. A 1.89 % maximum change in the resistance was observed when the sensor was subject towards a displacement of 2 mm, for 10,000 cycles. This response of the sensor demonstrated the potential of the fabricated sensor to be used in sensing applications for safety measures. This project is overseen by Drs. Massood Atashbar, ECE Professor and Margaret Joyce, PCI Professor.

h) Guided Shear Horizontal Surface Acoustic Wave (SAW) Sensor
In this project a portable, rapid detection 64° YX LiNbO₃ SAW transducer was fabricated. Aluminum Nitride (AlN) layer was then deposited on the active area as acoustic wave guiding layer with 10 μm electrode width and spacing. Acrylic material was used to fabricate a flow cell with a 3 μl reservoir volume having inlet and outlet ports for the micro fluidic chamber. Structural studies and morphological analysis, conducted on fluid channeled between the delay-line interdigitated electrodes, revealed that the deposited AlN thin film layers have strong preferential c-axis orientation and is compact with grain dimensions of less than 80 nm respectively. Polyaniline nanofibers were polymerized and synthesized to obtain 50 nm average diameters. The nanofibers were deposited on the layered SAW device and were tested towards hydrogen (H₂) gas, while operating at room temperature. The device demonstrated a large and reproducible response to different concentrations of the H₂ gas making it an ideal candidate for H₂ sensing at room temperature. This project is overseen by Dr. Massood Atashbar, ECE Professor.

i) Solidly Mounted Thin Film Bulk Acoustic Resonator (SMFBAR)
This research study aims to develop a prototype device based on the SMFBAR technology that will measure prostate specific antigen (PSA) efficiently in a cost effective manner at very low concentration (pg/ml region). The SMFBAR based sensor is designed with a piezoelectric thin film sandwiched between the top and bottom electrodes, on top of an acoustic mirror structure also known as Bragg reflector layers The specific aims for this project include: (a) Fabricating chips capable of detecting the binding of antibodies and their interactions with PSA based on FBAR technology, (b) Evaluation of the chips for the detection of PSA and (c) Development of on-chip detection system for point-of-care testing based on CMOS-MEMS technology. This project is overseen by Dr. Massood Atashbar, ECE Professor.
j) PMMA/64° YX-LiNbO₃ Guided SH-SAW Based Immunosensing System
In this study, a poly methylmethacrylate (PMMA)/64° YX-LiNbO₃ guided shear horizontal mode surface acoustic wave (SH-SAW) sensor was designed and fabricated for the detection of biological antigen-antibody interactions. Various thicknesses of PMMA guiding layer were spin coated on SH-SAW sensor. A test setup utilizing a small-volume flow cell with inlet and outlet ports for the microfluidic cell and employing polydimethylsiloxane (PDMS) based microfluidic channels, was also designed and fabricated using an acrylic material with a reservoir volume of 3 µl. The interactions between protein G and immunoglobulin G (IgG) solutions were measured and analyzed using the PMMA coated SH-SAW devices. The frequency shift of 64° YX-LiNbO₃ device with 0.4 µm PMMA guiding layer was measured from 3 kHz to 68 kHz as the concentration of IgG was increased from 1 µg/ml to 10 µg/ml. The calculated sensitivity of the guided SH-SAW was found to be 7.3 kHz/(µg/ml). This result showed that this guiding SH-SAW device was suitable for the liquid sensing applications. This project is overseen by Dr. Massood Atashbar, ECE Professor.

k) Development of Guided SH-SAW based Wireless Sensing Platform for Monitoring Protein Binding
In this study, a wireless biosensing platform was developed for the detection of protein binding. The system consisted of a layered ZnO/36° YX-LiTaO₃ guided shear horizontal mode surface acoustic wave (SH-SAW) device and a microfluidic flow cell. The influence of the interactions between protein A and mouse IgG on the characteristics of the SH-SAW device was measured and analyzed for varying concentrations of mouse IgG. The experimental results demonstrated that the insertion loss of the device increased from -46.8 dB to -50.9 dB and the center frequency of the device decreased from 94.56 MHz to 94.49 MHz as the mouse IgG concentration was increased from 1 µM to 40 µM, respectively. This sensor platform enabled real time monitoring of protein binding within a microfluidic flow cell. The experimental results show that this guided SH-SAW based wireless sensing system is viable for biosensing applications. This project is overseen by Dr. Massood Atashbar, ECE Professor.

l) Fully Printed Skin-Like Flexible Pressure Sensor
A flexible pressure sensor was gravure printed on a polyethylene terephthalate (PET) with silver (Ag) ink as the metallization layer. Initially, an array of 4 bottom electrodes with dimensions of 4 cm × 0.5 cm and 0.5 cm spacing were gravure printed. A 4 cm × 4 cm polydimethylsiloxane (PDMS) layer was then screen printed on top of the electrodes to act as the dielectric layer. This was followed by the gravure printing of an array of 4 top electrodes, with similar dimensions as that of the bottom electrode, with a 90° rotation in angle when compared to the bottom electrodes resulting in a grid structure. Finally, a passivation layer of PDMS was screen printed on the top electrodes. The overall thickness of the printed pressure sensor was measured to be 180 µm. The printed flexible pressure sensor was tested by placing varying weights on top of the passivation layer. This caused the distance between the top and bottom electrodes to be reduced, thereby resulting in a change of capacitance based on the change in the overall thickness and dielectric constant of the PDMS dielectric layer. A 4 %, 24 %, 39 % and 41 % change in capacitance was observed as the weight increased from 2.2 kPa to 8.6 kPa to 23.5 kPa to 0.1 MPa, respectively. This project is overseen by Drs. Massood Atashbar and Brad Bazuin, ECE Professors.
m) A Field-Portable Potentiostat System with Full Onboard Function Generation

A handheld, field-portable potentiostat system was successfully designed and fabricated to perform a wide range of electrochemical impedance spectroscopy (EIS) experiments. The onboard function generation capabilities of this system produces reference signals to drive numerous types of voltammetry experiments and thus provides increased functionality over previously built potentiostat systems. The system produced is capable of AC signal generation ranging from extremely low frequencies up to 200 kHz and signal amplitudes from 15 mV to 3 V at the counter electrode. This system also has a 16-bit DC resolution to bias AC signals or to produce a wide range of DC waveforms with an operating range of ±10 V. The capability of the potentiostat system was demonstrated by performing EIS on varying concentrations of mercury sulphide (HgS), a toxic heavy metal. The EIS based response of the potentiostat system revealed a very high sensitivity at pico molar (pM) concentration levels of HgS. This project is overseen by Dr. Massood Atashbar, ECE Professor.

n) Surface Enhanced Raman Spectroscopy (SERS) Based Optical Sensors

In this research, novel flexible surface enhanced Raman spectroscopy (SERS) substrates were successfully fabricated by inkjet and gravure printing a thin film of silver (Ag) nanoparticle ink, with 20~50 nm particle size, on a silicon (Si) wafer and flexible polyethylene terephthalate (PET). The feasibility of the fabricated SERS substrates for detecting toxic heavy metals such as mercury sulfide (HgS) and cadmium sulfide (CdS) were demonstrated. The SERS based response of the printed substrates produced an enhanced Raman signal when compared to target molecules adsorbed on bare PET. An enhancement factor of 5 orders of magnitude due to existence of hot spots between nanoparticles was obtained. This response demonstrated the feasibility of the novel SERS substrate to be used in applications for detection of toxic heavy metals. This project is overseen by Drs. Massood Atashbar and Brad Bazuin, ECE Professors.

The research group within the laboratory led by Dr. Atashbar consisting of Binu Baby Narakathu, Sai Guruva Reddy Avuthu, Ali Eshkeiti, Zeinab Ramshani, Sepehr Emammian, Sumeet Chaudhary and Morteza Rezaei are investigating the potential capabilities of various sensors for applications in the medical, environmental and defense industries. Chi-Jung Cheng successfully defended his PhD thesis in Electrical Engineering in the summer of 2012 titled “Design, modeling and fabrication of shear mode bulk acoustic wave sensor as a potential biosensor”. He is currently employed at Veeco Instruments as research engineer. Mr. Chen-Tung Feng and Mr. Akhil Moorthi successfully completed their Master of Science in Electrical Engineering at Western Michigan University. As a result of the research activities during the 2012-2013 academic year, 8 journal papers (Sensors and Actuators B: Chemical, Biosensors and Bioelectronics, IEEE Sensors Journal, IEEE Journal of Display Technology, IEEE Transactions on Instrumentation and Measurement and the International Journal of Science and Advanced Technology) and 13 conference papers (Proceedings of the IEEE Sensors conference, Annual Flexible Electronics and Displays Conference, International Meeting on Chemical Sensors, The Sixth Asia-Pacific Conference on Transducers and Micro/Nano Technologies, International Conference on Sensing Technology) were published. In 2012, Dr. Atashbar and Mr. Binu Baby
Narakathu presented the research work at the 11th IEEE Sensors Conference in Taipei, Taiwan (October 28-31). In 2012, Dr. Atashbar presented the research work at the 14th International Meeting on Chemical Sensors, May 20-23, 2012, Nuremberg, Germany.

Dr. Atashbar has been mentoring high school students from the Kalamazoo Area Mathematics & Science Center (KAMSC). This mentorship involves development of research project proposals and implementation of the research during the school year. These research projects have been focused on the development of printed electrochemical sensors on flexible substrates. Ms. Tracy Broomell and Ms. Tess Johnson presented the research work titled “The Detection of Bovine Serum Albumin (BSA) Antibody Using Electrochemical Impedance Spectroscopy” in the Intel International Science and Engineering Fair 2012. Mr. Grey Braybrooks and Mr. Sam Wachowski presented the research work titled “Detection of heavy metals through the use of electrochemical sensors” on the southwest Michigan regional science and engineering fair event at WMU and was selected for presenting in the Intel International Science and Engineering Fair 2013.

Mr. Ali Eshkeiti and Mr. Binu Baby Narakathu won the All-University Graduate Research and Creative Scholar award for 2012 and 2013, respectively; and Mr. Sai Guruva Reddy Avuthu won the departmental Level Research and Creative Scholar award in 2013.