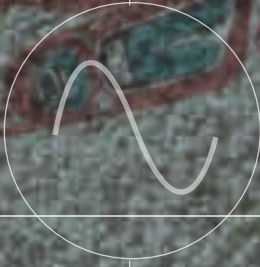# eeK08

electrical engineering kaleidoscope

A Publication of the Electrical Engineering Department | University of Washington

(Annual Research Review)

The quality and quantity of research at the Electrical Engineering Department have grown significantly over the last decade. There are many world-renowned scientists in the department. All of our new hires have emerged as stars in their respective areas of research. Last year we recruited Dr. Maryam Fazel and Dr. Micahel Hochberg both from Caltech in the respective areas of system biology and nanophotonics.

This year we are actively conducting a faculty search in the areas of molecular engineering, nanotechnology, networked radios and sensors, statistical signal processing, implantable and biologically-interfaced devices, and energy systems. The quality of our graduate students and their research is increasingly world class. Many EE graduate students have won best paper awards in international conferences in recent years. I hope you enjoy reading their research articles in EEK08.

— LEUNG TSANG
    Chair and Professor
    Department of Electrical Engineering

eeK 08

(Annual Research Review)

this issue...

WELCOME TO eeK 08

2008 appears to be a year of accelerating political, economic and social change. The increasing focus in UW EE on electrical engineering research topics that have a nanotechnology, biological or "green" component, is one manifestation of this dynamic. These topics are well represented among the student research projects described in EEK08.

The front cover incorporates an image of the silkscreen print "Every Year the Salmon Come Back" by Haida artist Robert Davidson.* The yearly cycle of the salmon return, like the yearly cycle of new students and graduations, reminds us that we are part of a greater whole, a dynamic system that we modify by our actions. Hopefully our educational and research work enhances and maintains it.

I hope that you find this eighth annual edition of EEK to be interesting and informative.

— HOWARD JAY CHIZECK
eeK faculty editor 2001-2008

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*Our sincere thanks to the artist, and to the Burke Museum of Natural History and Culture for permission to use this image.

Security and Privacy
in RFID Systems

BASEL ALOMAIR — Network Security Lab, Graduate Student (EE)

A Radio Frequency Identification (RFID) system can identify an item without the need for physical or visual contact. By using RFID readers, multiple tags can be remotely scanned and batch processed. Hence, RFID systems have a growing spectrum of applications such as fast merchandise scanning, contactless credit card payments, etc. This work aims to provide solutions to the security and privacy issues in RFID systems.

RFID systems consist of three main components: RFID tags, RFID readers, and a database. The RFID tags are small devices with minimal storage and computational capabilities. Tags can be attached to an item and store information, such as a unique product ID, type of product, expiration date, etc.

Integration of RFID tags in all aspects of everyday life, combined with the open nature of the wireless communication medium, can create significant threats to the security as well as privacy of RFID systems. For example, an unauthorized reader may interrogate multiple tags within its radio range to obtain data that is private and/or of considerable business value to users of the tagged items. Further, the uniqueness of a tag's identifier allows unauthorized location tracking of the tag that can lead to invasion of privacy of the tag user.

Therefore, for successful deployment of RFID systems, (a) the tags must provide information only to authorized readers, (b) the readers must verify the identity of the tag that provides information, (c) the integrity of the messages exchanged between the tag and the reader must be verifiable and, (d) the tags shall not be traceable via their unique identifiers. That is, the tag-reader pair must be mutually authenticated in a way that the privacy of the tag's ID is preserved.

Without the use of suitable cryptographic primitives to provide security and privacy for RFID systems, consumers are reluctant to use RFID technology with such security and privacy threats. By combining simple bitwise operations and modular arithmetic, we have been able to propose a privacy preserving mutual authentication protocol suitable for RFID systems. In addition to the computational efficiency of this protocol, security has been proven under realistic adversarial assumptions. eeK○8

Reader   Insecure Channel   Tag
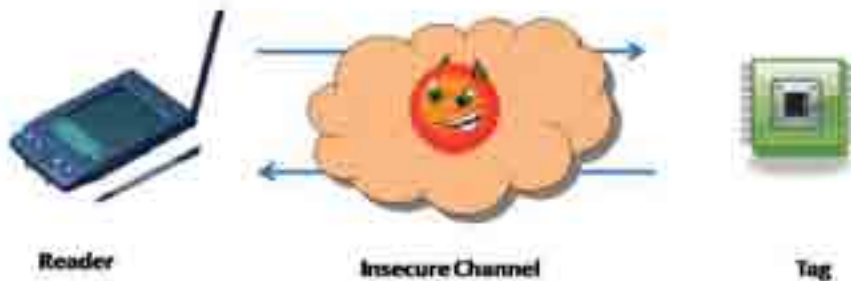
Wireless communications between tags and readers can be vulnerable to a variety of attacks.

Color Management System
for Soft Proofing

NASIHA HRUSTEMOVIC — Graduate Student (EE)

The graphic arts industry uses special monitors that can mimic the output of a printer. Matching the appearance of displayed and printed images is complex due to the difference in color gamuts of the devices and the difference in the viewing conditions. This research investigates how to use ordinary monitors to match the printed images so that any user can view the correct appearance of their image.

The human visual system performs "white-balancing" by adjusting what is believed to be white based on the illuminant and surrounding colors. When viewing hardcopy images, our notion of white is sensitive to the exact paper color as well as the illuminant. When matching printed images to monitor images, our notion of white also depends on the monitor's white. In such mixed viewing conditions, the human visual system partially adapts to the monitor white and partially to the illuminant.

This project engineers a color management system for soft proofing that can work given only limited information about the monitor, printer, and viewing conditions. This is a challenge because the existing color appearance models require generally unobtainable measurements about the user's set-up. Here, the image is modeled based on the cone responses of the human visual system and then transformed using von Kries chromatic adaptation model all while taking into account the user's mixed notion of white.

To implement a color management system, it is also necessary to correctly characterize the devices. The characterization process derives the relationship between device-dependent and device-independent color representations. It then stores this relationship in look-up tables which can be interpolated to adapt colors appropriately. The look-up table values are estimated using locally linear learning methods with adaptive neighborhoods. A new regularized regression method is introduced to allow a trade-off between fitting the data locally versus globally to ensure smooth color gradients.

Next steps in this project will investigate appropriate gamut mapping and perform subjective experiments to evaluate the color management for different viewing conditions. *eeK○8*

A block diagram of the Color Management Model.
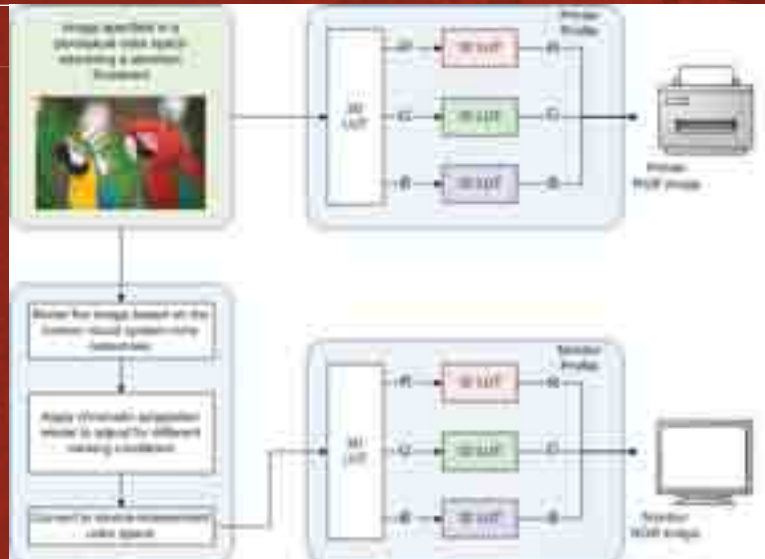
Improving Speech Corrupted by
Wind Noise

**BRIAN KING —** Graduate Student (EE)

The ubiquity and convenience of mobile phones have quickly made these devices a societal necessity. Unfortunately, the voice quality during a conversation is often insufficient for adequate intelligibility, especially outdoors on a windy day. Employing coherent modulation filtering can greatly improve the intelligibility of a voice distorted by loud bursts of wind.

Signal enhancement has been a major topic in digital signal processing, and many techniques have been developed to clean up noisy speech. The majority of these work well only in stationary noise, where the characteristics of the noise are relatively constant. Bursts of wind noise, however, change rapidly and unpredictably over time, causing the existing methods to fail. Instead of learning about the properties of the noise so that it can be removed, coherent modulation filtering picks out the speech from the noise and filters out parts of the signal that do not resemble speech.

This method takes advantage of the periodic nature of vowel sounds. The first step in the process tracks the pitch of the voice, which is easier in clean speech, but more difficult when the signal is corrupted by wind noise. In order to fill in gaps in the pitch estimate, interpolation is used to estimate the most likely frequency path. The second step in the process filters all extraneous frequency content around the predicted pitch trajectory. The algorithm significantly reduces wind noise while keeping the speech relatively free of unwanted artifacts.

Coherent modulation filtering has already provided direct applications to audio enhancement through wind noise removal. Exploration of new topics utilizing coherent modulation processing yields promising results in several areas of DSP, including speech recognition, speaker separation, and audio synthesis. eeKO8
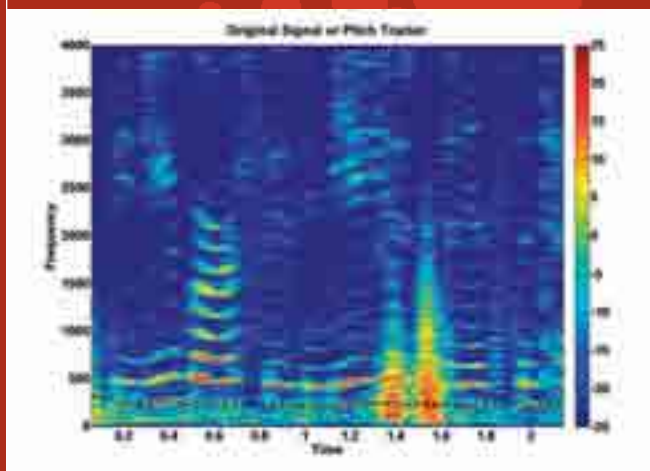
The original signal. The bursts of wind are seen between 1.3 and 1.6 seconds. The pitch tracker is also plotted as the black dashed line.
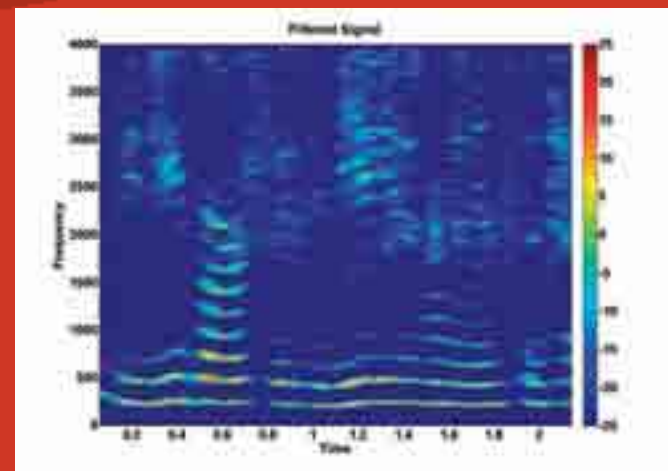
The filtered signal. Notice how the harmonic content is maintained while the two bursts of wind are gone.

Microwave Remote Sensing
of Snow to Monitor Water Resources and Global Climate Change

DING LIANG AND XIAOLAN XU — Graduate Students (EE)

Understanding the dynamics of water storage is critical to the effective management of water resources. Monitoring the snow thickness in terrestrial snow and in the polar regions is important for global climate change studies. Microwave remote sensing of snow with radiometers and radars is part of ongoing satellite missions such as AMSR-E (Advanced Microwave Scanning Radiometer — Earth Observing System) and WINDSAT (Satellite Based Wind Speed and Direction System) and future satellite missions such as the Snow and Cold Land Process (SCLP). This research develops microwave scattering and emissions models that describe the relation between remote sensing signatures and the physical parameters of snow.

Terrestrial snow consists of ice grains that are closely packed together. Scattering by microwaves of these densely distributed particles exhibits multiple scattering effects of dense media. The frequency, angular and polarization dependence of scattering deviate from classical predictions. This problem is studied by using both analytical and numerical methods. Analytically, the collective scattering effects are taken into account by the Quasi-Crystalline Approximation (QCA), which derives the dense media radiative transfer equations.

The numerical method consists of two steps. First, Monte Carlo simulations are used to generate the particle positions through random walk, and the stickiness potential through which particles can bond together to form aggregates.
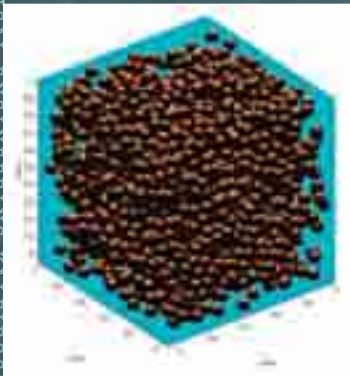

Monte Carlo simulation of the particle positions.

The second step solves the Maxwell equations for these generated particles, through the Foldy-Lax multiple scattering equations. To simulate coherent and incoherent fields correctly, a large number of particles are required in the simulations. Simulations have been performed up to several thousand particles. Numerical solution of the Maxwell equations for the large number of particles is facilitated by fast computation methods such as SMCG (Sparse Matrix Canonical Grid) and UV method. Using this, the extinction rate and phase matrix of multiple scattering can be calculated, which are then used to derive the radar backscattering in active remote sensing and the brightness temperatures in passive remote sensing. Below compares the QCA simulated backscattering scattering coefficients with that of AMSR satellite data.

Comparison between QCA simulations of radar backscattering coefficients of snow with Satellite observations. SWE is snow water equivalent.
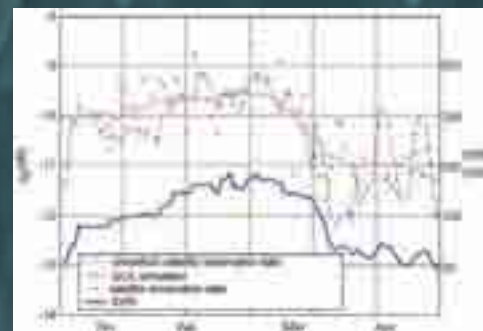
These results indicate that QCA is useful for simulation microwave signatures of snow. To give more accurate predictions, numerical methods are now being applied, and microwave modeling with snow accumulation hydrology models are also being combined. Field measurements of snow will also be taken at the Stanley Basin, Idaho. eeK○8

Applying Signal Processing to
Shipping Container Security

PATRICK McVITTIE — Graduate Student (EE)

With ever increasing international trade, the use of shipping containers has skyrocketed far beyond the ability to identify and search suspicious cargo. This widening security gap demands new technologies and new data processing methods to handle the sheer volume without reducing throughput. The two main approaches under development are point of entry scanning and smart containers utilizing embedded sensors.

Point of entry scanning allows for the use of expensive, high-resolution, and high-power sensing modalities which serially scan the containers. Since the scanning is done serially, the throughput of the port is limited by the scanning time necessitating fast acquisition and processing techniques.

Current research focuses on smart containers. Embedded sensors enable in transit monitoring and detection where time is less of a factor and problems can be detected before arrival at port. The primary challenges with this technology are power consumption, unit cost, and bandwidth.

One major aspect of the research investigates methods for enhancing the resolution of low-cost sensors using sensor fusion techniques. For example, the packing configuration or changes in the packing configuration might be estimated from an array of low cost air-coupled ultrasound sensors mounted on the shipping container ceiling. Temperature sensors can be used to improve the accuracy by estimating the speed of sound as is commonly done with air-coupled range estimates. By using the temperature swing as an advantage, the resolution can be improved even further. Since low-cost transducers are fixed frequency, and the temperature swings inside a shipping container over the day, the transmitted wavelength swings in a semi-predictable way. Using proper weighting and summing improves the resolution of the transducer beyond its specifications through interference patterns. Thus, the temperature swing data and ultrasound data are fused into a higher resolution estimate of the cargo configuration.

Practical application of this research makes ubiquitous embedded sensors in cargo shipping containers economically feasible. It will also begin integrating high-level signal processing research into the field of container security. eeK○8

The container security test site at the Port of Tacoma.

Underwater
Acoustic Networking

NATHAN PARRISH & LEONARD TRACY — Graduate Students (EE)

Networks of fixed and mobile underwater sensors can facilitate ocean environmental monitoring, tactical harbor and coastal security, and other ocean data gathering applications. However, acoustic communications in the ocean presents a variety of very difficult challenges such as long propagation delays, high delay and Doppler spreading, and limited bandwidth. Therefore, in order to further develop autonomous underwater networks, physical and MAC layer protocols need to be designed.

One of the primary difficulties in designing underwater acoustic communications systems is due to the lack of channel models that are both accurate and well-suited to communications system design. For example, in terrestrial wireless systems, path loss can be modeled as a function of distance alone, whereas acoustic energy underwater experiences path loss as a function of the underwater sound speed profile, frequency selective absorption and noise, bottom type, and surface conditions. Current research in the UW EE's Fundamentals of Networking Lab characterizes the fundamental capacity of an underwater channel using acoustics modeling tools such as Gaussian Ray Tracing. The capacity can then be used as a benchmark to compare current and future systems.

Research is also underway to develop a robust MAC protocol for the underwater network. Underwater channel characteristics, especially the long propagation delay, drastically reduce the efficiency of wireless protocols used in terrestrial networks. Alternative protocols are being designed to operate in the harsh underwater environment. In support of this task, a simulation environment is also being developed based on the NS 2 simulator that accurately models the underwater channel with reasonable running time.

This work conducted by the Fundamentals of Netorking Lab is in collaboration with researchers at the UW Applied Physics Lab (APL) who are developing underwater networking technology for ocean observatories and autonomous underwater vehicles. The vision for the future is to use this work in the planning and implementation of such networks, especially with the APL's Seaglider vehicle. eeK○8
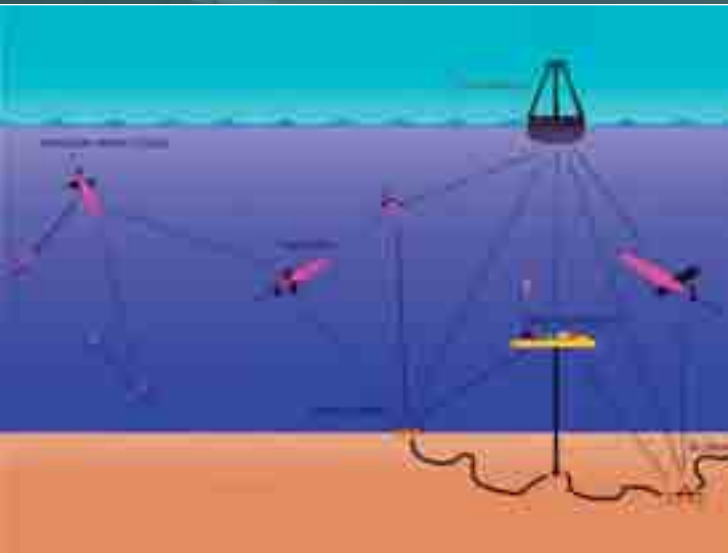
The envisioned underwater network which utilizes a combination of fixed and mobile nodes.

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FACULTY ADVISOR: Professor Sumit Roy
COLLABORATORS: Payman Arabshahi and Warren L.J. Fox (UW Applied Physics Lab)
RESEARCH AREA: Communications and Networking
GRANT/FUNDING SOURCE: NASA/DOD Fellowship

Using Electric Circuits to Evaluate Vulnerability in
# Wireless Network Routing

DAVID SLATER AND PATRICK TAGUE — Network Security Lab, Graduate Students (EE)

Evaluating security in wireless networks typically involves an independent analysis of the cryptographic security of each network link. However, since a routed message traverses multiple links en route from source to destination, the ability for an adversary to compromise the message (known as the vulnerability of the message) is a function of the network topology, the security provided by each link, and the adversary's ability to compromise network links. This work develops a metric to evaluate message vulnerability by mapping the compromised links in a given network topology to a current flow through an electric circuit.

An adversary compromises link security by capturing network nodes and recovering the cryptographic keys stored in memory. The metric is thus developed from the adversary's perspective to optimize the node capture attack, yielding the worst-case message vulnerability from the network perspective.
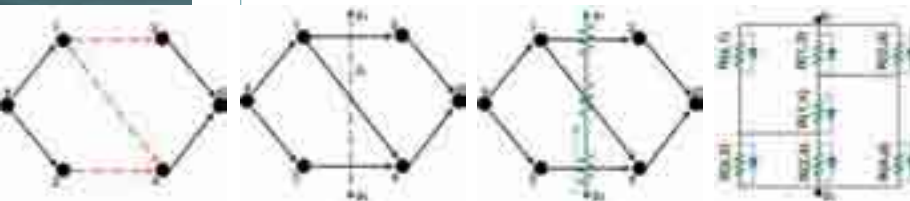
The metric is developed by focusing on a single source-destination pair in the network and modeling the message routing as a directed flow (figure A). Any message in the source-destination flow is compromised when the adversary compromises an edge cut set of the flow. Each cut set (figure A) corresponds to a possible attack solution for the adversary and is indicated by a possible attack path (figure B). By associating an electrical resistance with each link to be compromised, equal to the number of keys securing the link, the attack path can be mapped to a path of current flow (figure C). By considering all possible attack paths, the directed source-destination flow is mapped to an electric circuit (figure D).

By evaluating the equivalent resistance of the circuit constructed from the source-destination flow, the adversary can improve the efficiency of the node capture attack by choosing to capture the node leading to the greatest decrease in equivalent resistance. The impact of such an attack is compared to similar attacks using other node selection metrics.
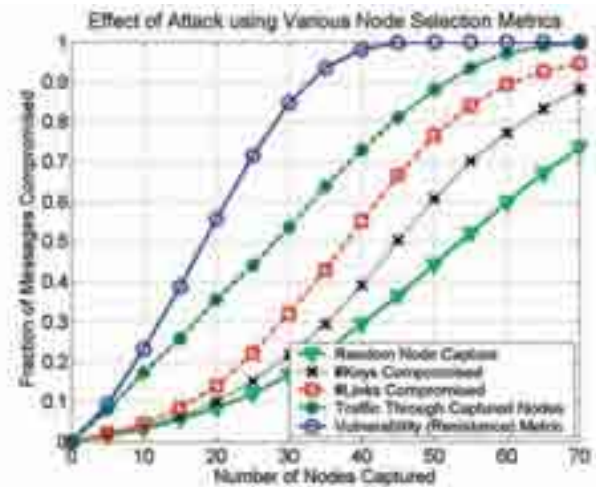
Five node capture strategies are compared for a network of 500 nodes in which each source sends fragments of each message over multiple paths to the destination. This is conducted in such a way that it forces the adversary to compromise an entire edge cut set of the route to recover the corresponding message.

The figure illustrates the mapping from the directed graph representing the route to an electric circuit. In A, a possible edge cut set is indicated by dashed lines. In B, the edge cut is represented as a curve crossing the edges in the cut set. In C, the curve is replaced by a wire, and a resistor is inserted where the curve crosses each edge. In D, the circuit is constructed by combining wires and resistors for all possible edge cuts. The parallel diode for each resistor maintains edge directionality.

The proposed metric provides a connection between protocols for message confidentiality and network routing. In the future, this metric will provide insight into the joint design of security and routing protocols that improve message vulnerability. eeKO8

MobileASL:

Video Cell Phones for American Sign Language Communication

RAHUL VANAM — Graduate Student (EE)

Video-enabled cell phones can potentially enable deaf Americans to speak in their community's native language, American Sign Language (ASL), and gain freedom, flexibility, and comfort of the wireless phone revolution. Current cell phone networks in the United States provide bandwidth that is not high enough for video transmission. Because video compression is computationally intensive, it is a challenge to compress video real-time on mobile devices. The MobileASL Project is developing algorithms to improve both the encoder speed and the compressed ASL video quality, targeting very low bit rates (under 30 kb/s).


A real-time ASL conversation using video cell phones.

This research uses the x264 encoder, which is an open source H.264/AVC video encoder. The H.264 standard provides higher compression ratios and better quality compared to previous standards, but it takes longer to encode. The H.264 encoder has several input parameters that determine the bit rate, the distortion of the compressed video, and the encoding speed.

Finding the input parameters with good distortion speed performance is time consuming because there are many possible combinations of parameter choices. Two fast algorithms have been developed based on the Generalized Breiman, Friedman, Olshen, and Stone (GBFOS) algorithm for selecting such good input parameters, but take fewer encodings compared to an exhaustive search. On both ASL and general videos for four variable input encoder parameters, these algorithms take about 1% and 8% of the number of encodings required by exhaustive search, and perform with a decrease in peak-signal-to-noise ratio of less than 0.71 dB.

Performance of exhaustive search and the fast algorithms (the GBFOS-iterative and the GBFOS-basic algorithms) on ASL videos using the x264 encoder at 30 kb/s.
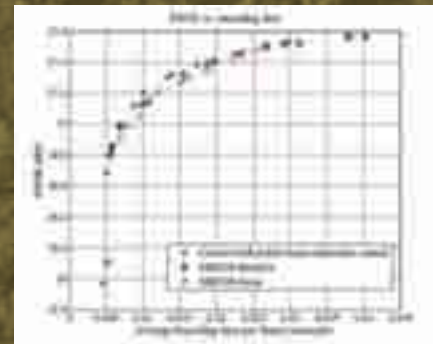
These fast algorithms are suitable for use in video cell phones for finding input encoder parameters that can compress ASL videos in real-time with good video quality. In the future, selecting input encoder parameters under varying network bandwidth conditions will be considered. eeKO8

Signal Integrity in
3D High-Speed Interconnects

RUIHUA DING & BOPING WU — Graduate Students (EE)

Signal integrity affects all levels of microelectronics packaging for high-speed circuits. Signal integrity research attempts to identify and avoid any effect that causes signal distortion and energy loss at high frequency range. Signaling rates are expected to exceed 10 Gb/s in a few years, which makes it important to understand off-chip loss due to metal surface roughness. Another issue is the multiple scatterings among the vertical via structures in the multi-layer dielectric substrate. Ever-increasing edge rates will raise the likelihood of cross-talk, ground bounce, resonance, attenuation and other signal discontinuities among squeezed signal lines. These are important issues for high speed circuit design and modeling.

To model the surface-roughness effect of the signal integrity in interconnects on high-speed packages and board, the rough surface is characterized by a stochastic process with spectral density function. From 3D roughness profiles of atomic force microscope (AFM) measurements, the spectral densities were extracted. We considered the problem of a plane wave incident on a rough dielectric-metal surface and also the problem of a source in a metallic waveguide with a rough interface. To solve Maxwell equations for the problem, the analytic small perturbation method and numerical methods were used (the Method of Moments (MoM) and the transfer operator matrix (T-Matrix)).

For multiple vias scattering problem, this method consists of a full wave 3D characterization using the MoM with layered media Green's functions for the exterior microstrip-to-via problem, and the Foldy-Lax multiple scattering equations for the interior vias between the reference planes. The semi-analytic formulations model the vias by using waveguide modes in the vertical direction, and cylindrical wave expansions in the horizontal direction. The layered medium Green's functions are generated rapidly, using fast all modes method (FAM) and numerical modified steepest-descent path method (NMSP). These methods solve the complicated interconnecting structures many times faster than the available commercial software.

Simulation shows that a rough surface interface can cause up to 100% more power loss than a smooth surface interface. The Via-Foldy-Lax simulation tool provides multi-port network parameters several thousand times faster than the commercial software (HFSS). The 3D full wave method is now being extended to more complicated configurations such as 3D waveguide roughness and multi-layered stacked problems. eeKO8

A side view of the rough interface between the printed transmission line and the substrate, taken at the polished cross-section.

A top view of the rough interface between the printed transmission line and the substrate taken by the atomic force microscope.
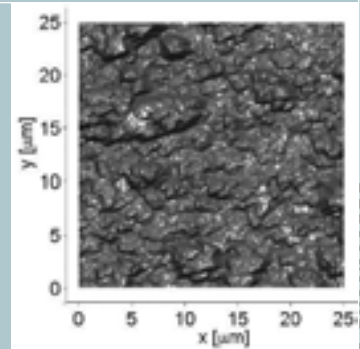
Below: Multi-layer stacked vias in the IC package.

Optimization and Control of
Synthetic Biological Systems

JOSH BISHOP — Graduate Student (EE)
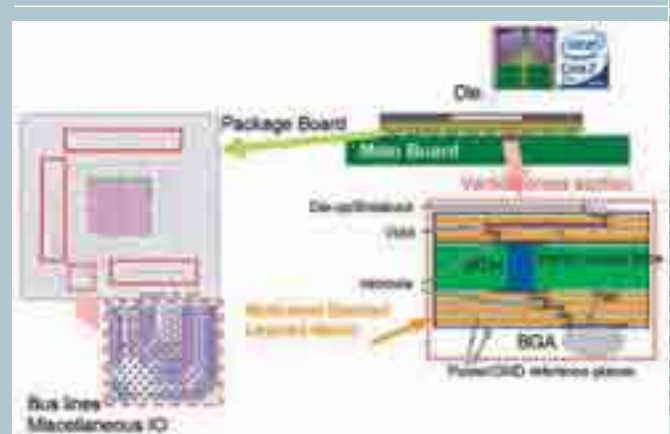
Synthetic biology is an emerging field in which new or existing biological systems are engineered for useful purposes. Engineered biological systems seek to harness the power of the living world — robust, complex, dynamic systems that work from the molecular scale up. Efforts to construct synthetic biological systems with similar degrees of robustness and complexity to those found in nature require the merging of biology with engineering techniques. This research applies techniques from control systems engineering in order to optimize and control the dynamic behavior of synthetic biological systems.

When engineering synthetic biological systems to produce desirable and predictable system dynamics, as well as robustness to potentially useful environments, scaling system size and complexity is often a challenge. A framework is needed to guide the interconnection of biological components into robust, predictable systems in much the same way that electronic components are wired into robust, predictable circuits.
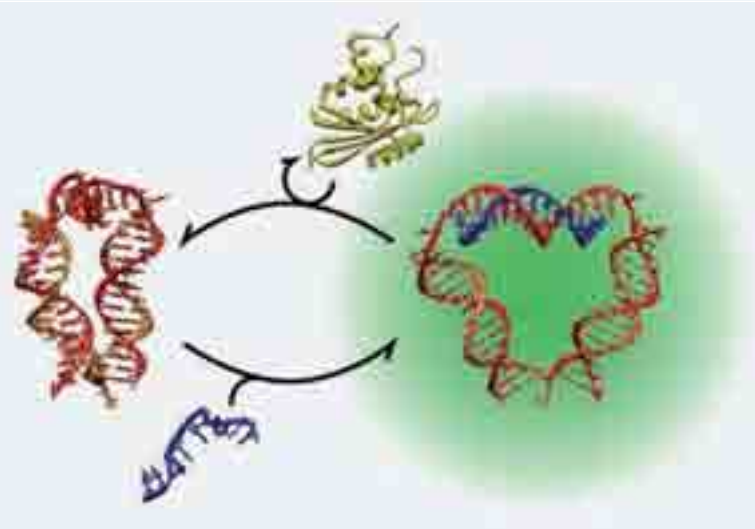
This research spans a continuum of systems ranging from simple biochemical components assembled in test tubes to more complex regulatory networks created in bacteria, and tests methods across a range of increasingly complex environments. For example, the analysis of an *in vitro* DNA nanomotor suggests a way to improve its dynamic performance. Modeling and sensitivity analysis reveals the adverse effects of waste to the repeatability of the system. The improved, redesigned system incorporates a waste management component in the form of an enzyme that degrades interfering waste products accumulating in the environment.

The analysis and design of these synthetic biological systems from a control systems perspective is complemented by their construction in an experimental setting. In the case of the nanomotor, the redesigned system was experimentally demonstrated to improve performance.

In more complex settings, robust synthetic biological systems will be useful in applications like gene therapy, virus detection, and biofuel synthesis. This research is a step toward understanding how to build robust, controllable biological systems that work in complex environments. eeK○8

A depiction of the improved autonomous DNA nanomotor two-stage work cycle. The motor (red/orange) first "opens" when an RNA fuel strand (blue) binds to it. The nanomotor then "closes" after a Ribonuclease H enzyme (yellow) digests the bound fuel strand. A pair of fluorescent molecules (not depicted) are attached to the nanomotor in such a way that they fluoresce at a specific wavelength when the motor is open, and do not fluoresce when it is closed — allowing us to observe the motor's behavior.

ELECTRICAL ENGINEERING KALEIDOSCOPE 2008

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FACULTY ADVISOR: **Professor Eric Klavins**
RESEARCH AREA: **Control Systems and Nanotechnology**

RAVEN Undersea Adventures:
NASA NEEMO XII

MITCHELL LUM & DIANA FRIEDMAN — Graduate Students (EE)

This spring the team from the BioRobotics Lab was on the road again, taking the RAVEN Surgical Robot (see EEK 2007 and EEK 2006) to Key Largo to participate in the twelfth NASA Extreme Environments Missions Operation (NEEMO). NEEMO is NASA's training analog to space flight. It takes place in the Aquarius Undersea Habitat 3.5 miles off the Florida Keys at a depth of about 60ft. The RAVEN was deployed in the habitat for three days of testing and experiments with surgeons operating remotely from Seattle. The RAVEN was also set up and run by NASA's Aquanaut team, with the BioRobotics Lab team providing mission support from on-shore in Key Largo.

Mitchell Lum and Diana Friedman were sent to Key Largo to provide on-site support while Hawkeye King, Gina Donlin and Ganesh Sankaranarayanan provided support in Seattle for surgeons Thomas Lenday (Seattle Children's Hospital), Andrew Wright (UWMC) and Mika Sinanan (UWMC). During the experiment from Seattle to Aquarius, the surgeons' motion commands were sent through commercial Internet to the on-shore base in Key Largo, then across a microwave communication link, ten miles out to the Life Support Buoy floating atop Aquarius, then into the habitat to control the RAVEN. Video feedback was then relayed back to the surgeons. The total round trip delay from the surgeon making a motion to the surgeon seeing that motion on the video display was about one second. The task performed by the surgeons was based on the Fundamentals of Laparoscopic Surgery block transfer, a standardized task used in surgical training.

Along with the main experiment, the RAVEN was used for other NASA objectives. Astrogeologist Dr. Mary Sue Bell remotely analyzed simulated lunar samples. In an educational outreach event, a group of high school students from Cincinnati also got a turn controlling the RAVEN, manipulating foam rocks. Once the RAVEN was back on shore, it was teleoperated from the American Telemedicine Association meeting in Nashville.

Participation in NEEMO XII allowed the BioRobotics Lab team to further develop, test and debug the RAVEN. It allowed NASA Aquanauts to learn how to set up and run a complex system themselves with remote support from the engineers who developed it. NASA was able to evaluate the use of a surgical robot for future space missions.

Developing robotic systems is a hands-on process, and the deployment in Aquarius provided an incredibly unique experience. Who knows where the BioRobotics team will be headed in 2008? eeK○8

Aquanaut Dominic Landucci peers in through a port hole to observe Lendvay's progress with the RAVEN.

At the Universtiy of Washington, Pediatric Urologist Thomas Lendvay MD, performs a surgical training task from over 3000 miles away.

Low-cost Stretchable Conductors
for Human-Machine Interfacing

GABRIEL ROWE — Graduate Student (EE)

Low-cost stretchable conductors have long been sought as one of the key enablers in electronics for direct human machine interfacing and the conventional notion of wearable electronics. A human machine interface in the future will go beyond the keyboard/mouse/display methodology used now. It will incorporate more senses such as touch, temperature sensation, and will eventually interface directly with the nervous system. These technologies will require conformal electronics that move and stretch with the body to maintain intimate contact with the skin and nerves.

A novel high-performance stretchable conductor was recently fabricated in a low-cost, highly-scalable fashion compared to other methods proposed over the last few years. Previous techniques either failed after small strains (less than 30%) or were fabricated in non-scalable or very expensive processes. The technique developed in this research involves creating a dimpled rubber surface then electrolessly depositing a metal on that dimpled surface. The dimples serve two important purposes: 1) to add surface area to the metal film for strain relief, and 2) to act as stress crack propagation terminators.

These stretchable conductors continue to function beyond 175% strain, and are very resilient, remaining functional after 100,000 strain cycles. With the excellent stretchability, mechanical lifetime, low cost, and scalability, this material will enable reliable human machine interfaces and realistic wearable electronics. The research focus now is to create a multifunctional sensor skin in a prosthetic device at the skin-prosthesis interface. This sensor skin will measure temperatures and pressures in real-time, actively cool the skin, and dynamically redistribute pressures to improve prosthetic function and comfort.

If these stretchable conductors were simply used as electrical interconnects between traditional non-stretchable integrated circuits, the possible applications are quite numerous and intriguing ranging from stretchable solar panels, wearable displays, and wearable computers, to virtual reality suits, and skin for humanoid robots. eeK○8
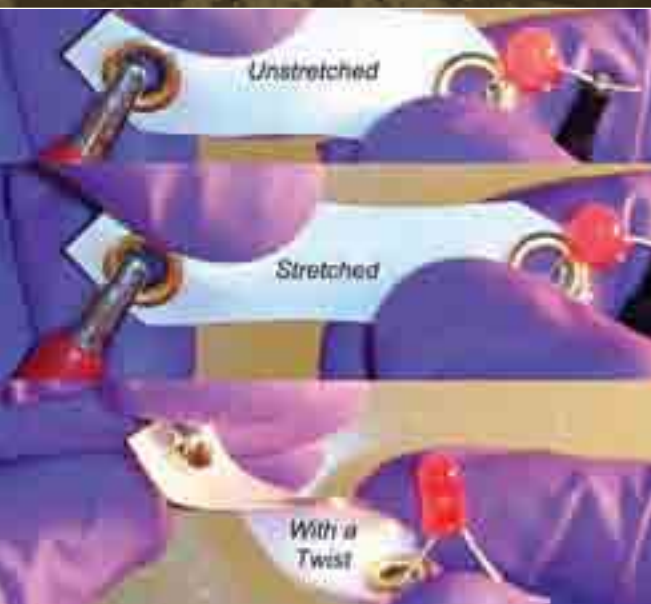
Whether it is stretched, flexed, or twisted, this material conducts quite well even when stretched to more than twice its original length.
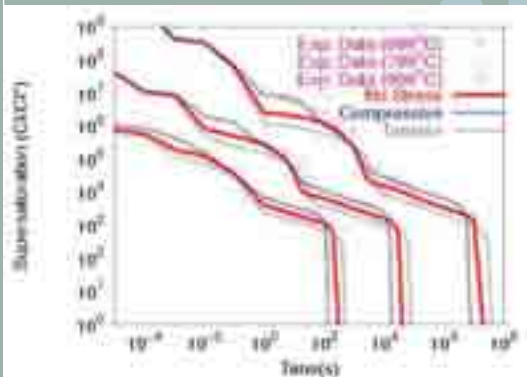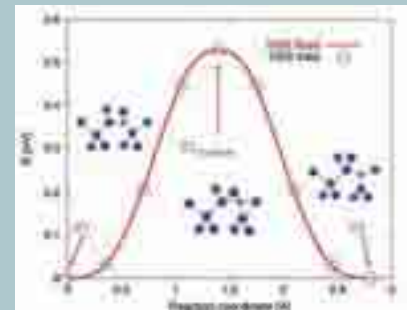
Diffusion and Precipitation Models
for the Formation of Ultra Shallow Junctions

HSIU-WU (JASON) GUO — Graduate Student (EE)

MOSFET evolution in the IC industry has relied on rapid miniaturization, new materials, or new structures. To achieve an ultra shallow junction (USJ) with a low thermal budget, dopant distribution and cluster/point defect incorporation during epitaxial regrowth play critical roles in controlling the final junction profiles and activation levels. Technology computer aided design (TCAD) provides an economical way to study materials and devices. Effective application of TCAD requires development of physical models from atomistic to continuum levels.

This research introduces a delta-function approximation (DFA) to the reduced-moment based model (RKPM) to study precipitation processes with better computing efficiency. These models were characterized by the experimental data and applied to the formation of USJ. Dopant atoms are commonly introduced into source/drain (S/D) regions through ion implantation to obtain an accurate dose and distribution. To accompany the scaling of semiconductor devices, both high doping and dopant activation must be achieved simultaneously in order to keep the sheet resistance low at the junctions.

Simulation using RKPM-DFA time evolution of I supersaturation under a biaxially strained state at various temperatures. Tensile stress favors both small I clusters and {311} formation, giving a longer but less intensive TED period; compressive stress has an opposite effect.

Calculated change of C diffusivity, using both ab-initio and KLMC simulations, under a biaxially strained condition at 1000 °C. In-plane and out-of-plane diffusivities are enhanced under tensile strain and reduced under compressive strain. Out-of-plane diffusivity shows stronger stress dependence.

The calculated transition path in unstrained silicon for C interstitial using the nudged elastic energy band (NEB) method. Blue and brown atoms are Si and C respectively. The calculated migration barrier is 0.53eV.
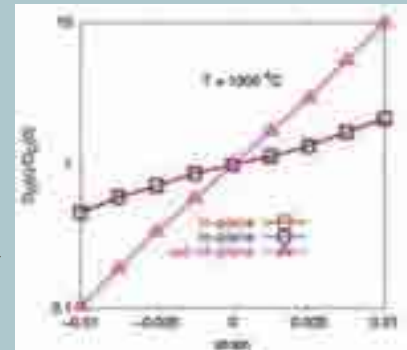
Modeling of transient enhanced diffusion (TED) was performed with the incorporation of I clusters and {311} defects. It is known that C can provide a highly efficient sink for excess interstitials during the annealing process. C diffusion path and clustering mechanisms were confirmed by utilizing ab-initio calculations. Studies of stress effects on TED and C diffusion/clustering were done to provide guidance for optimizing the fabrication processes.

Alloy materials (SiGeC) play a key role in scaling CMOS. Predictive models of recrystallization, diffusion, and activation during and following epitaxial regrowth as a function of strain and impurity/doping concentration are necessary. The results will provide insight and tools to identify optimum alloy compositions and recrystallization/epitaxial regrowth processes to achieve shallow abrupt junctions with high activation and low contact resistance. eeKO8
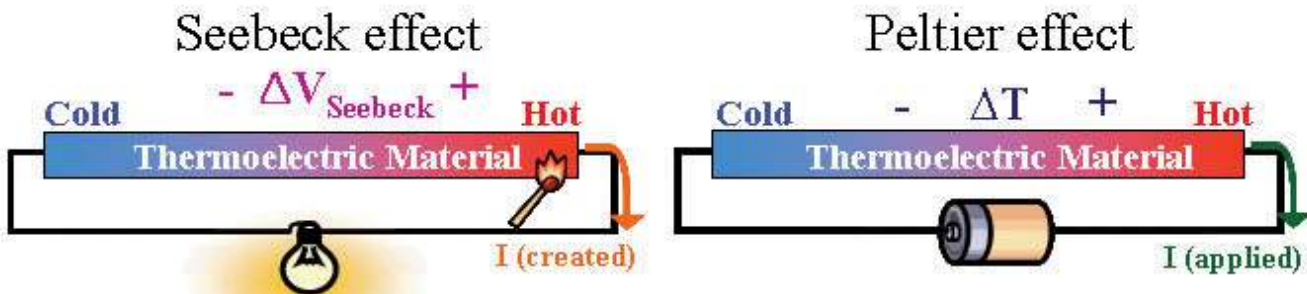
Thin Film
Thermoelectric Devices

SHIHO IWANAGA — Graduate Student (EE)

Thermoelectricity is a solid state phenomenon which directly converts heat into electrical energy, and vice versa. Thermoelectric thin films have drawn attention for their possible applications as on-chip temperature sensors, chip-cooling elements, or local micro-power generators. Developing cost effective and simple deposition techniques to fabricate thermoelectric thin films will open up doors for more energy efficient microelectronics and other various thin film device applications.

In bulk form, thermoelectric materials are already used in various applications, including thermocouples for temperature measurement, power generators for space missions, and in consumer products such as coolers for computer chips and vehicle seats.

A schematic of the Seebeck and Peltier effects. The Seebeck effect creates a voltage difference across two ends of a thermoelectric material in response to a temperature difference between the same two ends. The Peltier effect creates a flow of heat from one end to the other in response to an applied electric current. This effect can be used to implement refrigeration for beer, car seats, or computer chips.

In this research, the possibilities of creating these thermoelectric devices in thin film form are explored. Much research effort has been put into creating thin films from traditional bulk thermoelectric materials. In thin film form, however, these materials face issues such as susceptibility to oxidation and poor mechanical properties, which degrade the thermoelectric efficiency. Further, vacuum deposition which is required for these materials is an expensive and slow fabrication method.

Here, doped vanadium oxides are investigated as new thermoelectric thin film materials. This family of oxides remains very stable in aqueous solutions, which is an industrial advantage for inexpensive dip coating and spin coating methods. By developing a unique doping technique, a dramatic increase in thermoelectric properties was obtained. Various materials science analysis tools were used to optimize the process techniques, which successfully solved the issues of low electrical conductivity and poor mechanical properties of vanadium oxide thin films.

The thermoelectric models for a single thermoelectric device are being developed to optimize the materials design and dimensions of thin films necessary for the required performance of sensors, waste heat recovery devices, and thermoelectric cooling elements. Prototypes will be built and tested to compare with the model. eeK○8

ELECTRICAL ENGINEERING KALEIDOSCOPE 2008

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FACULTY ADVISORS: Professor R.B. Darling (EE) and Professor F.S. Ohuchi (MS&E)
RESEARCH AREA: Electronic Devices, Circuits and Sensors
GRANT/FUNDING SOURCE: NEDO grant, Ford Motor Fellowship, and UW Royalty Research Fund

Digitally-Assisted Sigma-Delta ADCs for
Technology Scaling

YI TANG — Graduate Student (EE)

The rapid proliferation of wireless communication devices and standards has been driven in large part by Moore's law, according to which the digital processing capability for a given power constraint doubles roughly every 18 months. In current evolving communication standards, the signal to be digitized occupies an ever-increasing bandwidth. Furthermore, implementation of high-precision analog systems, of which the analog-to-digital converter (ADC) is an example, has become more challenging due to the downward scaling of power supply voltage (and voltage headroom) and its associated consequence of lower gain. It thus becomes necessary to use digital processing capabilities to correct analog imperfections.
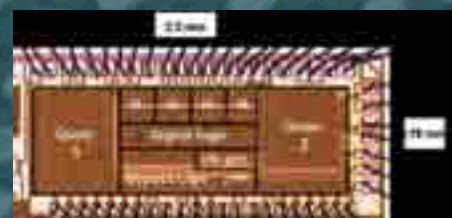
This research investigates the implementation of wide-bandwidth converters using op-amps with the lowest possible DC gain while maintaining high signal-to-noise ratio (SNR), linearity, and system stability. The key innovations use digital calibration techniques in conjunction with a low-distortion system topology. By pushing the DC gain requirements to very low values, a simple differential-pair op-amp can implement the integrators instead of the traditional folded-cascode or two-stage op-amps. This scaling-friendly approach offers several advantages: (1) A differential-pair-based implementation eases design effort and cost. (2) Digital scaling trends favor high-speed digitally intensive designs, whereas analog circuit performance is compromised by the ever-diminishing intrinsic gain of nanometer CMOS. The low-gain and digitally-assisted design techniques provide a solution to this dilemma. (3) The differential-pair amplifier reduces the minimum headroom requirements mandated by shrinking supply voltages. (4) It is maximally speed and power efficient — a property favored by Moore's Law that allows greater gm/ID efficiency at smaller feature lengths for a given speed.

A 2-2 cascaded Sigma-Delta ADC was designed and implemented in 0.13μm CMOS process with the lowest gain amplifiers reported to date (22dB). The ADC achieves 11b accuracy for a 10 MHz bandwidth, which is comparable/superior to those implemented with high gain amplifiers. This work demonstrates that digitally-assisted ADCs can be a very scale friendly solution. eeKO8
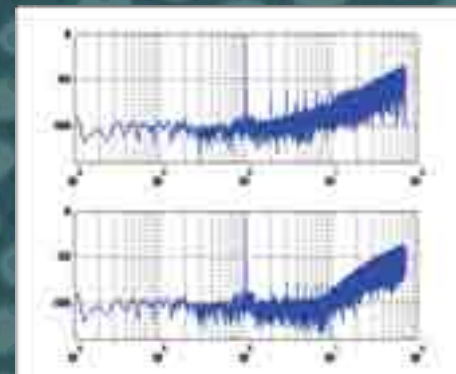

Die Micrograph in 0.13μm CMOS.

Measured output spectra before/after calibration.

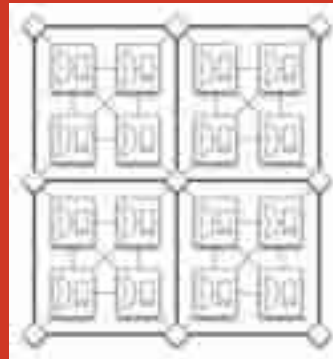Switched-capacitor implementation of 2-2 modulator (single-ended version).

Mosaic:
the Future of Reconfigurable Logic Chips?

BRIAN VAN ESSEN — Graduate Student (CSE)

DSP and scientific computing applications continually demand ever-increasing performance, but at an ever-diminishing power budget. Coarse-grained reconfigurable architectures (CGRAs) combine the horsepower and efficiency of an application specific integrated circuit (ASIC) with the re-programmability of a field programmable gate array (FPGA). They contain a sea of reprogrammable ALUs, with a statically scheduled interconnect, and are optimized for streaming applications.

CGRAs are typically designed monolithically, with little insight into which features are important in those designs. Future designers cannot leverage individual innovations without wholesale adoption of a design. CGRAs are also burdened by programming models that are either too abstract to achieve reasonable performance, or mired in the minutiae of hardware specification.

Prototype of a Coarse-grained Reconfigurable Architecture.

MOSIAC Logo

The Mosaic Project develops a high performance, yet power efficient CGRA. It also maps out the entire design space to demonstrate what features offer the best power and performance. Furthermore, this research attempts to make CGRAs more accessible by providing a more natural mechanism for programmers to write applications and by creating a tool chain that dramatically simplifies the task of mapping applications to architectures.

The Mosaic Project achieves high performance and power efficiency by creating a coarse-grained datapath for applications with intense data and loop level parallelism. Techniques like resource virtualization and time-multiplexing are used to improve user programmability of CGRAs. Another mechanism employs a CAD tool that integrates scheduling, placement, and routing of applications to architectures to achieve the best possible quality. Finally, the challenge of writing applications for CGRAs has driven this research on the Macah programming language. Macah is a specialized C-level language designed to easily express the fine-grained parallelism common to this application domain.

Coarse-grained reconfigurable architectures are poised to emerge as a new computing platform. But, how to create the best architectures, applications, and CAD tools is a murky area at best. The Mosaic Project focuses on solving these problems by designing a power efficient architecture and a tool chain that dramatically improves the application development process for CGRAs. eeK○8

Layout for component of interconnect switch controller.

Thermoelectric Energy Harvesting for Biological Monitoring:
The Thermocube

ROB EGBERT — Graduate Student (EE)

Successfully integrating energy harvesting devices with ultra low power electronics has many promising applications for self-powered systems. For example, this would enable a new class of wireless sensors for medical and biological monitoring. Thermal energy harvesting is a promising technique for powering sensors and transceivers to record biological data from warm-bodied animals. Current electrophysiological recording schemes require batteries or wires. This research eliminates both of these limitations to enable long-term, wireless recording. As a proof of concept, the "thermocube," a 1cm³ energy harvesting platform was developed to ultimately lead to completely autonomous medical health monitors.

The thermocube is a self-contained, perpetual energy source coupling thermoelectric generators and a solid-state charge pump to generate power for biomedical circuitry. The thermoelectric generators provide power given a thermal gradient via the Seebeck effect. Since comparably small thermal gradients are available when harvesting heat from organisms at ambient temperatures, four generators are series-connected to maximize output voltage. The charge pump operates at a minimum generator voltage of 250mV and provides a potential of 1.8V to supply the load until the voltage decays to 1.3V.

The system drives a 15µA-equivalent load for approximately 300ms per pulse. The pulse period relies heavily on the generator output voltage, resulting in a continual output if the thermal gradient is sufficiently high. The thermocube operates with a pulse period of approximately 3.5 seconds when secured to the skin surface of a human head.

Air flow enhances the steady state generator voltage output by cooling the end of the assembly that interfaces with the air. Choosing an optimal heat sink requires maximizing convective heat transfer while minimizing volume. While standard pin-fin heat sinks were used to characterize the system outputs to date, an integrated top plate/heat sink will be introduced to avoid poor thermal coupling at material interfaces.

The ultimate goal is to integrate the functions of energy harvesting, power conditioning, and sensor/transceiver circuitry on a single die. This will allow completely autonomous monitoring of human health (continuously worn devices monitoring health), structural health (particularly for aviation), and advanced biological research (continuous electrophysiological recording from small animal models). eeK○8
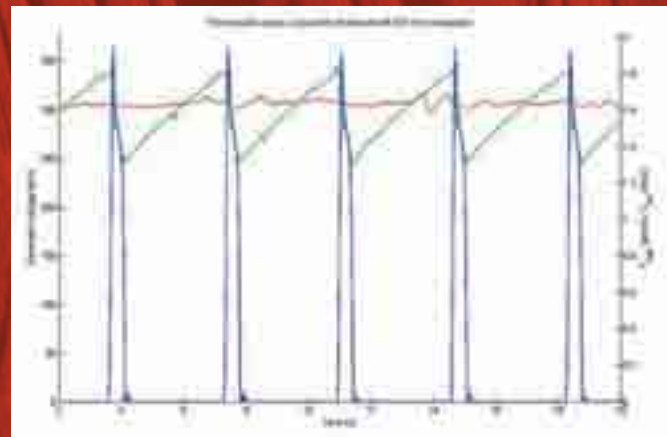
A sample thermocube output graph versus time while attached to forehead and 0.5 ms-1 windspeed. Red trace is the generator voltage output (left axis); green and blue traces are charge pump capacitor voltage and output voltage, respectively (right axis).

Pictured at top left: Thermocube assembly. Aluminum plates provide a heat path from heat source through generators to heat sink; load-bearing Delrin spacers isolate the generators from excessive mechanical stress; PCB was designed to accommodate generator leads, charge pump, and output circuit.

Integration of QD Waveguides
## with Nanoscale Photodetectors

LUDAN HUANG — Graduate Student (Physics)
MICHAEL C. HEGG & JEAN WANG — Graduate Students (EE)

As a gain-enabled nanocrystal, the quantum dot (QD) is an attractive structure for reducing loss when developing ultra-high density photonic integrated circuits. The Photonics Lab at UW EE proposes QD-based nanoscale photonic devices such as waveguides, photodetectors, and lasers. In this research, the first step towards nanophotonic integration is explored by developing a fabrication method to combine the QD waveguide with the QD photodetector.

In this integrated device architecture, an optical signal at the receiving edge of the QD waveguide is guided to the output edge, where a QD photodetector is positioned to receive and transform the output signal. The electric signal can then be further processed by on-chip electronic integrated circuits.

Alignment accuracy is one of the chief challenges in fabrication since multiple EBL writings are required to pattern different functional components in the integrated device. In order to achieve accurate alignment at the nanometer scale, the position of nanogaps in electrodes were systematically characterized, the waveguide position was adjusted accordingly, and a coarse + fine two-step alignment procedure was employed. This method helps achieve an alignment error of < 20 nm, which is essential for nanoscale photonic integration.
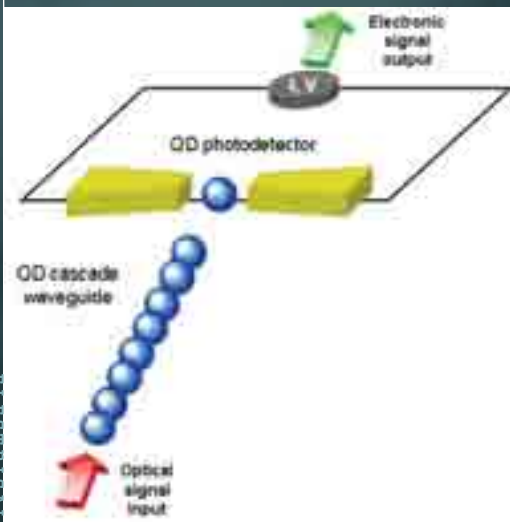
Schematic drawing of the QD nanophotonic waveguide and photodetector integrated device.

SEM micrographs of the integrated device by EBL nanogap patterning: (a) before, and (b) after integration of the waveguide and QD deposition.

Fabrication of the integrated device is achieved by multiple alignment-assisted EBL patterning of QD photodetector electrodes and QD waveguide, nanogap formation in the electrode, and self-assembled QD deposition. Two methods to create nanogaps in the photodetector electrodes have been investigated: electromigration-induced break-junction technique and EBL nanogap patterning. Overall, EBL nanogap patterning is preferred for its nanogap quality, fabrication simplicity, and consistency.

The fabrication of a QD waveguide and photodetector integrated device was demonstrated by alignment-assisted EBL patterning and QD self-assembly deposition. Next steps in research involve testing and optimizing of the QD waveguide and photodetector integrated device. eeK○8

Self-Assembled
Optoelectronic Sensor Systems

SAM KIM — Graduate Student (EE)

Non-contact optical sensing methods have many advantages over direct contact measurements in biological and chemical systems. In recent years there has been interest in integrating optical and photonic components with traditional silicon electronics to create chip level micro total analysis systems (μTAS). However, light emitting semiconductor materials, such as III-V compounds, require entirely different fabrication processes than silicon, making it difficult and expensive to combine them on to a monolithic platform.

By using self-assembly, components made from different materials can be batch fabricated separately. After the incompatible processes have taken place independently, the components are released from their substrates as a powder-like collection of micro-components, and then self-assembly combines them onto a common substrate. The fluidic self-assembly process in this research uses gravity, fluid flow, capillary forces, shape recognition, and external agitation to bring the self-assembling system to an energy minimum. A proof of concept has been demonstrated by integrating AlGaAs double heterojunction LED structures with silicon photosensors with integrated interference filters. The elements have been self-assembled into a glass template that has been patterned with electrical contacts, a low melting point solder alloy, and a photocurable polymer. A unique advantage of self-assembly is that it does not limit conventional microfabrication substrates, such as planar crystalline semiconductor materials. The freedom to use substrates such as glass and plastics can greatly reduce cost and give the final device new properties such as transparency and flexibility.

Self-assembly is an enabling manufacturing process technology and allows researchers to investigate new categories of devices. The fundamental ability to integrate heterogeneous materials cost effectively onto a common substrate may open the door to new applications and markets in the future. eeK○8

Double heterojunction AlGaAs LED self-assembled and turned on under 6V bias.

Self-assembled detection unit consisting of a circular LED excitation source surrounded by square silicon photosensors.
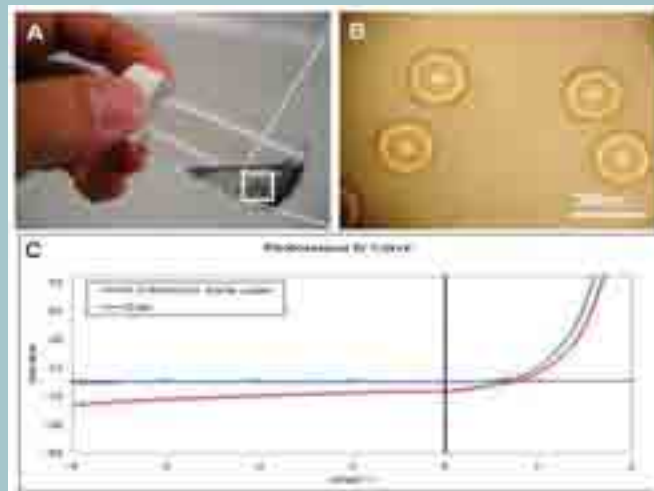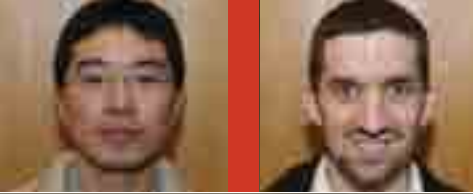

Figure A: Released microcomponents suspended in ethylene glycol.
Figure B: Released square photosensor elements under magnification.
Figure C: Photoresponse curve of photosensor.

All-Optical Plasmonic Mixer for Microfluidics

**XIAOYU MIAO & BEN WILSON** — Graduate Students (EE)

Microfluidic devices that perform chip-based chemical and biological analyses have received significant attention in the last few years. Much of these, such as immunoassays, cell-molecule interaction and DNA hybridization, require localized rapid mixing. In miniaturized devices, fluids with a low Reynolds number may take a long time. This is particularly true when the solution contains macromolecules with low molecular diffusion coefficients.

This research develops an active microfluidic mixing method employing light-induced localized surface plasmons. Localized surface plasmons are the collective electron oscillations confined in metal nanoparticles. The non-radiative decay of the plasmon energy is associated with the creation of electron hole pairs. The movement of the electrons is effectively a current, which feels the resistance of the metal. The energy dissipated through the non-radiative channels is ultimately transferred into heat. The non-radiative decay of the plasmon energy creates a localized heat source on the surface of the nanoparticle array. When the temperature gradient exceeds a threshold, a convective flow is formed to dissipate the energy. The flow that drives the fluids out from the central hot region is established at the liquid/substrate interface and the flow returns back to the center through the bulk region. Thanks to the enhanced absorption cross sections of metal nanoparticles and the associated large magnitude of the thermal gradient, the thermal induced convective flow can be very fast with low optical power requirements. Hence the microfluidic mixing induced by localized surface plasmons can have high energy conversion efficiency.

An all-optical microfluidic mixing method has been demonstrated by utilizing the localized surface plasmons on a gold nanoparticle array. Optimized design of the gold nanoparticle array can further help optimize the performance. The presented approach may open new opportunities in the emerging area of optofludics. eeKO8
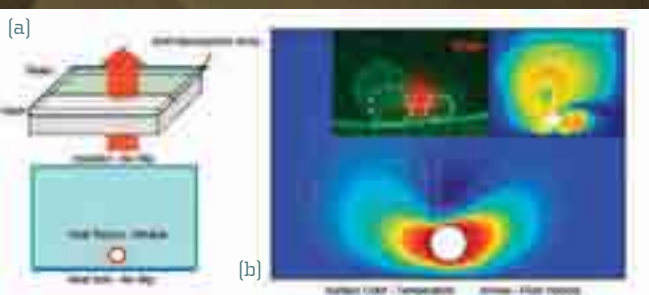
(a) Schematic of plasmonic mixer for microfluidics; (b) Temperature distribution and velocity streamlines simulated by FEMLAB.
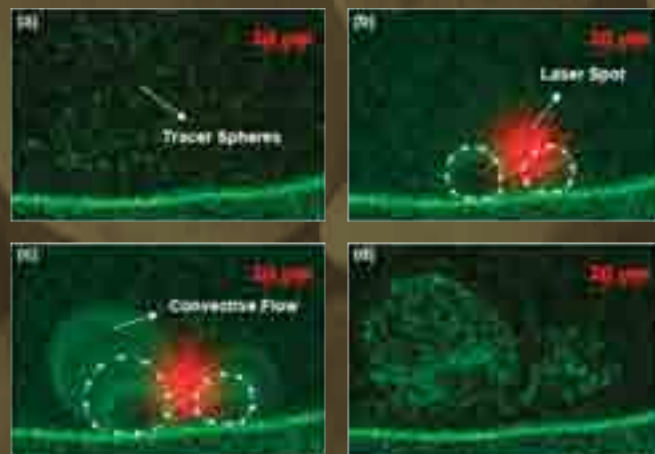
Above right: Demonstration of the plasmonic mixing using dyed polystyrene spheres with diameter 1 μm as the tracers. (a) When the laser is off, there is no temperature gradient along the boundary between the liquid layer and substrate. The motions of the tracer spheres are only induced by the molecular diffusion, which is very slow. (b) When the laser is on, the incident light beam forms a localized heat source at the location of the red spot. The convective flow of the fluid is formed immediately. (c) The convective flow of the fluid becomes stronger and reaches the steady state with continuous light radiation. The velocity fields exist both at the right and left side of the light spot. (d) The tracer spheres start to diffuse when the laser is turned off.

Dielectrophoretic Field-flow Fractionation for Bioanalysis in Microfluidic Devices

JOSEPH E. T. PEACH — Graduate Student (EE)

Bioanalysis using "lab-on-a-chip" technologies combines traditional electrical engineering aspects, such as microfabrication and EM simulation, with new cross-discipline fields such as microfluidics and bioengineering. Dielectrophoretic field-flow fractionation (DEP-FFF) is a method utilizing non-uniform electric fields to redirect target objects, such as cells or nucleic acids, in the hydrodynamic velocity profile of a microfluidic channel. This technique has promising applications in cellular study and genomic analysis.

DEP-FFF devices developed through this research use a microfluidic fluidic channel above an interdigitated array of electrodes to separate beads and biomolecules. Signals applied to the electrodes produce DEP forces in the channel that result in characteristic separation of the targets as they flow downstream in the channel. A variety of electrode arrays are being tested to maximize the separation capabilities of the microfluidic devices. Using this technique, submicron microspheres of various diameters can be separated, and testing the separation capabilities of these devices for large DNA length differentiation is underway.

Larger microspheres (1 μm, blue) move towards the center of the channel, while smaller microspheres (200 nm, red) are directed along electrode edges towards the sides of the channel. Downstream, the larger beads arrive prior to the smaller beads.
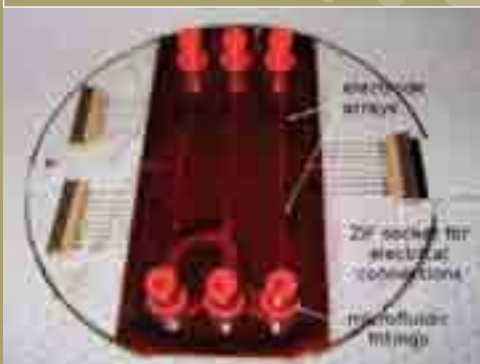
A fabricated DEP-FFF device prototype. The electrode arrays are aligned under the microfluidic channels.
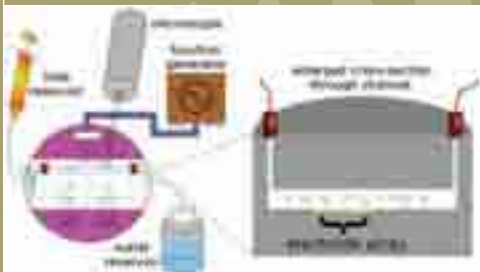
Schematic of the components and test-setup used for during device experimentation.

Pulsed-field gel electrophoresis (PFGE) is the most common method currently used for the separation of large DNA, but it often requires ten hours or more to achieve desired separation resolutions (~10%). The formation of a gel sieving matrix is also necessary prior to each PFGE separation, such that integration in microfluidic or lab-on-a-chip devices is extremely challenging. DEP-FFF offers numerous benefits over PFGE and other competing technologies because of its potential speed and ability to be integrated in biochips. The method may aid in DNA fingerprinting, whole plasmid purification for disease detection, or for separating chromosomes and large DNA prior to sequencing. The technique could become a standard in dozens of other applications requiring large DNA separation.

The goal is to obtain DNA separation parody with PFGE, but in less than five minutes. If such a result is achievable, the technology will be of immense commercial importance for future medical and bioanalytical devices, especially as "lab-on-a-chip" devices find additional applications in mainstream medical diagnostics and care. eeK○8

Electric Cell-substrate Impedance Sensing (ECIS) for Studying Adhesion and Spreading of an Individual Cell

PAHNIT SERIBURI — Graduate Student (EE)

Cell adhesion and cell spreading are fundamental processes. By recording changes in the cell-substrate separation or projected area (or both) of an individual cell, the dynamics of cell spreading and cell adhesion have been studied. Conventionally these two properties are measured using optical methods. However, optical techniques are not currently able to measure the properties of many individual cells simultaneously. The ECIS technique is a simple and cost effective method to measure many individual cells in parallel.

The ECIS technique is applied to solve a new problem: to measure properties of an individual cell. In conventional ECIS, the impedance spectrum of a bare microelectrode changes when cells adhere to the electrode. For this study, an experiment was designed to test whether the change could be seen in the impedance spectrum when one individual cell was on the microelectrode. Also, a way to interpret the impedance change was developed in terms of the properties of the cell.

The impedance spectra of individual cells were recorded in real time using a custom impedance sensing setup. Each impedance spectrum was fitted with an equivalent circuit model of the setup to obtain a value for the cell-substrate separation and the projected area of an individual cell. These ECIS measurements were compared to those obtained optically. Results showed that the cell substrate separation of an individual cell was in the nm range as expected. The projected areas of the cell from the ECIS and optical measurements were in agreement. ECIS was also used to monitor both the cell-substrate separation and the projected area of one individual cell for 18 minutes. The changes of both properties over time were as expected.

It has been demonstrated that the cell-substrate separation and the projected area of an individual cell could be obtained using ECIS. These properties have implications in the study of cell adhesion and cell spreading. This work will enable the measurement of two properties of many individual cells at once, which is important to single cell analysis. eeKO8
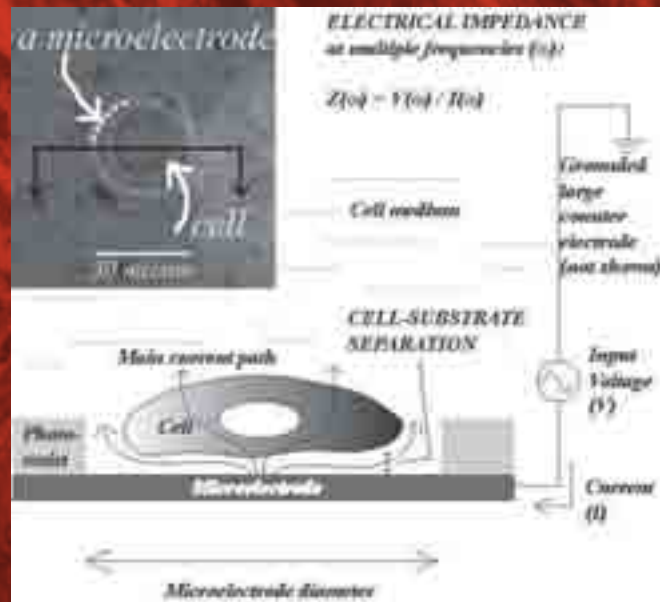
A schematic of an individual cell on a microelectrode under ECIS measurement. The cell-substrate separation and the projected area of the cell determine the values of Z(Ω) because these properties of the cell restrict how much I(Ω) can be obtained at a given V(Ω) in the ECIS measurement. The optical image at the upper left corner shows a top view of an individual cell sitting inside the microelectrode (inset).

Organic Electronics:
## Present and Future

VAIBHAV VAIDYA — Graduate Student (EE)

"Organic electronics" is an effort to create electronic circuits with components from the realm of carbon-chemistry. Carbon forms various chain and ring compounds with itself and other elements where the bond structure causes semiconducting properties. These include gate voltage controlling drain current in organic FETs, electro-optic interaction yielding efficient organic LEDs and solar cells. Such organic devices are made at sub- 150C° temperatures. Think low cost, ink-jet printable, flexible, large-area electronics. Who's for a cheap, light, roll-up ultra-bright 50-inch HDTV?

Organic field effect transistors (OFETs) are accumulation mode thin-film devices based on intrinsic organic semiconductors such as pentacene (p-type FETs) and C-60 (buckyballs, n-type FETs). Performance is comparable to that of competing thin film semiconductors such as amorphous-Silicon. Organic LEDs (OLEDs) show high quantum efficiencies and have demonstrated light power density sufficient for both displays and lighting applications.
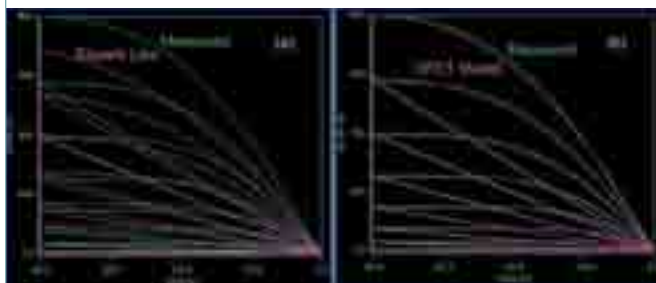
Organic solar cells are also in active development with the promise of high quantum efficiencies. This research focuses on OFET and OLED circuits for:

- Designing resilient display circuits that balance or cancel degradation effects in OFETs to prevent fading and nonuniformity in displays

- Modeling OFETs in SPICE: Explaining OFET behavior to a circuit simulator enables accurate circuit performance prediction

- Extending the applications of organic and thin film electronics with integrated MEMS components

Organic electronics is at a juncture where a shift in approach from making and optimizing single devices to designing circuits and complete solutions is evident. Applications such as displays are being demonstrated at a commercial level, while concepts like printable RFID tags, low cost integrated sensors and large area electronics are seeing active research interest.
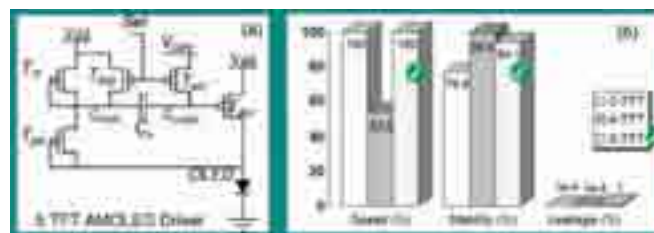
A switched capacitor driver to compensate for OFET threshold voltage degradation. (a) 5 TFT circuit, (b) performance relative to published 2 TFT and 4 TFT circuits.

Organic electronics is an interesting new field promising low-cost, flexible and large area electronics. Organic components are at the cusp of usability in all-organic circuits, and are expanding the envelope of new applications. From lightweight displays to integrated sensors, LEDs and MEMS, efficient performance prediction and application design can realize many new organic systems in the years to come. *eeK○8*

Comparison of models fitted to measured organic FET characteristics. (a) MOS Square Law Model, (b) OFET Model with field dependent mobility.

ee Faculty

AFROMOWITZ, MARTY
Professor
Microtechnology/Sensors
Ph.D., 1969 Columbia University
NIH Career Development Award

ALLSTOT, DAVID
Professor
System-on-Chip VLSI
Ph.D., 1979 UC-Berkeley
IEEE Fellow

AMMER, JOSIE
Assistant Professor
Circuits and Algorithms for Wireless Communication
Ph.D., 2005 UC-Berkeley

ATLAS, LES
Professor
Signal and Image Processing
Ph.D., 1984 Stanford University
NSF Presidential Young Investigator
IEEE Fellow

BILMES, JEFF
Associate Professor
Signal and Image Processing
Ph.D., 1999 UC-Berkeley
NSF CAREER Award

BÖHRINGER, KARL
Professor
Microelectromechanical Systems (MEMS)
Ph.D., 1997 Cornell University
NSF CAREER Award

BUSHNELL, LINDA
Research Assistant Professor
Controls and Robotics
Ph.D., 1994 UC-Berkeley
NSF ADVANCE Fellow

CHIZECK, HOWARD
Professor
Controls and Robotics
Sc.D., 1982 MIT
IEEE Fellow

CHRISTIE, RICH
Associate Professor
Energy Systems
Ph.D., 1989 Carnegie Mellon University
NSF Presidential Young Investigator

CRUM, LAWRENCE
Research Professor
Medical Ultrasound
Ph.D., 1967 Ohio University
ASA Fellow

DAILEY, DANIEL J.
Research Professor
Intelligent Transportation Systems
Ph.D., 1988 University of Washington

DARLING, R. BRUCE
Professor
Devices, Circuits, and Sensors
Ph.D., 1985 Georgia Institute of Technology

DUNHAM, SCOTT
Professor
Materials and Devices
Ph.D., 1985 Stanford University

EL-SHARKAWI, MOHAMED
Professor
Intelligent Systems and Energy
Ph.D., 1980 University of British Columbia
IEEE Fellow

FAZEL, MARYAM
Assistant Professor
Systems Biology
Ph.D., 2002 Stanford University

GUPTA, MAYA
Assistant Professor
Signal Processing
Ph.D., 2003 Stanford University
ONR YIP Award

HANNAFORD, BLAKE
Professor
Biorobotics
Ph.D., 1985 UC-Berkeley
NSF Presidential Young Investigator,
IEEE EMBS Early Career Achievement
Award, IEEE Fellow

HAUCK, SCOTT
Associate Professor
VLSI and Digital Systems
Ph.D., 1995 University of Washington
NSF CAREER Award, Sloan Research
Fellowship

HOCHBERG, MICHAEL
Assistant Professor
Nanophotonics
Ph.D., 2006 California Institute of
Technology
AFOSR YIP award

HWANG, JENQ-NENG
Professor
Signal and Image Processing
Ph.D., 1988 University of Southern
California
IEEE Fellow

JANDHYALA, VIKRAM
Associate Professor
*Electromagnetics, Fast Algorithms,
Devices*
Ph.D., 1998 University of Illinois
NSF CAREER Award

**JARUWATANADILOK,
SERMSAK**
Research Assistant Professor
Electromagnetics
Ph.D., 2003 University of Washington

KIM, YONGMIN
Professor
*Digital Systems, Image Processing and
Medical Imaging*
Ph.D., 1982 University of Wisconsin
– Madison
IEEE Fellow, IEEE/EMBS Early Career
Achievement Award

KIRCHHOFF, KATRIN
Research Associate Professor
*Multilingual Speech Processing, Machine
Learning*
Ph.D., 1999 University of Bielefeld

KLAVINS, ERIC
Assistant Professor
Controls and Robotics
Ph.D., 2001 University of Michigan
NSF CAREER Award

KUGA, YASUO
Professor
Electromagnetics
Ph.D., 1983 University of Washington
NSF Presidential Young Investigator
Award
IEEE Fellow

LIN, LIH
Associate Professor
Photonics, MEMS
Ph.D., 1996 UC-Los Angeles

LIU, HUI
Associate Professor &
Associate Chair for Research &
Development
Communications and Signal Processing
Ph.D., 1985 University of Texas, Austin
NSF CAREER Award, ONR Young
Investigator Award

MAMISHEV, ALEX
Associate Professor
Electric Power Systems, MEMS, Sensors
Ph.D., 1999 MIT
NSF CAREER Award

NELSON, BRIAN
Research Associate Professor
Plasma Physics
Ph.D., 1987 University of Wisconsin
– Madison

OSTENDORF, MARI
Professor
Signal and Image Processing
Ph.D., 1985 Stanford University
IEEE Fellow

OTIS, BRIAN
Assistant Professor
RF/Analog IC Design
Ph.D., 2005 UC-Berkeley

PARVIZ, BABAK
Assistant Professor
Microelectromechanical Systems (MEMS)
Ph.D., 2001 University of Michigan
NSF CAREER Award

PECKOL, JAMES K.
Lecturer
Digital Systems
Ph.D., 1985 University of Washington

POOVENDRAN, RADHA
Associate Professor
Communications Networks and Security
Ph.D., 1999 University of Maryland
NSA Rising Star Award, NSF CAREER
Award, ARO YIP and ONR YIP Awards,
PECASE Award

RISKIN, EVE
Professor & Associate Dean
Signal and Image Processing
Ph.D., 1990 Stanford University
NSF Presidential Young Investigator,
Sloan Research Fellowship

RITCEY, JAMES A.
Professor & Associate Chair
for Education
Communications and Signal Processing
Ph.D., 1985 UC - San Diego

ROSEN, JACOB
Research Associate Professor
Biorobotics, Human-Machine Interfaces
Ph.D., 1997 Tel-Aviv University

ROY, SUMIT
Professor
Communications and Networking
Ph.D., 1988 UC - Santa Barbara
IEEE Fellow

SAHR, JOHN
Professor & Associate Dean for
UGrad Academic Affairs
Electromagnetics and Remote Sensing
Ph.D., 1990 Cornell University
NSF Presidential Young Investigator,
URSI Booker Fellow, URSI Young
Scientist Award

SHAPIRO, LINDA
Professor
Signal and Image Processing
Ph.D., 1974 University of Iowa
IEEE Fellow, IAPR Fellow

SHI, C.J. RICHARD
Professor
VLSI and Digital Systems
Ph.D., 1994 University of Waterloo
NSF CAREER Award, IEEE Fellow

SOMA, MANI
Professor & Associate Vice
Provost for Research
Mixed Analog-Digital System Testing
Ph.D., 1980 Stanford University
IEEE Fellow

SUN, MING-TING
Professor
Signal and Image Processing
Ph.D., 1985 UC-Los Angeles
IEEE Fellow

TSANG, LEUNG
Professor & Chair
Electromagnetics, Remote Sensing
Ph.D., 1976 MIT
IEEE Fellow, OSA Fellow

WILSON, DENISE
Associate Professor
Circuits and Sensors
Ph.D., 1995 Georgia Institute of
Technology
NSF CAREER Award

EMERITI

ALBRECHT, ROBERT
Controls and Robotics
Ph.D., 1961 University of Michigan

ALEXANDRO, FRANK
Controls and Robotics
Ph.D., 1961 University of Michigan

ANDERSEN, JONNY
Circuits and Sensors
Ph.D., 1965 MIT

BJORKSTAM, JOHN L.
Controls and Robotics
Ph.D., 1958 University of Washington

DAMBORG, MARK
Energy Systems
Ph.D., 1969 University of Michigan

DOW, DANIEL G.
Ph.D., 1958 Stanford University

GUILFORD, EDWARD C.
Ph.D., 1960 UC-Berkeley

HARALICK, ROBERT
Signal and Image Processing
Ph.D., 1969 University of Kansas
IEEE Fellow

HELMS, WARD
Circuits and Sensors
Ph.D., 1968 University of Washington

ISHIMARU, AKIRA
*Electromagnetics and Waves in Random
Media*
Ph.D., 1958 University of Washington
IEEE Fellow, OSA Fellow, IOP Fellow,
IEEE Heinrich Hertz Medal, URSI John
Dillinger Medal and Member, National
Academy of Engineering

JACKSON, DARRELL
Ph.D., 1977 California Institute of
Technology

JOHNSON, DAVID L.
Ph.D., 1955 Purdue University

LAURITZEN, PETER O.
Ph.D., 1961 Stanford University

MORITZ, WILLIAM E.
Ph.D., 1969 Stanford University

PEDEN, IRENE
Ph.D., 1962 Stanford University
NSF "Engineer of the Year" Member,
National Academy of Engineering,
IEEE Fellow, IEEE Harden Pratt Award,
U.S. Army Outstanding Civilian Service
Medal

PORTER, ROBERT B.
Ph.D., 1970 Northeastern University
ASA Fellow, OSA Fellow

POTTER, WILLIAM
MSEE, 1959 US Naval Postgraduate
School

SIGELMANN, RUBENS A.
Ph.D., 1963 University of Washingt

SPINDEL, ROBERT
Signal Processing/Ocean Acoustics
Ph.D., 1971 Yale University
IEEE Fellow, ASA Fellow, MTS Fellow,
A.B. Wood Medal, IEEE Oceanic
Engineering Society Technical
Achievement Award

YEE, SINCLAIR
Photonics, Sensors
Ph.D., 1965 UC – Berkeley
IEEE Fellow

ZICK, GREG
VLSI and Digital Systems
Ph.D., 1974 University of Michigan

Congratulations to Karl Böhringer
who was promoted to Full
Professor, and to Katrin Kirchhoff
who was promoted to Research
Associate Professor.

New Faculty

Dr. Maryann Fazel

In January 2008, Dr. Maryam Fazel joined the EE department as an Assistant Professor. She received her MS and PhD degrees in Electrical Engineering from Stanford University in 1997 and 2002, and her BS degree from Sharif University of Technology, Iran, in 1995, where she ranked first in the nation-wide University Entrance Exams. Before joining the University of Washington, she was a Postdoctoral Scholar and later a Research Scientist at the Control and Dynamical Systems department at Caltech. She says that she is very excited about the collaborative atmosphere that fosters research across disciplines and departments at UW.

My research interests are in optimization and systems theory and their diverse applications. In the past decade computational methods, in particular convex optimization, have played a central role in modeling, analysis, and understanding design trade offs of engineered systems. Today these tasks present new challenges, as the engineered and natural systems we encounter are large-scale, uncertain, and generally complex. I aim to express such tasks as optimization problems and develop techniques for solving them exactly or approximately along with guarantees on the quality of the solution.

As an example, I am interested in what we term parsimonious modeling — obtaining simple mathematical models that approximate complex behavior. In many engineering applications, notions of order or complexity of a model can be expressed as the rank of an appropriate matrix. A low-rank matrix could correspond to, for example, a low-order controller for a plant or a low-dimensional embedding of data. It is thus not surprising that rank minimization has many applications: following Occam's razor, we often seek "simple" models or explanations. Part of my research has focused on developing a novel optimization-based algorithm for parsimonious modeling and matrix rank optimization (a notorious, computationally hard problem), and applying it to a range of problems from machine learning to portfolio optimization.
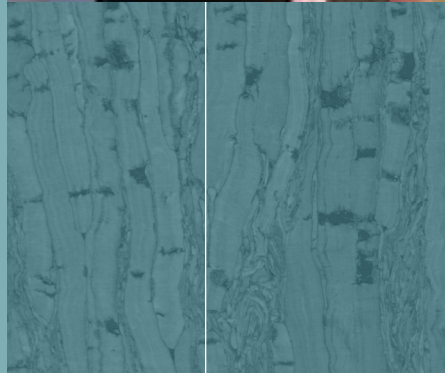
Dr. Michael Hochberg

In the autumn quarter of 2007, Dr. Michael Hochberg joined the EE department as an Assistant Professor. He received his MA and PhD degrees in Applied Physics from the California Institute of Technology in 2005 and 2006, and his BS in Physics from Caltech in 2002. Recently, it was announced that his proposal "Nanophotonic Devices in Silicon for Nonlinear Optics" was one of 29 receiving funding as part of the Air Force's inaugural Young Investigator Research Program.

The work that we're doing is mostly aimed at using silicon-based integrated optics as a platform for building ultrafast devices. The idea is to take advantage of effects that fundamentally operate at speeds of 10 Terahertz (10,000 Gigahertz) and higher, and to use them to build optical devices with bandwidth that's orders of magnitude higher than what can be achieved with conventional electronics. UW has provided an absolutely extraordinary startup package, and I have a number of existing collaborations with other faculty on campus, particularly the Jen and Dalton groups, who make some of the critical nonlinear optical materials that I use in my devices.
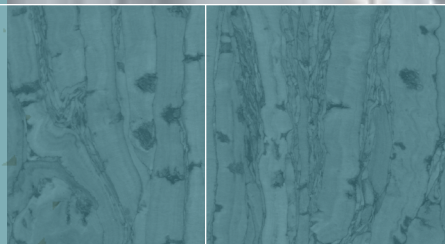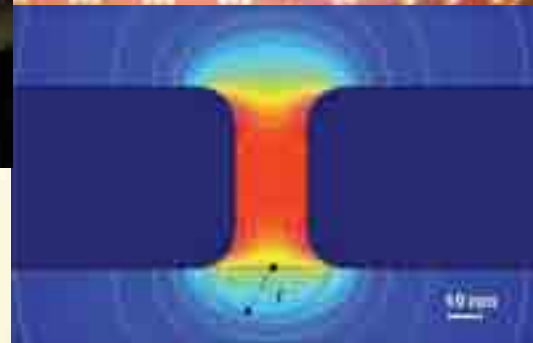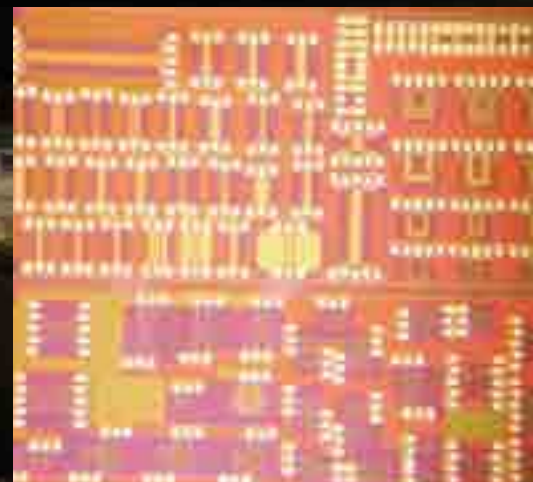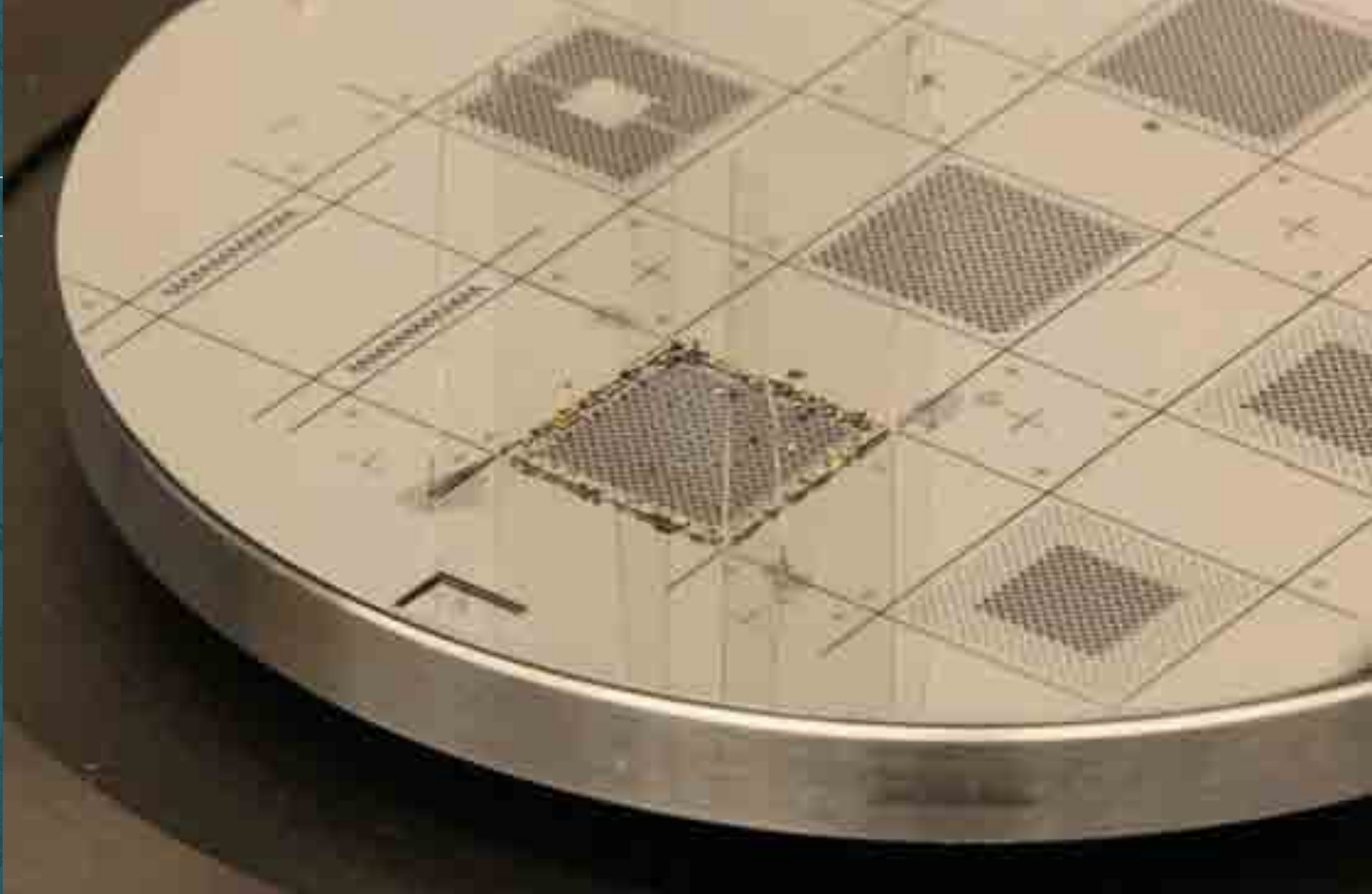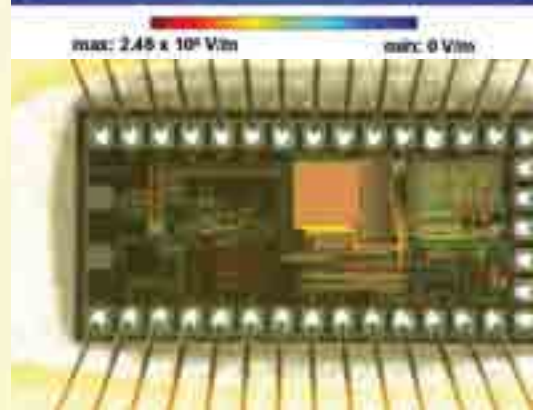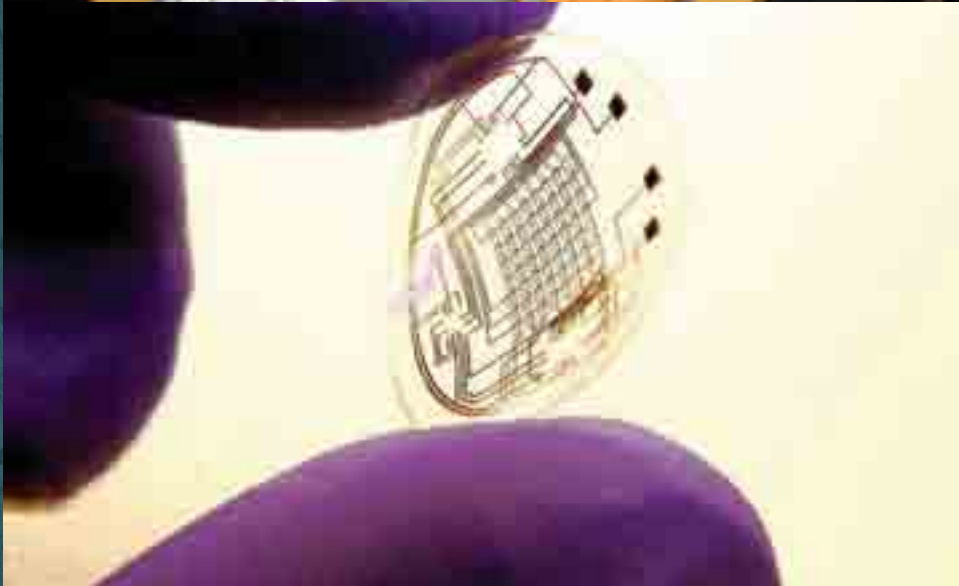
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CAMPUS BOX 352500

SEATTLE, WASHINGTON 98195-2500