UC DAVIS
UNIVERSITY OF CALIFORNIA

2012-13

Electrical & Computer Engineering

Department Report

2012-13

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Welcome from the ECE Department Chair

Since its birth, Electrical and Computer Engineering (ECE) has exploited the physical sciences to create a revolution in information technology that has marked the greatest changes of the last part of the 20th Century. These changes culminated in the design of laptop computers, wireless communication networks, smart phones and the Internet. The field has changed and molded human progress in ways that are breathtaking. At UC Davis, we believe there is much more to come!

Richard A. Kiehl, PhD.

We think that the future will open even more exciting avenues for innovation as electronics becomes embedded in the most unexpected sites and enables powerful new systems. Our faculty's research includes nanoscale devices, energy scavenging circuits, cognitive radios, reconfigurable terabyte computers, implantable biosensors, and pervasive communications. We are also pursuing research on sustainable technologies, such as green computing with embedded systems that run on harvested energy, lighting that uses a fraction of the energy of traditional technologies, and algorithms & networking protocols that control the energy demand of smart appliances.

UC Davis is well positioned to explore exciting new options for meeting the challenges of the 21st Century. We benefit from our proximity to Silicon Valley, which supplies a valuable resource for connections with world leaders in the electronics industry. These interactions keep us well informed about today's needs for innovation and provide us with opportunities for collaborations and the transformation of ideas into products.

Our department also benefits from UC Davis's world-renowned strength in the life sciences, which provides a rich environment for interfacing electronics and biology. Recent breakthroughs in the biological sciences have set the stage for a new revolution in the 21st Century. We foresee that ECE will play a key role in this revolution: both through the application of the tools of our core disciplines to biology, and through the use of biology for creating new types of electronic devices, circuits, and systems.

Our department continues to attract outstanding faculty with a vision and broad perspective. A list of our faculty's awards and honors is given elsewhere. Within the past year, six new faculty have joined our department: two junior faculty in the area of physical electronics with an emphasis in biology, three junior faculty in the area of microwave/mmWave/THz electronics with an emphasis in high performance systems and one senior faculty, a National Medal of Technology Laureate, in the area of physical electronics with an emphasis in energy.

Our faculty's research continues to have a high impact and to attract substantial funding for our graduate program from governmental agencies and industry. Our departmental research expenditures have risen to $9,839,000 in 2011-12.

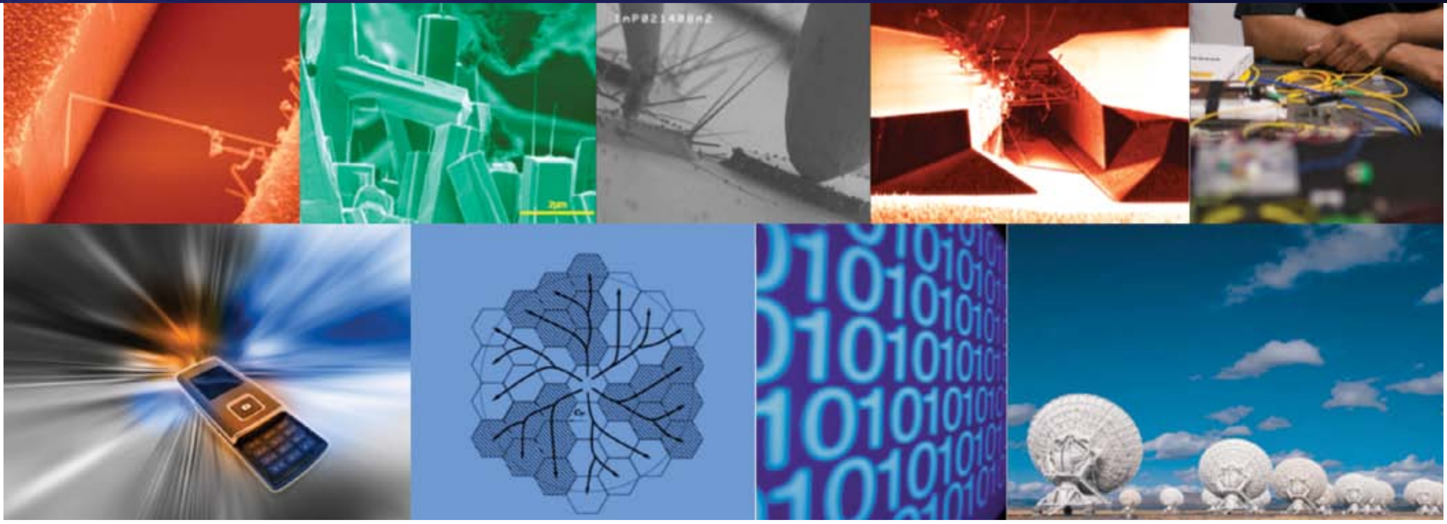
Our graduates are in high demand, and our proximity to the large corporate R&D centers and the vibrant start-up and venture capital communities of Northern California provides a wealth of opportunities for launching careers.

We welcome talented students who share our enthusiasm and optimism for creating the technologies of the future.

We hope that you will explore the many opportunities for you in Electrical and Computer Engineering at UC Davis!

Richard A. Kiehl
Department Chair

The Faculty of Electrical & Computer Engineering



Overview of the Department

Electrical and Computer Engineering is one of the largest departments in the College with 35 ladder-rank faculty, 19 emeritus professors, and several adjunct and research faculty, post-docs and visiting scholars.

We serve about 500 undergraduate and 200 graduate students, thereby meeting the needs of a diverse constituency. Our mission, research and educational objectives, and program objectives stem directly from the land grant origins of the University of California and our constituent's needs.

Our research activities are divided into seven major areas of electrical and computer engineering highlighted in the next page of this report. We have strived to maintain a balance in each area, and have succeeded in hiring new talents. Our faculty's research and teaching activities receive constant recognition from professional communities and sponsoring agencies.

The level of extramural funding for faculty research activities continues to grow, last year ECE research expenditures were $9,839,000.

The department faculty has been very active in defining and developing new interdisciplinary research and collaborative efforts. The department also has been effective in recruiting and training top graduate students in its multi-disciplinary environment. We invite the reader to browse our Research Highlights section to learn about our wide array of faculty-led projects. The section concludes with a synopsis of important research recognitions earned by our faculty over the year.

Finally, in addition to graduate student education and research, our undergraduate programs provide a rigorous foundation, and enhance the undergraduate experience through exposure to a strong research environment.

ELECTRICAL & COMPUTER
ENGINEERING DEPARTMENT

Research Areas

Electronic Circuits

Rajeevan Amirtharajah
Bevan Baas
Paul J. Hurst
Stephen H. Lewis

Computer Engineering

Venkatesh Akella
Hussain Al-Asaad
Rajeevan Amirtharajah
Bevan Baas
Chen-Nee Chuah
Soheil Ghiasi
John Owens
G. Robert Redinbo
Kent D. Wilken

Information Systems

Khaled Abdel-Ghaffar
Chen-Nee Chuah
Zhi Ding
Bernard C. Levy
Shu Lin
Anna Scaglione
S. J. Ben Yoo
Qing Zhao

Optoelectronics

Brian Kolner
André Knoesen
Diego Yankelevich
S. J. Ben Yoo

Systems and Control

Tsu-Shuan Chang
A. Nazli Gündes

Physical Electronics

Erkin Seker
Joshua Hihath
Charles E. Hunt
M. Saif Islam
Richard A. Kiehl
André Knoesen
Diego Yankelevich
S. J. Ben Yoo
Jerry Woodall

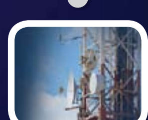
Rf, Micro- and Millimeter Waves

G. Rick Branner
Linda P.B. Katehi
Brian Kolner
André Knoesen
Xiaoguang "Leo" Liu
Neville C. Luhmann, Jr.
Omeed Momeni
Anh-Vu Pham
S. J. Ben Yoo
Q. Jane Gu









SPOTLIGHT ON THE FACULTY

AWARDS 2011–2012

Neville Luhmann

Professor Neville C. Luhmann, Jr. receives the 2012 John R. Pierce Award for "outstanding contributions and leadership in the field of vacuum electronics as a scientists, engineer and educator." The IEEE John R. Pierce Award is awarded annually to an individual or group to recognize outstanding contributions to the field of vacuum electronics.

M. Saif Islam

Professor M. Saif Islam receives the 2012 "Outstanding Mid-career Research Faculty Award" from the College of Engineering. This award honors the outstanding achievements of College of Engineering faculty members. The names of each year's awardees are added to plaques on display in the main lobby of the college main building.

Brian Kolner

Professor Brian Kolner has been selected for elevation to IEEE Fellow for "contributions to optical waveform analysis and modelocked lasers." IEEE Fellow is conferred upon a person with an "extraordinary record of accomplishments" and is recognized by the technical community as a prestigious honor and an important career achievement. The total number selected in any one year does not exceed 0.1% of the voting membership.

Education Achievements

2012 Zuhair A. Munir Award

Dr. Keqin Liu is the recipient of the 2012 Zuhair A. Munir Award for his research entitled "On Multi-Armed Bandit in Dynamic Systems." Research was completed under the mentorship of ECE Professor Qing Zhao and received his Ph.D. in June 2010. The Zuhair A. Munir Award is an annual award given by the College of Engineering to honor the student who has submitted the best doctoral dissertation.

Keqin Liu

Benjamin Tobias

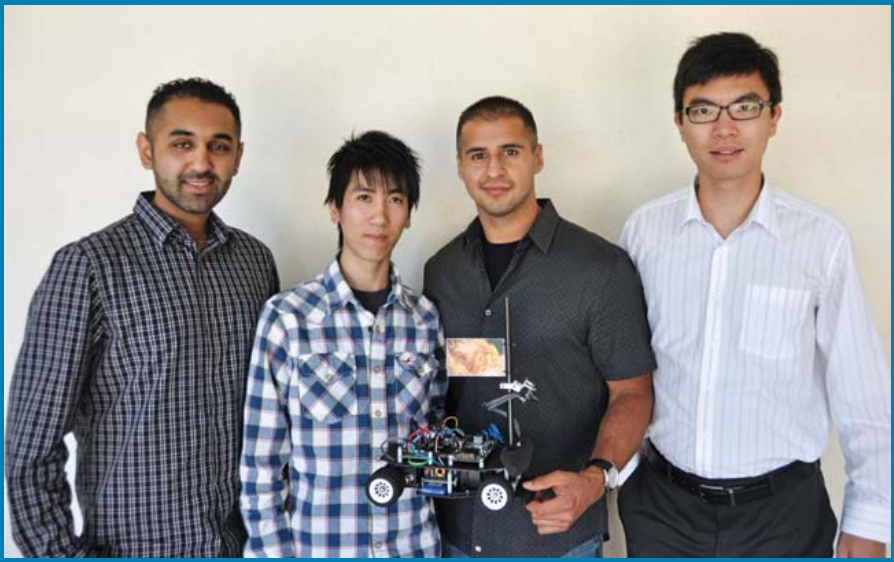
2012 Allen G. Marr Prize

Dr. Benjamin Tobias is the recipient of the 2012 Allen G. Marr Prize for his dissertation entitled "Electron Cyclotron Emission Imaging and Applications in Magnetic Fusion Energy." Research was completed under the mentorship of ECE Professor Neville C. Luhmann, Jr. The Allen G. Marr Prize is an annual award given by the University in alternating discipline areas. The fields for the 2012 award were Social Sciences, Mathematics, Physical Sciences and Engineering.

NATCAR 2012 Champions

UC Davis NatCar Teams Sweep the Competition

The UC Davis NatCar teams, led by ECE development engineer Lance Halsted, placed first, second and third against UC Berkeley, UC San Diego, UCLA, CalPoly and other schools. NatCar is a design contest created by UC Davis and National Semiconductor and run in conjunction with UC Berkeley. It is currently sponsored by Texas Instruments and Intel. Teams design, build and race autonomous cars on a track marked by 1″-wide white tape. In addition, there is a wire under the tape that has a 100 mARMS 75 kHz sinusoidal current flowing in it.



The first place team for 2012 was team UCD7 of (left to right) Waqas Saeed, Fuwen Xu, Enrique Garcia and Wanpeng Liu. Taking into account cone penalties, UCD7's car finished the track with an average speed of 9.12 ft/sec.

Professor Shu Lin's Low Density Parity Check Code Selected for NASA Missions

An (8176, 7156) quasi-cyclic low density parity check (QC-LDPC) code, devised by Professor Shu Lin and his co-workers, has been selected as a standard code for use in the NASA Landsat Data Continuation Mission (LDCM). LDCM is now at the integration and test stage and planned to be launched in December 2012. Due to large LDCM data file size (1 GByte), the required error rate is 10^{-12}. The (8176, 7156) QC-LDPC code can easily achieve the required error rate with a good margin.

The LDPC code development is part of a larger Goddard Space Flight Center (GSFC) effort and is funded by NASA Headquarter's Space Communications and Navigation program office. For more than 30 years of continuous data gathering, the Landsat series of spacecrafts are one of the most successful series of NASA Earth observing spacecrafts. The high-resolution on-board instruments will produce an aggregate data rate of 384 Mbps with a error rate of 10^{-12}. More information on Landsat can be found at: http://ldcm.nasa.gov. The (8176, 7156) QC-LDPC code has also been used in several other NASA missions. More information about the code can be obtained at http://public.ccsds.org/publications/archive/131x0b2.pdf

KARIN HIGGINS, UC DAVIS

Cypress Semiconductor CEO T.J. Rodgers in discussion with Cevin Freed (left) and Nick Shrake (third from left) and Archana Yarlagadda and Max Kingsbury, both Cypress Engineers about the next generation of sensors for winemakers. Photo by Karin Higgins, UC Davis.

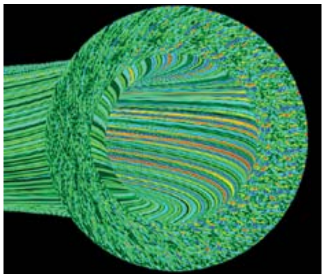
Engineering Faculty Lead Multidisciplinary Project on Wireless Technology for Winemaking

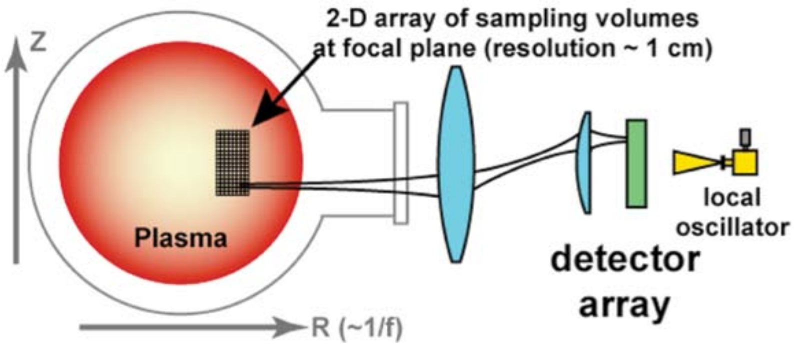
Winemaking has a long tradition in California and especially at UC Davis, which boasts one of the world's best viticulture and enology (V&E) departments, along with a cutting-edge winery at the Robert Mondavi Institute for Food and Wine Science. ECE Professors Andre Knoesen and Raj Amirtharajah, in collaboration with Professors David Block and Roger Boulton in V&E, and with the support of T.J. Rodgers, Chief Executive of San Jose-based Cypress Semiconductor Corp., have launched a multidiscipline project that aims to develop next-generation smart winemaking sensors for controlling and monitoring the temperature and sugar levels inside fermentation tanks and transmitting data over a wireless network to a central computer.

Professor John Owens leads Graphics System theme in Center for Visual Computing

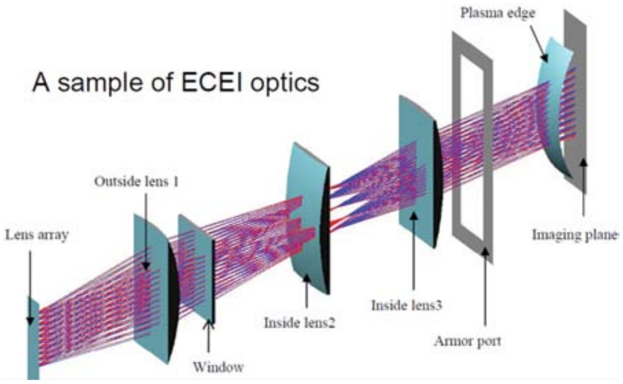
Intel's Science and Technology Center for Visual Computing; a $2.5M/5-year collaboration between Intel and eight universities, includes Associate Professor John Owens who leads UC Davis's involvement as theme leader in "Graphics Systems" theme within the center. (ISTC home, Press Release)

The Davis Millimeter Wave Research (DMRC) Center was founded in June 2008 by Professors Anh-Vu Pham and Neville Luhmann, Jr. as an industry university cooperative research program. The DMRC is broadly focused on fostering millimeter wave technology for wireless communications, radar, sensing, and imaging systems. The activities in the DMRC range from devices, integrated circuits, components and packaging, sub-systems to system implementation. Sponsors and collaborators include Agilent Technologies, Lockheed Martin, Boeing, Endwave, Cobham, GE, Raytheon, DARPA, etc. More details can be found at http://www.ece.ucdavis.edu/dmrc/





2-D Electron Cyclotron Emission Imaging (ECEI) System



Directors

Neville C. Luhmann, Jr.

Anh-Vu Pham

Professors

G. Rick Branner

David A. Horsley

Saif Islam

Linda P.B. Katehi

Xiaoguang "Leo" Liu

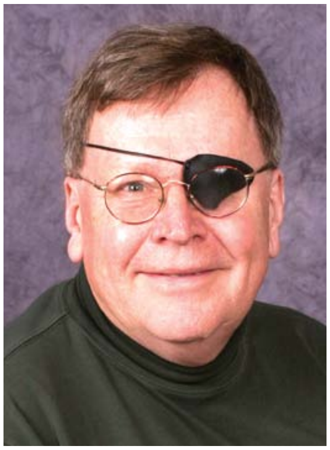
Omeed Momeni

Stephen O'Driscoll

Q. Jane Gu

Welcome
New Faculty

Jerry Woodall



Professor Jerry Woodall, National Medal of Technology Laureate, joined out department in July 2012 as a Distinguished Professor. Woodall is well known for his prolific and seminal contributions to compound semiconductor materials and devices for high-speed circuits and photovoltaic applications. He is also engaged in work on "green" energy storage using bulk aluminum alloys. Woodall, who has co-authored over 350 publications and holds over 60 patents, will add a wealth of industrial and academic experience to the department.

Q. Jane Gu

Professor Q. Jane Gu joined the department in August 2012 as an Assistant Professor. She received her Ph.D. from University of California, Los Angeles in 2007. Her research interest spans high efficiency, low power interconnect, mm-wave and THz integrated circuits and SoC design techniques, as well as integrated THz systems for communication, radar and imaging.

Research Highlights

Our school continues to attract and produce leaders in science and technology. Our faculty's research continues to have a high impact and to attract substantial funding for our graduate program: from the National Science Foundation, from the Department of Defense and other governmental agencies, and from industry. Our graduates are in high demand within industry and academia. ECE at UC Davis benefits from its proximity to Silicon Valley which supplies a natural source of collaborations with the world's leading electronics industry. Within our tradition of academic freedom, we have an increasing involvement with industry, which keeps us informed about today's needs for innovation.

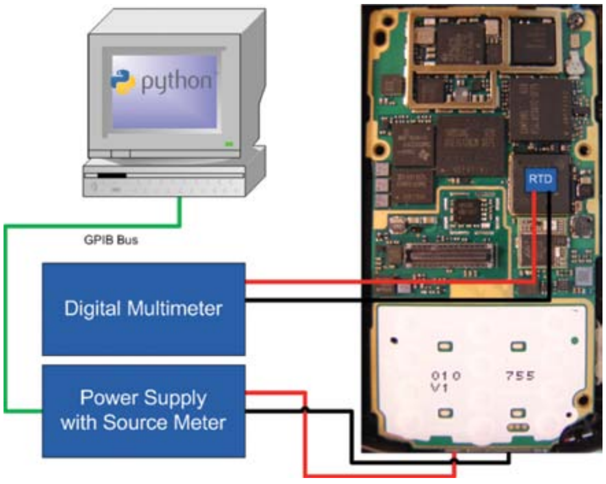
Power Optimization of Embedded Software on Cellphones

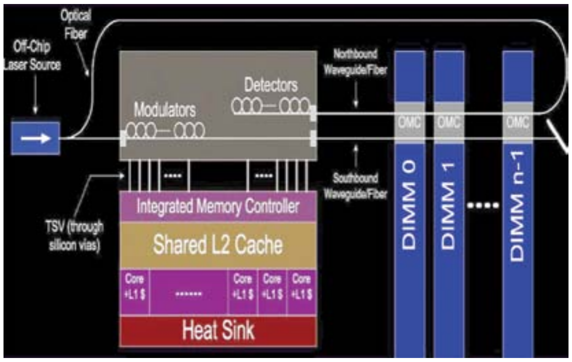
(Sponsor: Nokia Research)

The 2008 launch of the iPhone SDK ushered in the cellphone as a new platform for embedded software. As users know, battery life is a cellphone's most precious commodity. No easy method currently exists for third-party application developers who wish to optimize their software for power on cellphone platforms.

In collaboration with Prof. Amirtharajah, Prof. Akella is developing a systematic design methodology to optimize the power consumption of applications running on cellphones and also to develop energy scalable software that can make dynamic trade-offs between the quality or fidelity of an application, and available battery life based on the usage profile. The approach uses the thermal profile of the cellphone's integrated circuits platform to prune the application configuration space. The top figure below shows the experimental setup to create a thermal profile of an application on a commodity Nokia phone, based on the S60 platform.

Venkatesh Akella





WDM-Based Optical CPU/DRAM Interconnect for Balanced Computers

(Sponsor: Intel, CITRIS)

Building balanced computers in the terascale era is challenging, because one must simultaneously scale both memory capacity and memory bandwidth. Due to power constraints and pin limitations, it is impossible to provide both very high bandwidth and very high capacity memory with electrical signaling. In collaboration with Prof. Amirtharajah, and Yoo, Prof. Akella is developing protocols and algorithms to harness the potential of wavelength-division multiplexed optical interconnects to increase memory capacity (to hundreds of gigabytes) and memory bandwidth, with a simultaneous decrease in memory latency.

Reliability Enhancement Techniques for Future Digital Systems

Hussain Al-Asaad

100 percent design correctness will be very difficult to guarantee in future electronic circuits. This will be forced primarily by technology scaling, which leads to more transient and permanent failures of signals, logic values, devices and interconnects. Furthermore, existing methods for accelerated lifetime testing (burn-in) become infeasible as supply voltages decrease, which results in exponentially longer burn-in times. These are the most severe variations that we should expect in future designs:

- As technology scales further, parametric variations will become so severe that it will be impossible to correct for them during design.
- Single event upsets (soft errors), another source of concern, are caused by alpha particles and, more importantly, cosmic rays (neutrons) that hit silicon chips, creating a charge on the nodes that can possibly flip a memory cell or a logic latch.
- Aging has had a significant impact on transistor performance. Studies have shown that a transistor's saturation current degrades over time, and researchers expect this degradation to become worse as we scale transistor geometries in the future.

Four primary types of measures to protect against soft errors have evolved:

- Circuit-level techniques modify transistor characteristics, such as forward body bias or size.
- Logic-level techniques detect and recover from errors by using a redundant or self-checking circuit to validate the output of a combinational circuit; and in flip-flop elements by providing redundant latches, or by re-using scan flip-flops to hold redundant copies of flip-flop data.
- Architectural-level techniques include providing duplicate functional units or independent hardware, to mimic and verify expected functionality, and detect unexpected behavior.
- Software-level fault tolerance techniques, such as replicating application execution.

As the severity of the above-mentioned errors increases, designers will need to make reliability a first-class design constraint. Since a large fraction of raw soft errors often is masked at higher levels, in comparison to the circuit level, it's more important to focus on improving high-level techniques, where a potential for lower-cost solutions exists.

The primary focus of our project is to develop protection methods via the automatic insertion of robustness into digital systems, starting at the logic level and continuing up to the software level. Our project focuses on the development of the following:

- Fault modeling, fault simulation, test generation and verification methods for protected designs;
- Logic-level protection mechanisms via time-redundant computations;
- Architectural-level protection mechanisms, without excessive hardware overhead; and
- Software-level, time-redundant protection mechanisms for single- and multi-processor systems.

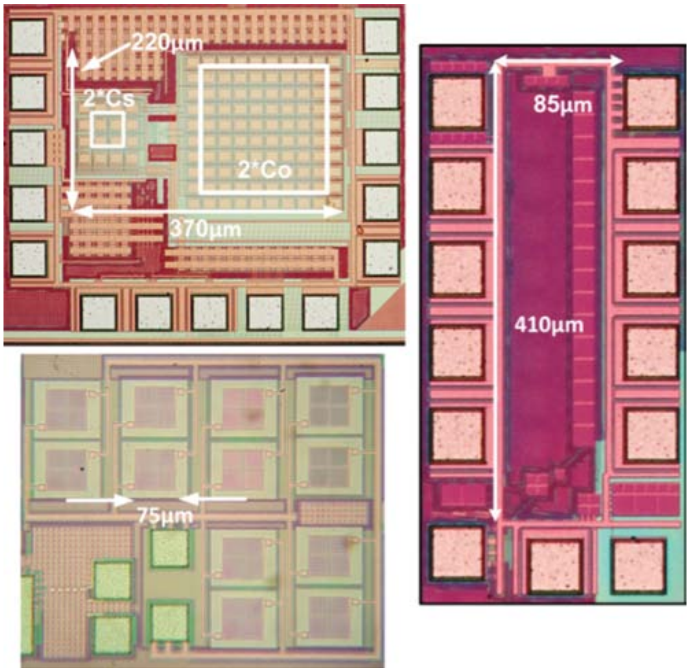
Photovoltaic Energy Harvesting for Tissue Engineering

(Sponsor: Texas Instruments, CITRIS)

Rajeevan Amirtharajah

Networks of wirelessly connected sensors have been proposed for numerous applications, in fields as diverse as infrastructure monitoring, health care, space exploration, and national security. The aging population of the developed world – and the increasing wealth of emerging economies continue to drive the development of new implantable biomedical devices. But the size and operating lifetime of individual sensor and medical implants, and the cost of maintaining their operation, are limited by the finite energy capacity of batteries. One approach to transcending these limitations is to have low-power devices harvest energy from their environment: for example, from sunlight or parasitic mechanical vibrations.

Professor Amirtharajah and his students in collaboration with researchers at the UC Davis Center for Biophotonics Science and Technology, the University of Michigan, and with support from Texas Instruments, are developing a photovoltaic-powered electrical stimulation device for growing cardiac tissue constructs. These constructs may eventually be implanted to replace diseased heart muscle. Using solar power eliminates electrical wiring that provides routes for pathogens to infect the growing tissue, helping to maintain a sterile environment for tissue development.



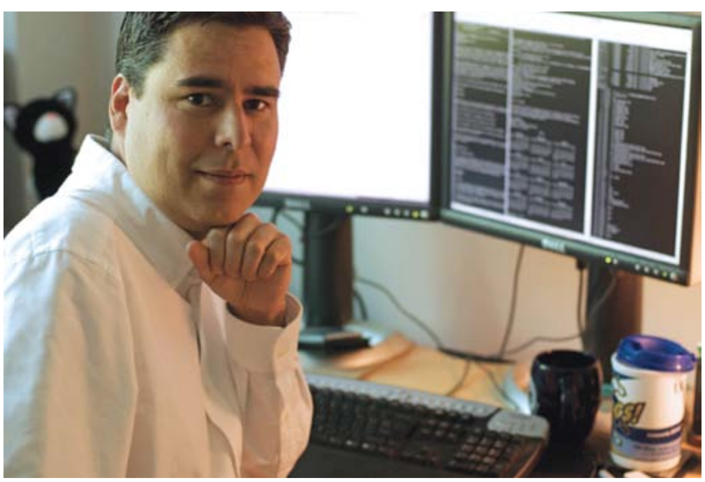
Professor Amirtharajah and his students have demonstrated a novel device for harvesting mechanical energy.

High Performance VLSI Computation

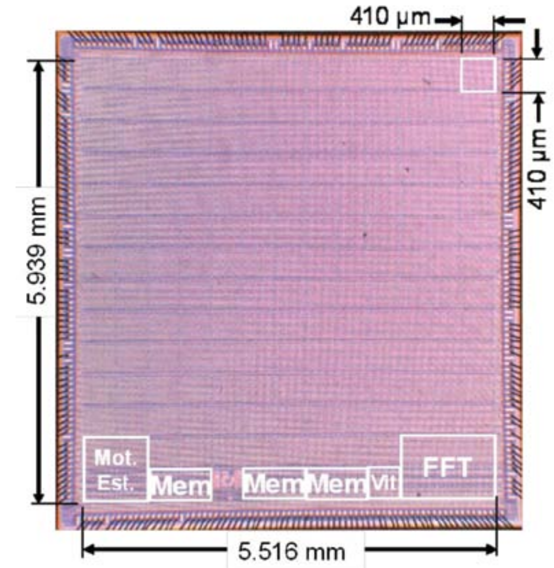
(Sponsors: NSF, SRC, ST Microelectronics, C2S2, Intel, UC MICRO, Intellasys)

Prof. Baas and his research group focus on algorithms, architectures, circuits and VLSI design for high-performance, energy-efficient and area-efficient computation, with strong consideration of the challenges and opportunities of future fabrication technologies. Prof. Baas is interested in both programmable and special-purpose processors, with an emphasis on digital signal processing (DSP), multimedia and embedded workloads.

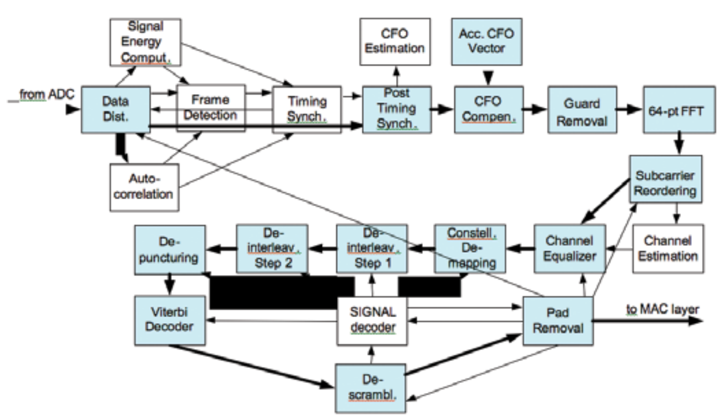
Recent projects include the Asynchronous Array of simple Processors (AsAP) programmable array processor chip, applications and tools; Low Density Parity Check (LDPC) decoders; fast Fourier transform (FFT) processors; Viterbi decoders; and H.264 video codecs. The AsAP1 chip contains 36 programmable processors, operates at more than 610 MHz, and is believed to be the second-highest clock rate processor designed at any university. The 167-processor 65nm 1.2 GHz AsAP2 chip is believed to be the highest clock-rate processor designed at any university. Each of the chip's programmable processors can independently control its supply voltage and clock frequency.



Bevan Baas



Several dozen DSP and general tasks have been coded, along with more complex applications that include: JPEG encoders; AES encryption engines; a full-rate 1080p HDTV residual encoder; a real-time fully-compliant IEEE 802.11a/11g Wi-Fi wireless LAN baseband transmitter and receiver; a complete H.264 encoder; and a large portion of the mid- and back-end processing for a medical ultrasound unit. Power, throughput and chip area results compare very well with solutions on existing programmable DSP processors. A recent project has applied the processor arrays to enterprise workloads as co-processors and functional units, which achieved promising results.

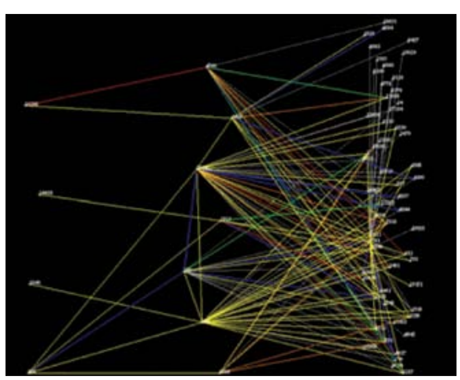


TOWARD SECURE CYBERSPACE: Monitoring, Mining, Inference and Detection (Sponsors: NSF, HP, AT&T and Sprint)

While we increasingly rely on the Internet to be "connected everywhere, anytime," the current cyberspace infrastructure is plagued by challenges that range from unexpected failures and misconfigurations to malicious attacks. Tackling these challenges, and making sound network design decisions, would require accurate information about the network state and the traffic traversing it. Unfortunately, the original Internet was not designed with measurability and accountability in mind. Under the supervision of Prof. Chuah, the Robust & Ubiquitous Networking (RUbiNet) Research Group focuses on designing network measurement solutions for tracking traffic footprints that are central to network operations, management, security forensics and many other business applications.

Chen-Nee Chuah

In 2003, Chuah received a National Science Foundation CAREER award to improve the robustness, stability and security of wide-area routing. In collaboration with researchers at Tier-1 ISP, she conducted large-scale measurement experiments to analyze the health of Internet routing protocols. Her efforts led to the design of fault-resilient and more table-routing schemes and traffic engineering practices. In two other NSF-funded projects, the RUbiNet team designed advanced sampling and streaming techniques that can preserve important traffic features for effective anomaly detection, and developed a unified framework for verification and optimization of firewall configurations.



During this effort to re-architect the Internet for accountability, Chuah guided her students to design the first programmable, query-driven network measurement platform to track arbitrary traffic sub-populations. Under the programmable measurement framework, a set of hardware and software primitives easily can be reconfigured and composed to collect data at different desired granularities. This work is funded by NSF and Hewlett Packard.

As more social interaction shifts to the Internet, many online social networking (OSN) sites and OSN-based applications have experienced viral growth. To assess the impact of this new workload on the underlying data storage/distribution infrastructure, the RUbiNet team conducted one of the first large-scale measurements of user activities on OSN sites such as Facebook. The team also applied machine learning techniques to detect fake profiles based on observed usage characteristics, which paved the way to develop strategies to counter cyber-crime and facilitate Internet security on OSN sites.

The RUbiNet team also is active in several collaborative projects that explore the use of information technology for societal benefits, including improving intelligent transportations, tracking carbon footprints, and conserving resources such as energy.

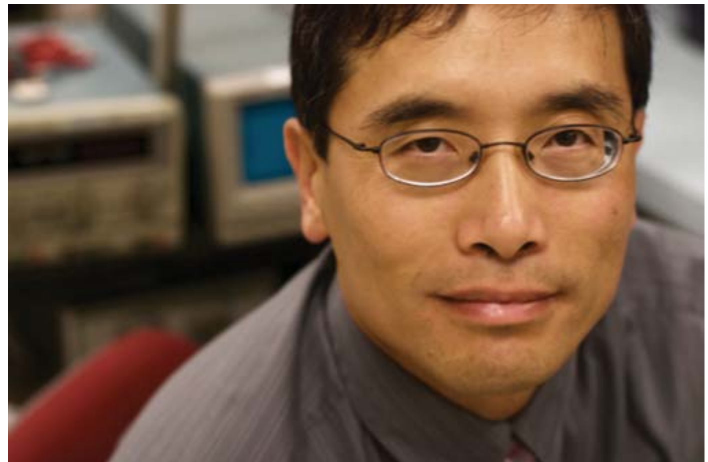
RUbiNet

www.ece.ucdavis.edu/rubinet

Integrative Design of Wireless Networks

(Sponsors: NSF, Verizon)

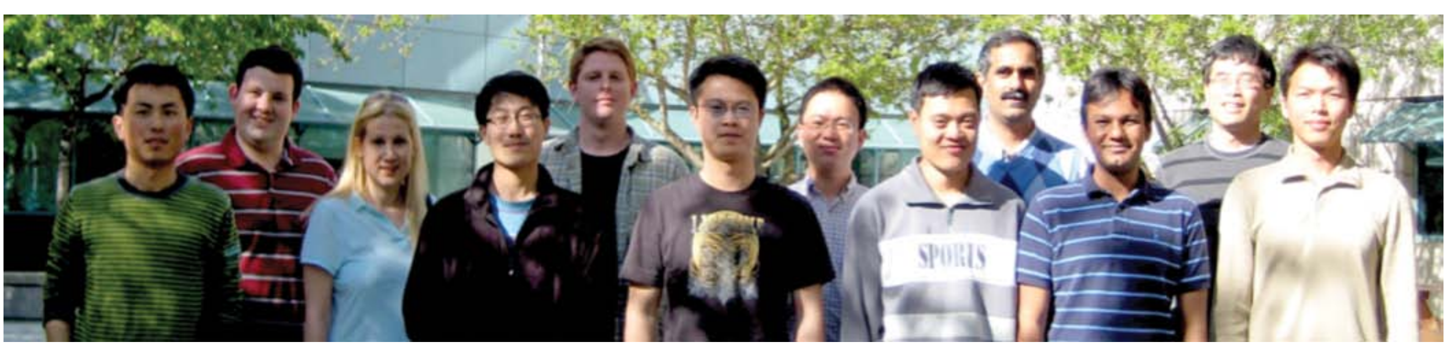
The research conducted by Prof. Ding and his group cover a broad range of signal processing and communication problems including wireless transceiver optimization, channel estimation and equalizations, multi-input-multi-output communications, multiuser detection, source separation, adaptive signal processing, parameter estimation, radar target discrimination, multimedia wireless communications, and cross-layer wireless communications.



Zhi Ding

In a recent project funded by NSF, Prof. Ding and his group are investigating robust low-complexity approaches to source localization and sensor placement in wireless networks. Source and sensor localization is a fundamental capability broadly useful in a number of emerging applications. For example, a network of sensors deployed to combat bioterrorism, must not only detect the presence of a potential threat, but also pinpoint the source of the threat. Similarly, in pervasive computing, locating an errant mobile user permits the computer network to identify the most appropriate server with matching capabilities for the user. There is also an emerging multi-billion dollar wireless localization industry. This research project addresses issues that hold the key to fast efficient localization.

In another project sponsored by NSF, Prof. Ding, Prof. X. Liu (CS), and students are investigating the design, analysis, and implementation of resource-efficient heterogeneous wireless communication systems. Their research goal focuses on a different cognitive radio perspective which utilizes data link control information in order for secondary users to more accurately assess the channel utility, user susceptibility, and interference effect in spectrum sharing.

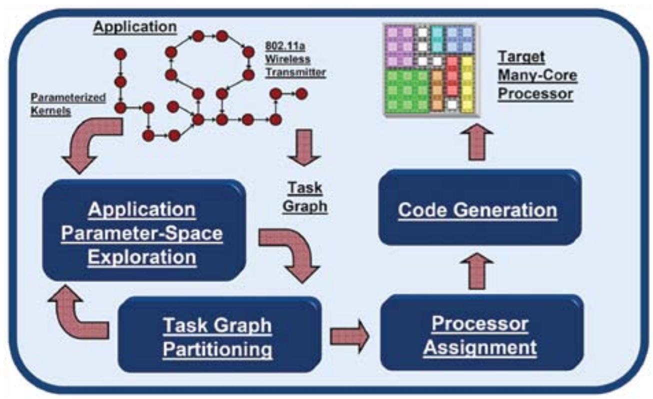


Synthesis of Streaming Applications for Manycore Processors

(Sponsor: NSF, SRC)

Soheil Ghiasi

Streaming applications are commonplace in many application areas such as multimedia, networking and signal processing. Embedded manycore processors offer a promising platform for implementation of streaming applications due to the attractive tradeoff that they offer between programmability, application throughput and energy consumption. Prof. Ghiasi and his group, in collaboration with Prof. Baas and his team, are working to develop a set of tools for productive development of streaming software targeting distributed-memory multiprocessors with hundreds to thousands of cores. The approach is to synthesize software modules from malleable dataflow specifications. Optimizing algorithms for a number of fundamental problems in the design flow, such as parameter-space exploration, task graph partitioning, processor assignment and buffer allocation are developed.



Monitoring Physical Therapy and Rehabilitation

(Sponsor: CITRIS)

Wearable wireless sensor modules enable continuous fine-grain monitoring of the physical activity of human subjects. In collaboration with UC Davis Sport Medicine Scientists, Prof. Ghiasi and his students work to develop cyber-physical systems for enhanced monitoring of the athletic activity, prevention of injuries, and supervision of rehabilitation and recovery process. As part of the project, the team has developed a software infrastructure for realtime collection, analysis and classification of data from inertial sensors (accelerometer, magnetometer and gyroscope). The analysis engine detects activities of interest, such as rehabilitation drills for recovery from an ACL injury, and can make the information available to authorized professionals via the internet. Other sensor modalities, such as electromyography or electrocardiography, will be integrated in the system for improved analysis, and/or extension to other applications.

Q. Jane Gu

Mm-wave Passive Imager based on Heterogeneous Technology

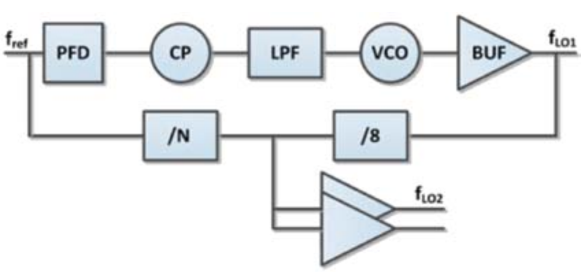
(Sponsor: HRL, DARPA)

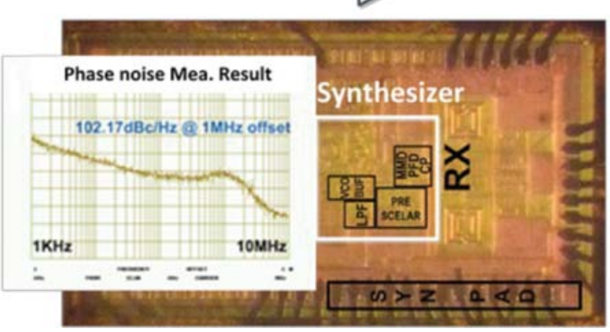
Passive imagers aim to detect extremely small black body radiation signals, which impose stringent requirements of receiver sensitivity and robustness to environment changes and process variations.

To address these requirements, Prof. Gu's group is developing a new D-band passive imager architecture based on a heterogeneous technology, combining InP and CMOS devices on the same chip fabricated by HRL Laboratories. This passive imager leverages the advantages of both high performance III-V devices and unparalleled signal processing capabilities in CMOS technologies to achieve extra sensitive passive imagers with robust/reliable system performance. This heterogeneous technology based D-band passive imager is expected to achieve a system performance which cannot be achieved in any single process.

E-band Integrated Synthesizer for Wireless Communications

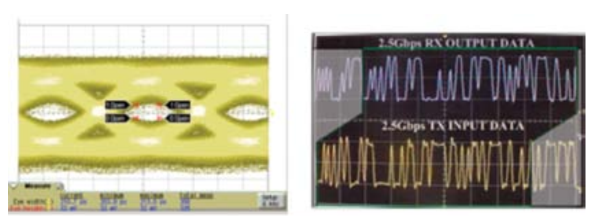
E-band is a precious spectrum resource for high speed wireless communications. To reduce system size, power and weight (SPaW) for portable applications, CMOS holds high potential. This project has developed a fully integrated E-band synthesizer to power wireless systems. This frequency synthesizer, implemented in 65nm CMOS technology, features coarse phase rotation and achieves phase noise of < -83dBc/Hz at 1MHz offset with the reference spur <-49dBc. Total power consumption is 65mW.





D-band CMOS Wireless Link based on OOK Modulation Scheme

Jammed lower GHz bands stimulate the interest to move the wireless carrier frequency higher for numerous wide band resources. Dr. Gu's group pushes the carrier frequency into 140 GHz and demonstrates a D-band wireless link prototype with On-Off keying modulation scheme. The wireless link has demonstrated up to 2.5Gbps with less than 2.3x10-7 BER performance. This work paves the road for ultra-high-speed data communications between board-to-board, board-to-backplane and chip-to-chip, for space and cost constrained computer, communication and consumer electronics systems.



Technology	1P6M 65 nm CMOS
Chip Area	TX: 0.03 mm²; RX:0.12 mm²
Power Consumption	TX: 115 mW; RX:120 mW
Carrier Frequency	140 GHz
NFC Speed	~ 2.5 Gbps
NFC Distance	~ 1cm
BER	$2.3X10^{-7}$

Energy Conversion in Single Molecule Devices

Heating and power dissipation are primary concerns in integrated circuits today, and it is necessary to develop an understanding of heat generating processes in nano-scale devices. Molecules represent the smallest possible electronic devices, and understanding heat generation, electron-phonon coupling, and power dissipation in molecular systems will increase our understanding of these processes in nanoscale electronics.

To develop a better understanding of electron-phonon interactions in a single-molecule, Prof. Hihath has been studying the inelastic transport properties of a single-molecule diode, as is shown in the figure below. As part of an international, multi-disciplinary effort Prof. Hihath demonstrated that this molecular system exhibits strong rectification behavior even at low biases. Furthermore, by studying the probability of exciting inelastic processes in this molecular junction, it has been shown that the molecule itself dissipates the same amount of power in forward and reverse bias despite the significant change in current within the device. These effects demonstrate that electron-phonon coupling can be strongly bias dependent in nanoscale devices, and that internal heat dissipation may not scale directly with current in such systems.

Joshua Hihath

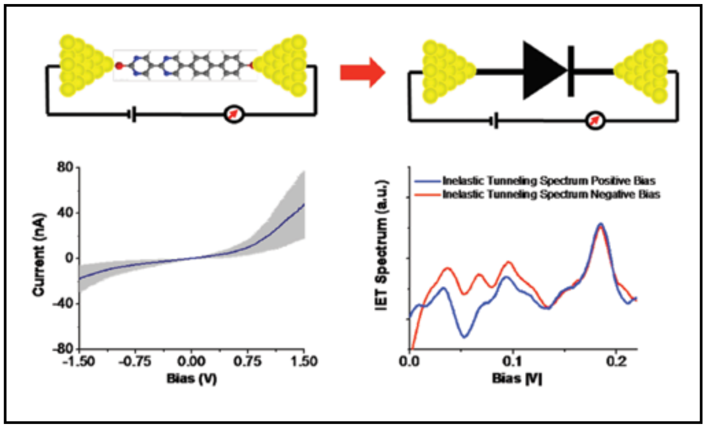


Figure 1. Example of a single molecule device that behaves as a diode. The graph in the bottom left shows the rectification behavior, and the curve in the bottom right demonstrates that the inelastic scattering due to electron-phonon interactions is similar in forward and reverse bias despite a significant change in total current.

Electrical Detection of Epigenomic Information in DNA Duplexes

The ability to accurately measure the resistance of a single molecule may provide unique advantages over traditional techniques for sensing or diagnostic applications. One example is in the study of DNA, where avoiding processes like PCR may drastically speed up diagnosis. A particularly exciting target for diagnosis lies in the area of epigenomics. Epigenomics is the study of the genes that are active within an organism. One way to turn specific genes on and off is by adding an additional methyl group to the cytosine bases within the gene. In collaboration with Prof. NJ Tao and Dr. Peiming Zhang of Arizona State University, Prof. Hihath has demonstrated that the addition of a methyl group to the cytosine bases in a short DNA sequence causes a finite change in the molecule's resistance. Such efforts point toward new methods for biological diagnostics as well as new applications for single molecule electronic measurements.

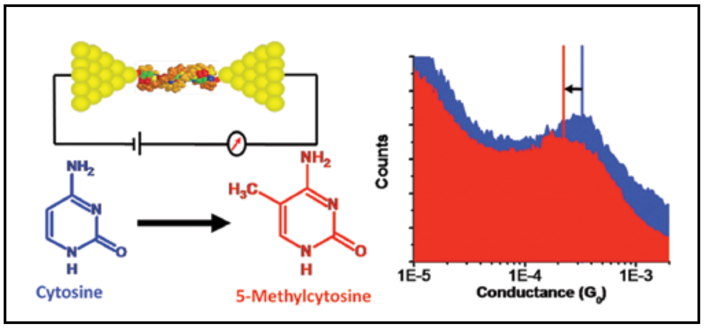


Figure 2. Electrical Detection of Cytosine Methylation. The histogram on the right demonstrates that methylation of the cytosine bases in the sequence studied caused a finite decrease in the molecular conductance.

Energy-Efficient High-Color-Quality Lamp Technology

(Sponsors: DuPont, IREC, Vu1)

Charles Hunt

Current Technology for energy-efficient lighting is limited to fluorescent lamps and solid-state lighting, using light-emitting diodes. These technologies, although reasonable stopgap measures in this era when lowering carbon footprint is mandated, are very poor options for consumers due to poor color quality of the light, and the unsustainable use of limited-resource materials (such as Eu, Ga, Tb, etc.) as well as environmentally-unfriendly elements, notably mercury. Prof. Hunt and his team have pioneered field-emission lamps (FEL) which avoid these limitations, as well as Electron- Stimulated Luminescence (ESL), which is now emerging on the marketplace for residential consumers. The resulting light of ESL lamps is virtually indistinguishable from that of the inefficient incandescent lamps they replace; but they employ sustainable materials and technologies, and use only 25% of the electrical power.

MicroFocus Field-Emission X-Ray Source

(Sponsor: DARPA)

Current x-ray technology used by the medical community employs“amplitude contrast” imaging, that is, the object being observed blocks the x-rays being transmitted by absorbing photons before they can reach the imager or film. This works well for contrasting body parts, such as tissue vs. bone. However, amplitude contrast is not effective for imaging body parts of similar density, such as muscle, fat, nerves, veins, and various internal organs. A recent technique for overcoming that limitation employs “phase-contrast” imaging; giving high resolution of differing body parts with similar density. However, a low-cost, high-flux x-ray source for performing phase contrast imaging has not yet been produced.

The Vacuum Microelectronics Group at UC Davis, led by Prof. Hunt, is investigating a high-flux, low-cost x-ray source, which produces monochromatic radiation suitable for phase-contrast imaging. Once developed, this source has significant utility when applied to mammography. Phase contrast imaging exposes the patient to substantially smaller x-ray doses and is more reliable than amplitude contrast imaging because breast-cancer tissues are so similar in density to breast tissue. The novel x-ray source technique uses a unique field-emission cathode and novel pulse circuitry, both originating in Prof. Hunt’s Group at UC Davis, through this program.

Experimental microfocus accelerator

Analog and Mixed-Signal Circuits for Digital Communication

(Sponsor: INDUSTRY)

Paul Hurst

Prof. Hurst and his group carry out research on data converters and on mixed-signal integrated circuit (IC) design for communication applications. The research on data converters is focused on developing techniques and circuits that advance the performance of data converters in CMOS technologies. Digital calibration is used to relax the requirements on or overcome limitations of the analog circuits in the data converters. The communications research focuses on adaptive-equalizer circuits and receiver architectures for high-speed applications. Research goals include: carrying out research that is useful to the IC industry and training research assistants for jobs in research or IC design.

High-throughput Printing of Devices and Circuits Nanowire Transistors, Sensors & Devices with Charged Particles

(Sponsors: NSF, CITRIS, DARPA and UCOP)

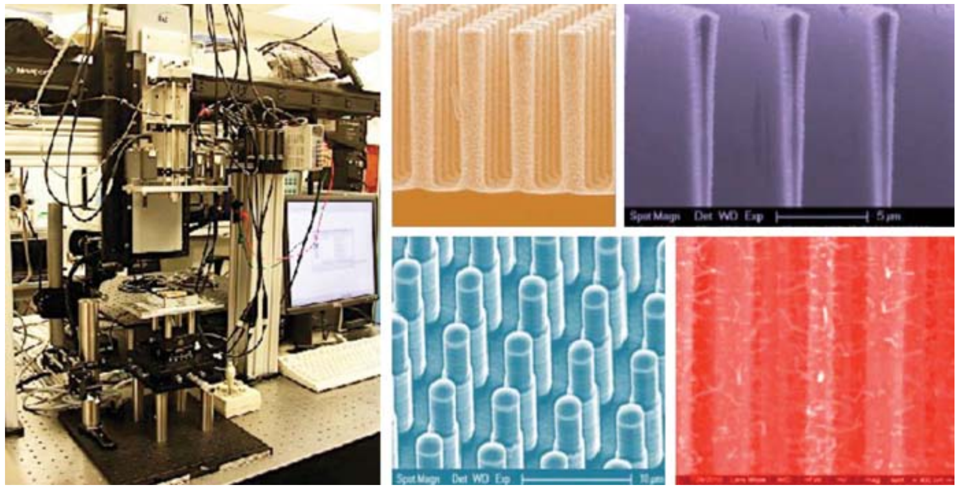
The Integrated Nanodevices and Nano- systems Laboratory (Inano), led by Prof. Islam, has built a unique nanomaterial and device transfer-printing tool, which enables the development of a commercially viable, low-temperature manufacturing process and architecture for high-quality, single-crystal semiconductor devices on inexpensive, lightweight, flexible plastic substrates. It is currently the only demonstrated process capable of harvesting and transferring vertically aligned, single- crystal semiconductor pillars and walls from a single-crystal substrate (mother substrate) to a low-cost carrier substrate, while simultaneously preserving the integrity, order, shape and fidelity of the transferred device arrays. The process facilitates sheet-to-sheet manufacturing integration by exploiting a vertical embossing and lateral fracturing method, using a polymer layer on a carrier substrate. This manufacturing process technology will enable a new generation of heterogeneously integrated, high-performance optoelectronic devices on lightweight flexible plastics, exploiting the unique optical, mechanical and electrical proper- ties of different semiconductors, specifically in solar cells, displays and lighting.

Saif Islam

Nanosensors and Devices with Charged Particles: An electric field-assisted, ultralow-voltage gas ionization sensor with record low ionization voltages, was designed and demonstrated by engineering nanowhiskers with controlled quantum confinement, surface and bulk properties for accurate fingerprinting of gases. This device can be used in bio-chemical, environmental and disease-sensing applications. Inano

continued on next page

Saif Islam (continued)

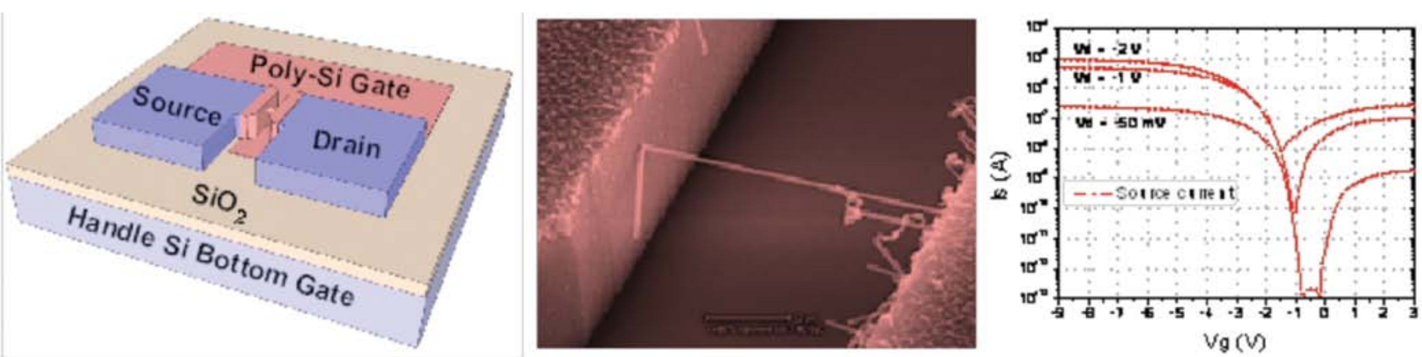


A high-throughput device- printing tool built in Inano; and various sensing, energy harvesting and imagining devices in the shape of micro/nano pillars and walls that are transfer-printed using this tool.

is now working with NIST and Sandia National Labs to explore the application of such devices in pollution control in industrial processing facilities and coal-fired power plants.

Surround Gate Nanowire Transistors: Multiple gate field effect transistors (FETs) such as a 3D tri-gate FET are emerging as a new structure to address the downscaling limit of integration circuits. The successful development of tri-gate FET is regarded as one of the greatest transitions from the conventional FETs. 3D FETs not only enhances the integration density, but also the performances of microprocessors in terms of power loss, clock frequency, mobility, etc. Interests in nanostructured materials have been considerably increasing because nanostructured materials can be synthesized relatively easily with high control on the material properties. Inano researchers fabricated Si nanowire FETs using bottom-up techniques in more feasible manners than ever reported. Fully surrounded gate FETs with the suspended Si nanowire channel are successfully fabricated in silicon on insulator (SOI) wafers. The NW FETs showed good performances such as the minimal sub-threshold swing of 125 mV/dec and good on-off current ratio of about 6 orders of magnitude.

Inano is actively involved in technology transfer initiative and received several grants from DOE, University of California Office of the President and the UC Davis Engineering Translational Technology Center (ETTC).



A schematic diagram and an SEM micrograph of a nanowire FET with typical Is-Vg characteristics.

Richard Kiehl

Nanoelectronics & Bio-Nanotechnology Research

Kiehl explores new device concepts, circuit architectures, and self-assembly techniques for the development of nanometer-scale electronics for information processing, signal processing, and sensing applications. His work draws on extensive experience at corporate research labs in developing high performance electronics exploiting new materials, novel device structures, and unconventional fabrication techniques in GaAs-based and Si-based heterostructures. A major theme in his current research is the exploration of novel concepts at the interface between nanoscale electronics and biological systems.

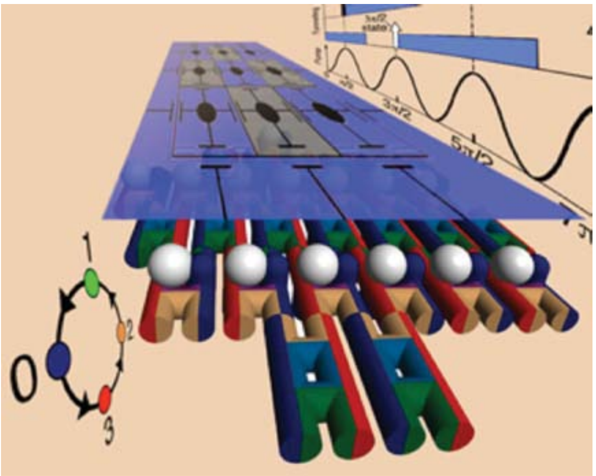
His work in information processing includes the investigation of nanoscale circuitry based on radically different approaches in which the dynamics of interactions between the tunneling phase or the spin of electrons is used for computation. He investigates device concepts for such novel circuitry based on single-electron effects and spin magnetic moment coupling in nanoparticle arrays and on the nonlinear behavior in arrays of organic molecules.

In addition to using e-beam lithography and scanning probe techniques for the fabrication and characterization of these devices, he explores the use of DNA as a precise and programmable scaffolding for self-assembling nanoparticles, nanowires, molecules and other components into electronic circuitry. This biological approach, which he helped to pioneer, offers device integration at a density and a precision far beyond those possible with lithographic techniques.

Kiehl's research is unusually interdisciplinary in nature. He collaborates with faculty and students in electrical & computer engineering, physics, chemistry, chemical engineering & materials science, and biochemistry - both at UC Davis and other institutions.

Kiehl's research in nanotechnology began with his use of material composition and strain to create linear arrays of nanoparticles within a semiconductor. He continued this research at Stanford University and extended his activities to molecular nanotechnology at the University of Minnesota, where he created MONALISA (Molecular Nanoscience Alliance for Interdisciplinary Studies and Activities) to foster interdepartmental collaborations in this emerging field. He was theme leader for the research team on "Nanoscale Architectures and Information Processing Paradigms" in the SRC/MARCO center on Functional Engineered Nano Architectonics (FENA – Phase I, 2004-2010). He also led a DoD Multidisciplinary University Research Initiative (MURI) on "Biologically Assembled Quantum Electronic Arrays" comprising a broad range of activities carried out by nine co-PI's at six universities exploring biological routes for creating novel quantum electronic systems with potential applications in computing, signal processing and sensing.

Kiehl continues to explore the frontier of using new materials, processes and physics for the creation of electronic devices and circuits with advanced capabilities.



Opto-Electronic Biosensors (Sponsor: NSF)

Andre Knoesen

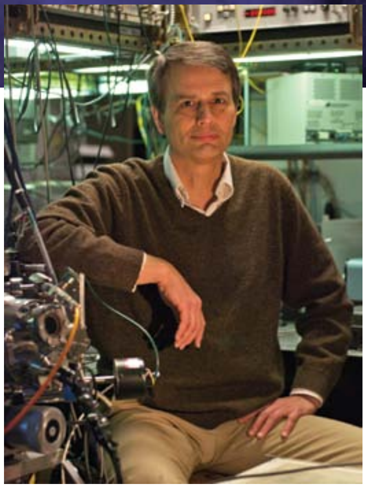
Surface plasmon resonance (SPR) biosensors have emerged rapidly as a technology of choice, because they follow biological interactions in physiological environments, in real time. In principle, they also offer the opportunity for sensitive detection and selectivity, without the need for molecular tags (for example, fluorescent segments). Fluorescent biosensors have great sensitivity and selectivity, but use molecular tags; because of practical constraints, they mostly are restricted to taking freeze-frame snapshots of biological reactions. The sensitivity and selectivity of current SPR sensors are not as good as fluorescent sensors, but existing SPR biosensors do not operate at their limits of sensitivity, owing to technical noise and not to any fundamental limitations.

Prof. Knoesen and his students, in collaboration with IBM scientists, have shown that by using active electronic noise suppression techniques — integrated with sensor configurations — a SPR sensor can operate at the fundamental limits of system noise. Prof. Knoesen and his students are developing nanostructured porous materials, to increase sensor sensitivity and selectivity of SPR sensors. A SPR sensor with increased sensitivity and selectivity will allow, in addition to kinetic measurements in the aqueous phase, the detection of highly diluted pathogens in the gas phase. Such a sensor could be used to map biochemical pathways that lead to disease states, monitor patients for clinically relevant analytes, target the development of drugs, and detect infectious agents and environmental toxins. This research is sponsored by National Science Foundation.

Self-Assembly of Supramolecular Structures: Nature provides intriguing examples of collective organization of biomolecules that occurs spontaneously. This organization occurs over large length scales (up to centimeters), and remains stable under adverse conditions. A fundamental understanding of this self-assembly process could provide insight into how molecular structures can be directed to self-assemble, to create molecularly based electronic structures. Nonlinear optical techniques are increasing being used to understand the self-organizational behavior of biological structures.

Conventional thinking is that if electric dipoles are free to self-organize, the result will be an anti-parallel organization of dipoles. It's therefore surprising that biological structures intentionally self-organize into structures where the average orientation of electric dipoles point in the same direction, and intentionally creates a polar structure. This non-centrosymmetric symmetry occurs in collagen, cellulose and starch: three basic supramolecular biological structures commonly found in nature. Collagen, the most abundant protein in animals, forms scaffolds that provide structural support. In an analogous manner, cellulose creates a scaffold in plants. Starch, finally, is used by photosynthesizing organisms to store the energy.

Prof. Knoesen has developed nonlinear imaging and spectroscopic methods that make it possible to directly probe the non-centrosymmetric symmetry in biomolecular supramolecular assemblies. His group has identified the molecular origins of non-centrosymmetry in collagen, using sum-frequency spectroscopy. In collaboration with Dr. Reiser, from the Department of Neurological Surgery, second harmonic polarization-sensitive imaging techniques have been developed to probe structures over large length scales. The technique is being used to investigate the structural disorder of collagen in intervertebral disks and cartilage.



Brian Kolner

Space-Time Analogies in Optical Physics

(Sponsors: The David and Lucile Packard Foundation, NSF, DOE)

This work sprang from my time at Hewlett-Packard Laboratories in Palo Alto, and was launched when I joined the UCLA faculty in 1991. The work continued when I came to UC Davis and the Lawrence Livermore National Laboratory (LLNL) in 1996. Although I have moved on from an active program in this area, it still intrigues me and is blossoming in other laboratories and institutions. In this work, I exploited the mathematical dualities between the equations of paraxial wave propagation and narrowband dispersion, to develop the concepts of the time lens, temporal imaging and local time reversal of electromagnetic fields. In one experiment, the research team demonstrated a time microscope capable of expanding and time-reversing subpicosecond optical bits in a stream by a factor of 100 times, so that they could be detected using ordinary high-speed optoelectronics. Today, this technique is being explored as a high-speed diagnostic tool at the National Ignition Facility at LLNL, and by other groups that are integrating the technology into silicon waveguides.

Influence of Pump Noise on Timing Jitter in Femtosecond Laser Clockworks

(Sponsors: The David and Lucile Packard Foundation, NSF)

The 2000 revolution in optical clockworks led me to wonder what controls the ultimate timing stability of such laser clocks. The Kolner lab conjectured that the random fluctuations of pump power might be imprinted on the spectrum of the laser clocks, and we then characterized the effect using a very sensitive spectrum analysis system, capable of seeing noise 180 dB below a carrier. The conjecture was proven to be true, and we've since developed a comprehensive theory based on our introduction of the "noise transfer function." It appears that pump noise will set the ultimate limit, and we're working to quantify that limit.

THz Spectroscopy and THz Emission from Plasmas

(Sponsor: DOE)

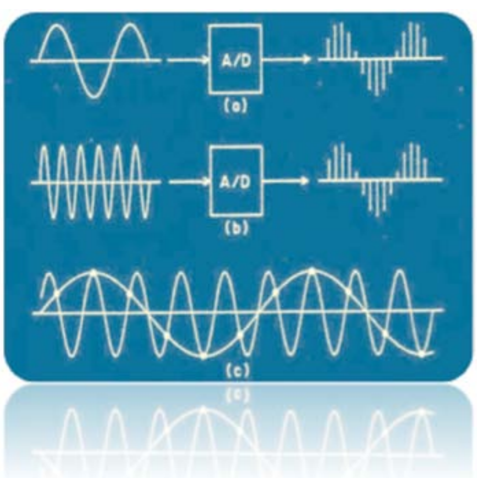
In my laboratory, we rely on femtosecond mode-locked lasers for much of our work in linking high-frequency electronics and femtosecond light pulses. For example, we can generate nearly monocycle pulses of approximately one picosecond duration, with a bandwidth from 50 GHz to 3 THz. These pulses then are sent through and pulsed discharge plasma, with the result that we can time-resolve the evolution of the electron density and scattering times. In effect, this is a time-domain vector network analysis system, with 3 THz bandwidth. We also plan to use this system in the future, to study the properties of plasmas as sources of sub-millimeter waves.

Integrated – Circuit Design For Signal Processing Systems

(Sponsor: UC Micro)

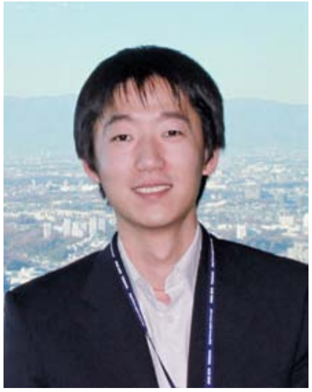
Steve Lewis

Prof. Lewis' research is in the area of integrated-circuit design for signal-processing systems. Many signal-processing systems operate in the digital domain, on signals that start in analog form. After analog processing, such systems also require analog-to- digital (A/D) interfaces. To reduce cost, analog and digital functions often are built on the same integrated circuit in a CMOS technology. The minimum feature size available in such technologies is decreasing. This technology scaling is helpful on the digital side, because it reduces power dissipation, area and cost; however, technology scaling also reduces power-supply voltages, thus increasing the errors made by analog circuits.



One approach toward solving this problem is to design more complicated analog circuits, but this solution tends to increase power dissipation, which limits portability. To overcome analog errors while reducing power dissipation, we are studying the digital background calibration (which is transparent to the user) of A/D interfaces. The key idea is that the raw performance of analog circuits need not limit the interface performance, as in the past. Instead, digital circuits can be used to sense and correct the increasing errors made by low-voltage analog circuits. If the calibration is done in the background, it does not reduce the system throughput. Since digital circuits are amenable to technology scaling, this solution takes advantage of the characteristics of modern CMOS process technologies.

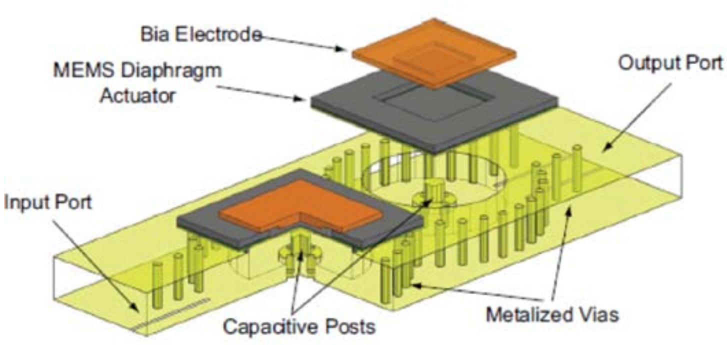
Xiaoguang "Leo" Liu research interests mainly lie in reconfigurable RF/microwave and millimeter-wave components and circuits. He has extensive experience in the design, fabrication and testing of high-Q radio-frequency Microelectromechanical Systems (RF-MEMS) devices and circuits. In his graduate research, he demonstrated highly tunable high quality factor (Q) RF-MEMS tunable filters with ground-breaking performances. He is also broadly interested in the application of the MEMS and RF technologies to other areas such as chemical, biomedical engineering and life sciences.



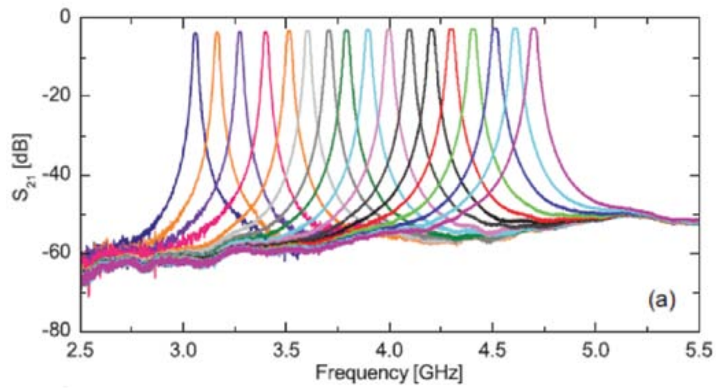
Xiaoguang "Leo" Liu

Tunable RF/microwave filters are essential components for the next-generation reconfigurable radio front-ends in wireless communication systems with multiband and multi-standard characteristics. Existing technologies for making tunable filters have achieved either high quality factor (Q) or high tuning range, but not both simultaneously.

In his graduate research, Dr. Liu took up the challenge and demonstrated highly tunable, high-Q tunable filters for RF/Microwave frequencies using micro-electromechanical systems (MEMS) technology. The aforementioned tunable filter is based on a highly-loaded evanescent-mode cavity resonator.

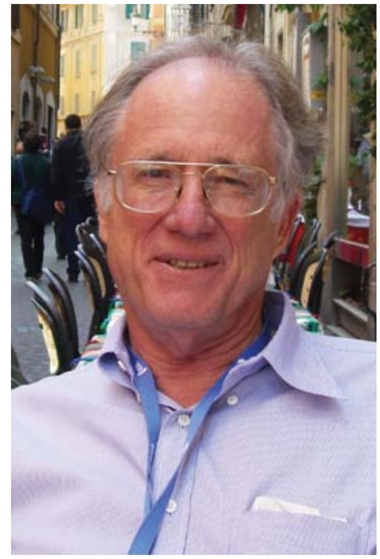


A MEMS thin diaphragm with gold coating on the bottom surface is bonded to a copper electroplated evanescent-mode cavity to form a resonator. When a bias voltage is applied on the top electrode, electrostatic force pulls the flexible diaphragm away from the post, therefore changing the resonant frequency. The tuning range depends on the initial gap and the mechanical movement range of the diaphragm. By bringing the diaphragm within micrometer range to the evanescent post, diaphragm deflection of a few micrometers can change the resonant frequency significantly. Dr. Liu has demonstrated tunable resonators and filters with tuning range as high as 2.6:1 and Qu in the range of 300-650. The tuning technology is also inherently immune to material creep and has shown excellent mechanical stability under constant bias (<0.2%/hr drift in frequency).



After joining UC Davis, Dr. Liu plans to extend his research activities into areas such as tunable RF/microwave components and systems, high power RF-MEMS devices, and biomedical applications of MEMS and RF technologies.

Scientists visualize thermonuclear plasmas with millimeter waves



Neville C. Luhmann Jr.

Fusion is the process that powers the sun and the stars. Scientists are trying to understand and harness this powerful process here on Earth, eventually allowing for efficient clean commercial energy production. Controlled thermonuclear fusion requires temperatures of 100 million degrees or more, sufficient to ionize electrons from their nucleus and to form an ionized gas or plasma. Magnetic confinement fusion uses magnetic fields to hold the plasma in place while it is heated to ignition temperatures by external sources. One way this can be achieved relies on a toroidal (donut-shaped) device called a tokamak. However, a major challenge with tokamak experiments is an issue of confinement, keeping the particles within the core of the reactor so they have sufficient time to fuse and maintain the temperature of the plasma.

At UC Davis, Professor Neville C. Luhmann Jr. and the Plasma Diagnostic Group (PDG) within the Davis Millimeter Wave Research Center (DMRC) is developing advanced millimeter-wave plasma diagnostic instruments to measure and visualize temperature and density fluctuations within the plasma. Collaborating with fusion scientists and millimeter-wave technology researchers worldwide, the PDG has developed imaging systems spanning the globe from the U.S. (DIII-D tokamak) to Germany (ASDEX tokamak) all the way to China (EAST tokamak). These millimeter-wave imaging technologies have provided researchers with the unique ability to visualize the behavior of the hot plasma with unsurpassed quality.

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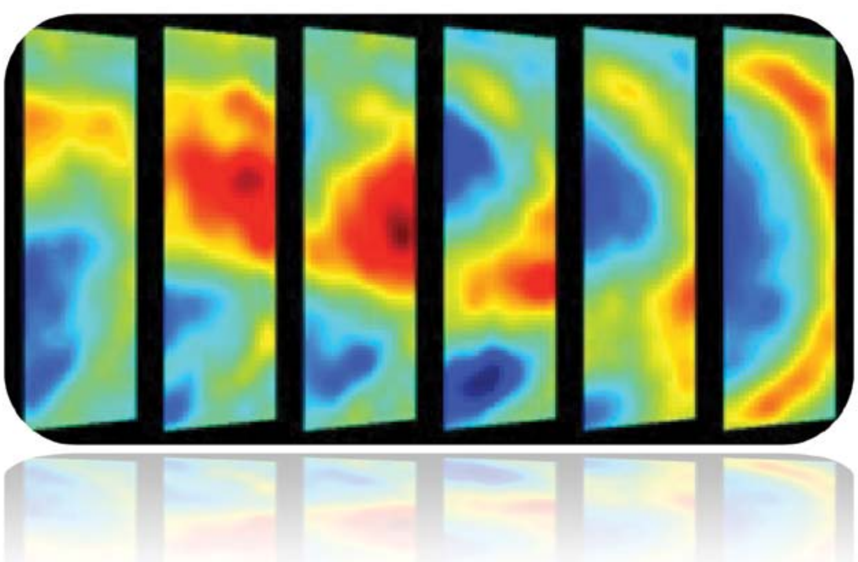


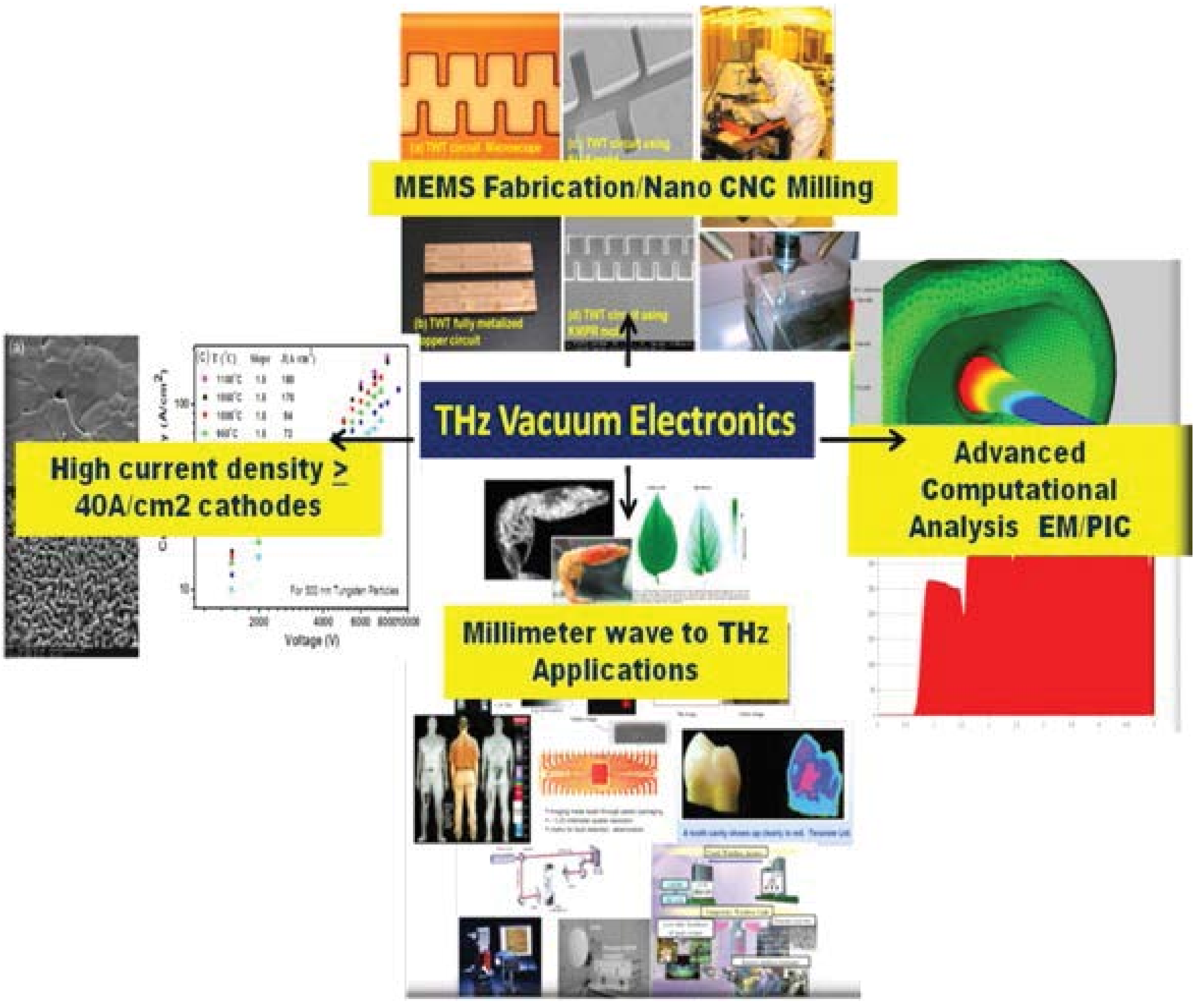
Magnetically confined plasmas are susceptible to instabilities that can degrade the temperature and confinement. Shown at left are time frames of the electron temperature during a so-called sawtooth collapse obtained using a PDG millimeter wave "camera." This instability leads to energy and particle fluxes out of the core of the reactor.

Neville C. Luhmann Jr. (continued)

Bridging the "THz gap" by micro-Vacuum Electron Device (μVED) Technology

To fill the applications-rich "THz gap," Vacuum Electron Device (VED) technology has come under the spotlight in recent years as it is known for the generation of high power, coherent electromagnetic radiation in compact volume with reliability, thermal robustness, and reasonable cost.

Prof Luhmann's group has been working on all key aspects of the realization of vacuum electron device technology up to the mmwave-THz region. As an example, for the 220 GHz, 50 W output, > 30 dB gain, > 1000W-GHz product, ultra wide band traveling wave tube amplifier (TWTA) project, the research and development ranges from (a) MEMS Fabrication/Nano-CNC Milling (b) High current density tungsten-scandate nanocomposite cathodes synthesis/characterization (c) advanced computational electromagnetic analysis and particle-in-cell simulations for realistic tube performance analysis.

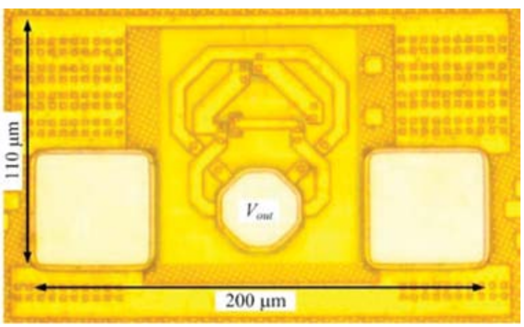


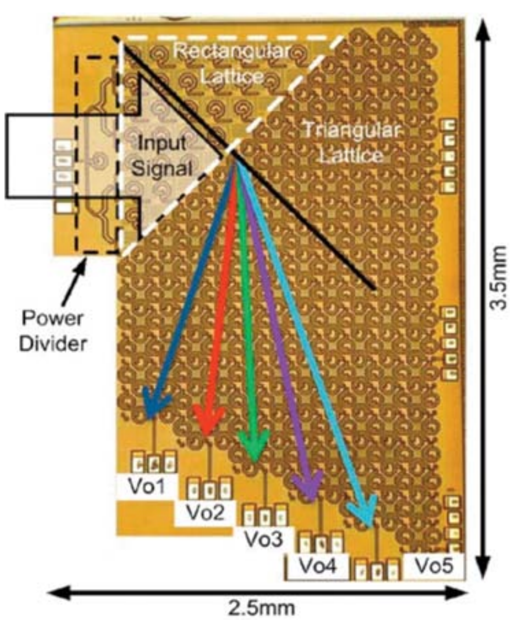
Solid-State Terahertz and mm-Wave Electronics, Reaching the Fundamental Limits

Omeed Momeni

Terahertz (300 GHz - 3 THz) systems are known to have unique and significant applications in health, security and industry. However, today's solid-state technologies including silicon and compound semiconductors can barley cover the lower part of the terahertz band. In order to overcome this problem, it is essential to develop innovative design methodologies to desige circuits and systems operating close to or even beyond the limits of the devices.

By analyzing the fundamental limits of the devices and combining circuit theory, device physics and mathematics, Prof. Momeni proposes systematic methodologies for designing circuits and components operating close to and beyond the conventional limits of the devices. This approach can be used to reach performances such as the maximum output power, power gain, power efficiency, and/or operation frequency of a device and therefore can be utilized in almost every circuit component.





By expanding this approach, Prof. Momeni's group is working toward implementing high-power and high frequency oscillators, high gain amplifiers, broad-band frequency dividers, high power frequency multipliers, wide-band phased-locked loops and eventually, high performance terahertz transceivers. The proposed structures are implemented in different platforms such as silicon for high volume applications, GaN for high power systems, and InP for extremely high frequencies up to 3 THz. As a proof of concept and in the context of signal generation, this method has led to the implementation of a 500 GHz oscillator (top figure) in a 65 nm CMOS process with an output power of 160 µW, which is 10,000 times higher than any other signal source in CMOS. In signal amplification domain, an amplifier was implemented with 12.5 dB of gain at 107 GHz in a 130 nm CMOS with fmax of ~135 GHz. In passive filtering, an Electrical Prism structure (bottom figure) was proposed that could achieve quality factor of 420 at 460 GHz using individual elements with the quality factor of 20.

Wireless Power Delivery for Implantable Medical Devices

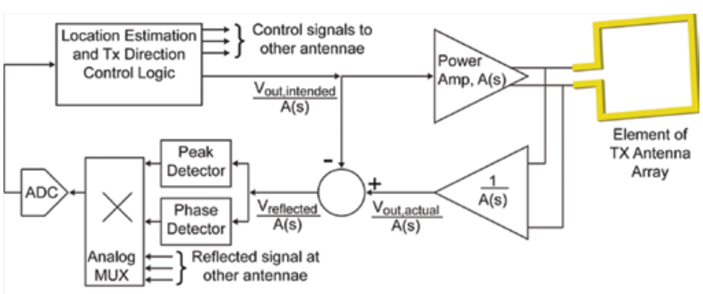
Implantable Medical Devices (IMDs) monitor and treat key physiological parameters and thereby greatly assist in managing health and preventing disease. Today's IMDs use either batteries or inductive coupling as their power supply. Battery volume restricts the range of viable applications to those which can accommodate large device sizes, while inductive coupling is efficient only in the near field: in other words, at shallow implant depths.

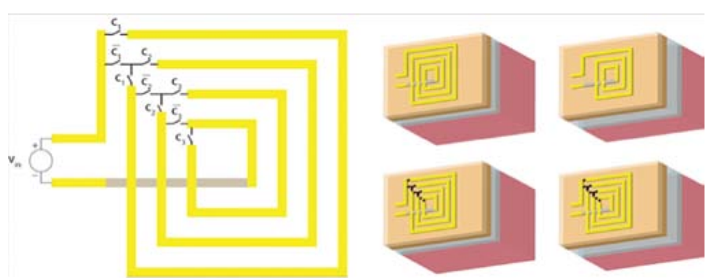
Stephen O'Driscoll

Prof. O'Driscoll's group is developing wireless power delivery systems for the next generation of IMDs, with the goal of targeting distributed sensing and mm-scale IMD dimensions at greater implant depths. To this end, his group is researching: circuits and antenna structures to estimate the location of implantable devices, while directing transmitted power toward that location; near and intermediate field antenna structures that adapt to changing tissue dielectric properties; high-efficiency class E power amplifiers; adaptive matching circuits; low-voltage rectifier and regulator circuit architectures; and circuits and system architectures to maximize data rate on the bi-directionally modulated power carrier.

In medical sensors — whether portable, hand-held, wearable or implantable devices — and in the broad range of wireless sensor applications, real-world analog signals must be converted to the digital domain. Unfortunately, power budgets are very constrained. The sensed signals often are very low-strength, with low signal-to-noise ratios and very low bandwidth.

Prof O'Driscoll is investigating low-frequency, on-chip filtering techniques, very low-noise voltage amplifiers and transimpedance amplifiers (TIAs), and high-efficiency analog-to-digital converters. By way of example, his group intends to: overcome mismatch limitations in charge redistribution successive approximation analog-to-digital converters, by dynamic reconfiguration in the capacitor array; and extend the lifetime of electrochemical sensors by developing sharper low-frequency filters integrated with low-noise TIAs. In general, the group seeks to employ knowledge of the signal characteristics — together with reconfigurable analog circuits — to dynamically vary performance as a function of the signal information content, thus expending only the minimum required energy at all times.





Low Power Signal Acquisition Front Ends

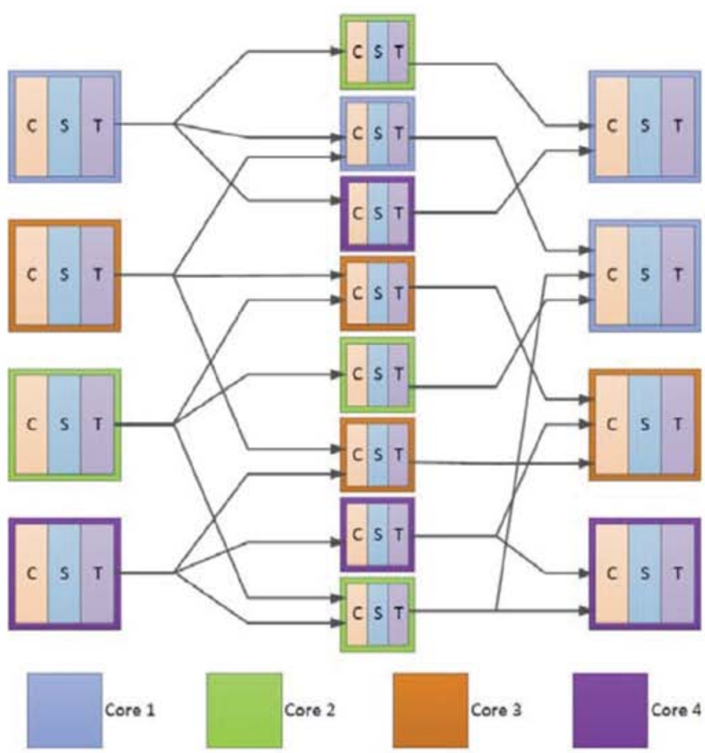
John Owens

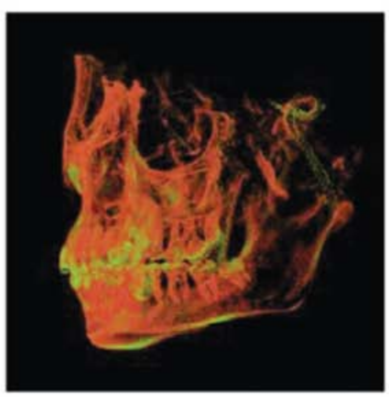
Programmable Pipelines for Real-Time Computer Graphics (GPU) (Sponsors: Intel Science & Technology Center for Visual Computing, NSF)

One of the most exciting developments in computer graphics over the past decade has been the addition of *programmability* into the graphics pipeline. Formerly limited by the fixed-function capabilities built into graphics processors (GPUs), programmers can now not only use hardwired, graphics-specific functionality in GPUs but also a rapidly growing and increasingly powerful set of parallel computing cores within the GPUs.

Our group is using these programmable capabilities to look at new ways to build real-time graphics systems, with graphics pipeline abstractions that differ from traditional real-time pipelines. For instance, we are analyzing the Reyes pipeline (originally developed by Pixar), previously limited to offline graphics, as an interactive graphics API. While we are advancing the state of the art in graphics pipelines, our main focus is building tools and abstractions for building programmable pipelines.

Famed supercomputer pioneer Seymour Cray used to ask "would you rather plow a field with two strong oxen or 1024 chickens?". Cray preferred having a few, powerful processors (the oxen), but the modern GPU instead has an enormous number of individually weak processors (the chickens). With an army of chickens, we hope to target not just graphics but also a wide range of computationally challenging scientific workloads.





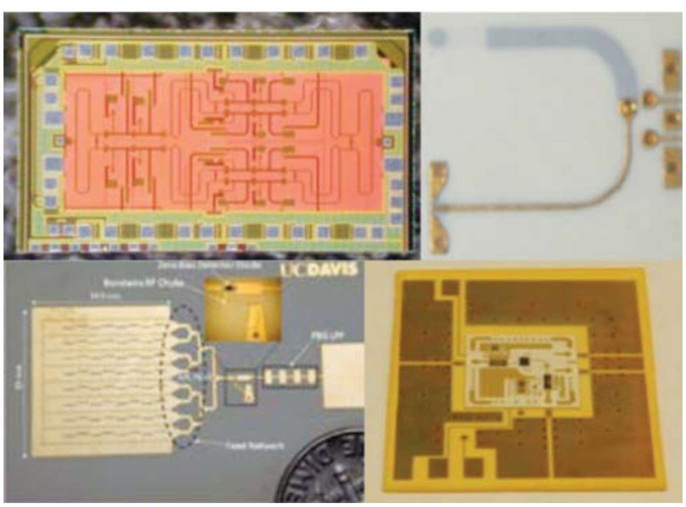
Microwave and Millimeter-Wave Frequency Circuit, Component, Multi-chip Module and Antennas

Sponsors: Agilent Technologies, Panasonic, Samsung, L-3 Communications, Raytheon, AFRL, and UC Discovery GrantUC MICRO, UC Discovery)

Pham and his group are conducting research to develop innovative circuits, components, modules and antennas for communications, radars, sensors and energy harvesting devices at microwave and millimeter wave frequencies. Our goals are to develop circuits and integration techniques that provide more functionalities, better performance, high efficiency, lighter weight, and smaller size for system applications. In addition, we are developing circuits, components and modules that will enable emerging communications, radar, sensor and energy harvesting applications. Pham's on-going research thrusts include: 1) development of microwave and millimeter-wave frequency integrated circuits in GaN, GaAs, SiGe and Si CMOS, 2) development of miniaturized microwave and millimeter-wave frequency passive components, 3) development of miniaturized and reconfigurable antennas and phased array antennas for radars and energy harvesting, and 4) development of light weight and highly integrated modules for communication and radar systems. On thrust 1, Pham and his group are developing high efficiency and

Anh-Vu Pham

highly linear amplifier circuits in a number of foundry processes such as GaN, GaAs, SiGe and Si CMOS. Specific research and developments include high efficiency techniques such as inverse class F, J and E, etc, linearization techniques, and power amplifiers that maintain peak efficiency with 7 to 10 dB power back-off. Furthermore, we are currently developing wide bandwidth and highly linear amplifiers to 110 GHz. On thrust 2, we have been developing left-handed and defected ground structures to design compact and high performance, wide bandwidth, integrated passive devices to 110 GHz. Examples of wide bandwidth passive components developed by our group include baluns, couplers, power dividers/combiners, and filters. On thrust 3, Pham and his group are developing miniaturized reconfigurable and multi-band antennas that can be used in energy harvesting and communications applications. On thrust 4, we are developing compact and near hermetic multi-chip modules for communication and radar front-ends using multi-layer organic materials to 110 GHz.



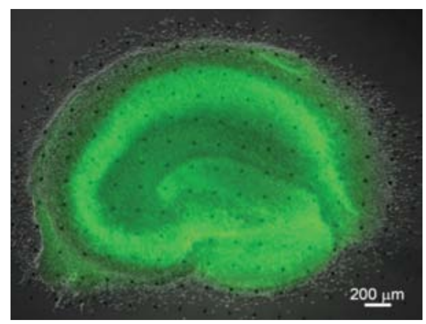
Engineering Multifunctional Nanomaterials for Diagnostic and Therapeutic Tools (Sponsor: UC Office of Research)

Erkin Seker

Miniaturized devices have had a significant impact on our society in revolutionizing the electronics industry. A similar trend of size-reduction is emerging in the health care industry to produce small bioanalytical devices for disease diagnosis, novel methods for drug delivery to treat diseases, and microfabricated platforms for studying microorganisms. Nanostructured materials, in particular, offer tremendous opportunities for engineering advanced device components for diagnostic and therapeutic applications. Despite the recent research on these materials, significant challenges remain in controlling material properties, interfacing nanocomponents with instrumentation, and engineering their interaction with biological systems. The overarching objective of Prof. Seker's group is to develop innovations at the intersection of nanostructured materials development, microfluidics, and device engineering to overcome challenges in the evolution of miniaturized devices relevant to microelectronics and life sciences.

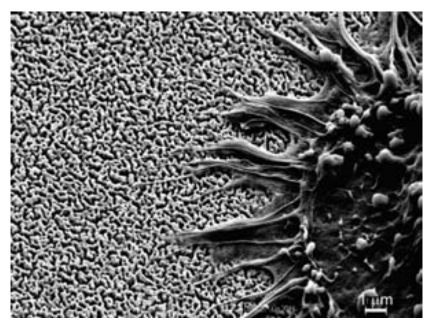
Nanoporous Metal Synthesis and Characterization

Nanoporous metals, with their highly tunable properties, are promising candidates for multifunctional device coatings for applications such as high-capacity energy storage and advanced biomedical devices. Prof. Seker is working to create a library of application-specific nanoporous metals, high-throughput characterization tools to study key material properties, and a framework that captures the link between material properties, mechanical properties and nanofluidic transport.



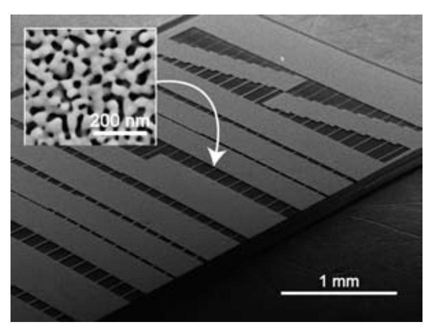
Engineering Tissue-Material Interaction

Tissue response is due in part to a complex set of material properties. Understanding the correlation between material properties and biological responses is a crucial step in the development of biomedical devices with higher efficacy and safety. Prof. Seker is combining nanoporous metal technology and microfluidic platforms to create large-scale, material-tissue interrogation arrays to identify optimal tissue-material combinations that maximize the desired biological response.



Creating Translational Biomedical Devices

The scarcity of medical devices that can both detect and stimulate physiological activity imposes a significant obstacle to effective therapeutics in diseases, including those that are neurological and metabolic. Prof. Seker is applying the recent progress in fundamental science and technology from his accompanying research thrusts to create multifunctional neural electrodes that can detect and modulate physiological activity.



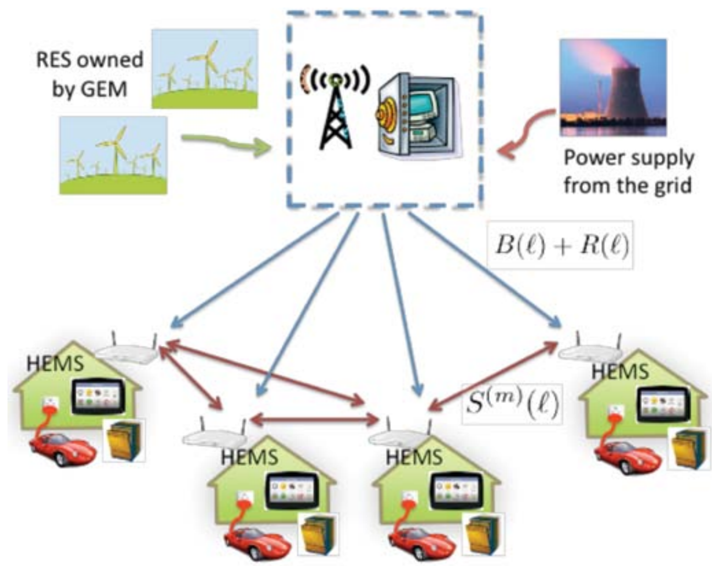
Networks Signal Processing for cyber physical systems

Anna Scaglione

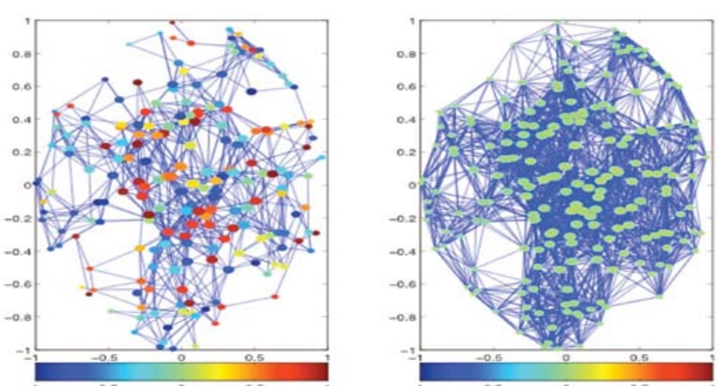
Infrastructures are increasingly networked over wide areas and comprise a variety of sensing modalities. From controlling electrical loads to harnessing computer power to perform rapid trading decisions, systems and organizations that were once controlled by humans and managed locally, are now highly coupled and depend on computer networks to operate.

As society is connecting the cyber-physical world, Prof. Scaglione's research is concerned with approaching the problem of scalable sensing and decision-making in networks from a systematic fashion. She is focusing on areas where specialized research in networking has been lacking, compared to personal communications.

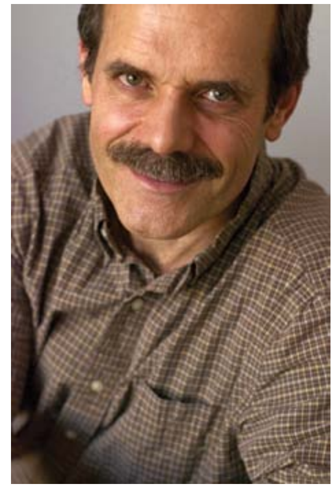
Given the importance that energy management will occupy in this area Scaglione and her students are investigating scalable and secure solutions for the cyber-physical infrastructure in the power grid. Part of this effort requires modeling the data to be acquired from the physical systems to make their state transparent to a resource allocation algorithm. For example, her group developed one of the first queueing models for scheduling electrical loads that are deferrable, such as Electrical Vehicle charging. The model provides a mechanism to describe a large amount of requests and making optimum dispatch decisions to follow the erratic profile of renewable generation, while requiring modest telemetry and feedback cost from and towards the loads.



Scaglione is also considering more broadly scalable algorithms to coordinate several independent agents, solving coordination and signal processing problems using "peer to peer" communications. Some of these algorithms are inspired by swarming phenomena and provide also a window into understanding and interpreting social networks and herding behavior and their convergence to some form of order. Algorithms that emulate the same types of random local interactions that occur in these phenomena, are studied in her group to, for example,, synchronize random networks of sensors, find conflict free schedules for their transmissions and also to solve optimization problems all without a central controller.



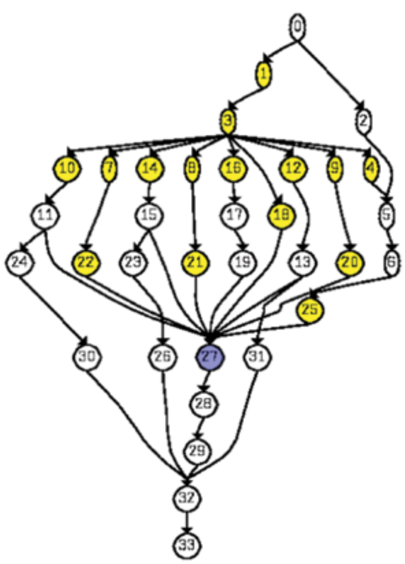
Precise Compiler Optimizations



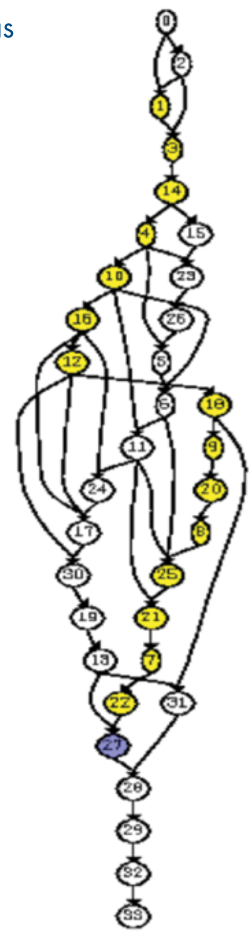
Kent Wilken

Compiler optimizations are used to transform a high-level language program into a binary machine-code program, with the goal of increasing program performance, reducing program memory size, and reducing the energy needed to execute a program. Various existing compiler optimizations are based on algorithms that use a simplified model of the underlying optimization problem. These compiler optimizations leave a gap between the performance increase, memory size reduction and energy reduction that are achieved, and that which might be achieved if an optimal solution could be produced.

Prof. Wilken's research focuses on developing more precise compiler optimizations that close this gap. The precise optimizations usually are based on more complex models of the underlying optimization problem, which require additional computation to produce a more highly optimized program, making use of the increased computational power available from today's processors. For an important class of instruction scheduling optimization problems, a pre-processing algorithm has been developed that can restructure and simplify the scheduling problem — as illustrated below — without losing solution precision. A following algorithm more consistently finds an optimal solution using the restructured, simplified problem. Precise optimizations are being developed for register allocation, instruction scheduling and redundant-instruction elimination, using both heuristic and combinatorial optimization methods.



Original Dependency Graph



Transformed Dependency Graph

An Integrated System to Produce Electricity via Al, Water and SOFCs

Jerry Woodall

Currently, according to the US EIA, about 40% of the total power (4.6 gigawatts) used in the U.S. is in the form of electricity generated by utility plants via dynamos and generators powered by fossil fuel, dams, nuclear and geothermal energy sources. Most electricity for mobile applications also derives from generators, powered by fossil fuels, e.g. diesel electric trains, and nuclear, e.g. submarines. Also, a small fraction is supplied by various kinds of batteries, e.g. starters, EVs, Hybrids, etc. Finally, there is the consumer electronics battery market, which consists of power units ranging from milliwatts to kilowatts. A large fraction of this market is composed of rechargeable secondary batteries, e.g. lead-acid, followed by a much lesser fraction due to secondary batteries, e.g. Li-ion and NiMH, and finally by single use primary alkaline batteries used in, e.g. flashlights. Currently, there is a cost vs. energy density disconnect between scaling low power secondary batteries to their scaled use in applications requiring multi-tens of kilowatts or greater, e.g. EVs and advanced hybrid EVs. This disconnect is aptly described semi-quantitatively by Richard A. Muller, in his textbook, *Physics and Technology for Future Presidents,* where he claims it costs about $4.00/kWh to use a Li-ion battery over its life compared to 5-20 cents/kWh to supply energy via fossil fuels This disconnect is economically stressful to the point that many recent large scaled power Li-ion battery companies have failed.

The goal of this project is to mitigate the current limitations of generating global scale electricity via fossil fuel and develop and integrate a new hydrogen generation technology with an improved SOFC technology to create a system that reduces the need to use critical materials for large-scale electric power applications. Prof. Jerry Woodall has pioneered a new, reliable, and global scale capable technology that enables bulk Al rich alloys to safely store its large mass chemical energy density of 8.8 kWh per kg of Al and corresponding volumetric energy density of 23.6 kWh/liter of Al, which is the highest volumetric *chemical energy* density of any known material. Being inert in air, it can then be safely transported. And, when brought into contact with any kind of water, splits the water into hydrogen gas (whose energy of combustion is 4.4 kWh/kg of Al), heat (whose energy is 4.4 kWh/kg of Al] and, aluminum hydroxide. Thus Al can safely store and transport its energy (without any reference to hydrogen) and when water is added hydrogen gas is made on demand at the point of use.

Aluminum forms the basis of an ideal energy storage materials technology. It can complete the triangle of a perfect fuel whose vertices are safe storage, safe transport, and economically recyclable. It should be noted that the aluminum hydroxide is restored to metallic Al via commercial systems already used in the Al industry: fused salt electrolysis of aluminum oxide dissolved into a low temperature viscous salt. The process is known as the Hall-Heroult process and accounts for the current world-wide production of 50 billion kg of Al per year. Thus using Al to make hydrogen is the perfect fuel. It has global scale impact possibilities since Al is the third most abundant element on the planet, i.e. it is light and earth abundant. When it liberates its energy it does not go up a smokestack and does not adversely affect the environment.

continued on next page

Jerry Woodall (continued)

The key to how the Al alloys split water is due to the presence of liquid gallium in the grain boundary region of the polycrystalline alloy. Melting the Al and Ga in a crucible at 700 C and rapidly cooling it back to room temperature makes the reactive alloy. The science of metallurgy demands that the Ga in the melt is mostly rejected from being incorporated into the solid Al grains, which form doing cooling. Thus, after a return to room temperature the alloy is composed of small grains of solid Al containing a small amount of Ga. Liquid Ga surrounds the Al grains and this liquid Ga in the grain boundary can dissolve up to about 2 wt% Al. If these grain boundaries of Ga saturated with Al intersect the sample surface where there is water, the Al will split the water. The diagram in Fig. 1 shows the mechanism of how the Al-Ga alloys split water.

The second phase of the systems project is to design and test reactors that can connect to the SOFC system, which is under development in Prof Wachsman laboratory at the University of Maryland.

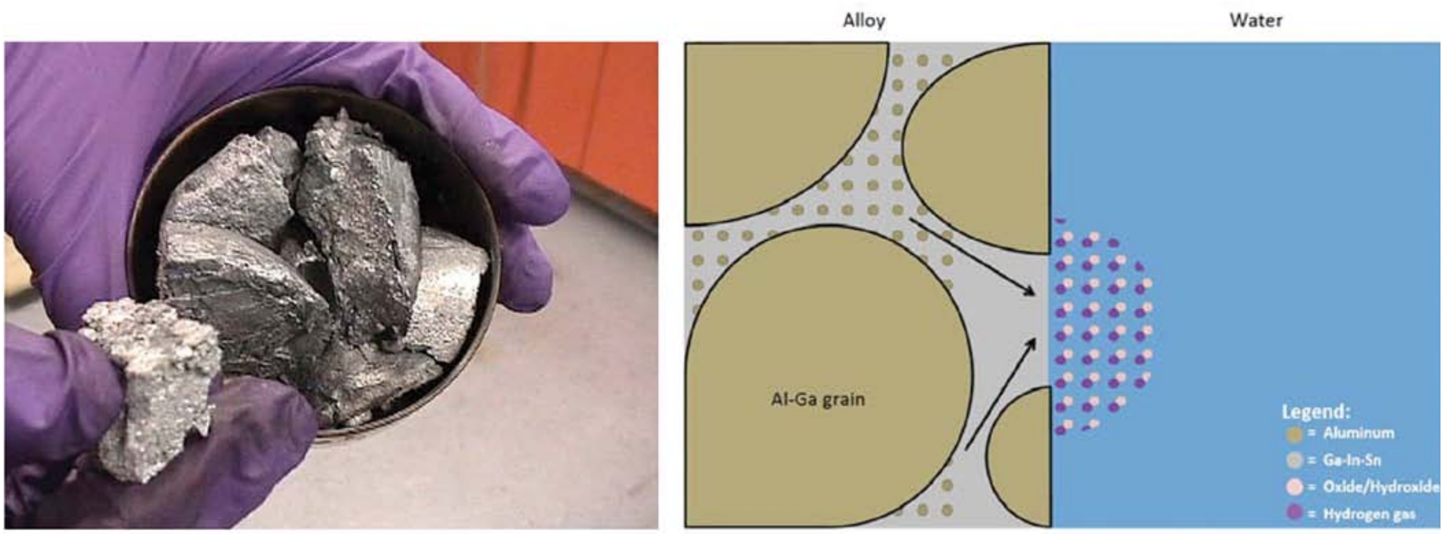


Fig. 1. (a) is a macro-photograph of chunks of a "solid-like" Al-Ga (or Ga,In,Sn) alloy. (b) is a cartoon of how the alloy works. First, pieces of solid aluminum along with either liquid gallium or a liquid mixture of gallium, indium and tin* are placed in an inert crucible, e.g. an alumina crucible. These alloy components are heated to 700 C in a nitrogen gas atmosphere and melted. Then they are rapidly cooled to room temperature forming solid Al grains with a small concentration of Ga which are surrounded with liquid Ga (or Ga,In,Sn), which have dissolved about 2 wt.% of the Al, i.e. the solubility limit at room temperature. The Al in the liquid Ga at the water/alloy interface immediately reacts with the water to make hydrogen gas, heat, and aluminum hydroxide. This creates a concentration gradient of Al in the Ga near the surface. This causes the Al farther away from the water/Al interface to diffuse to the interface to create more hydrogen gas. This diffusion of Al to the interface causes the Al concentration in away from the interface to fall below its solubility limit. Thus, the Al grains dynamically continue to dissolve in the liquid Ga, diffuse to the interface, make hydrogen and so forth until all the Al grains are converted to hydrogen via water splitting.

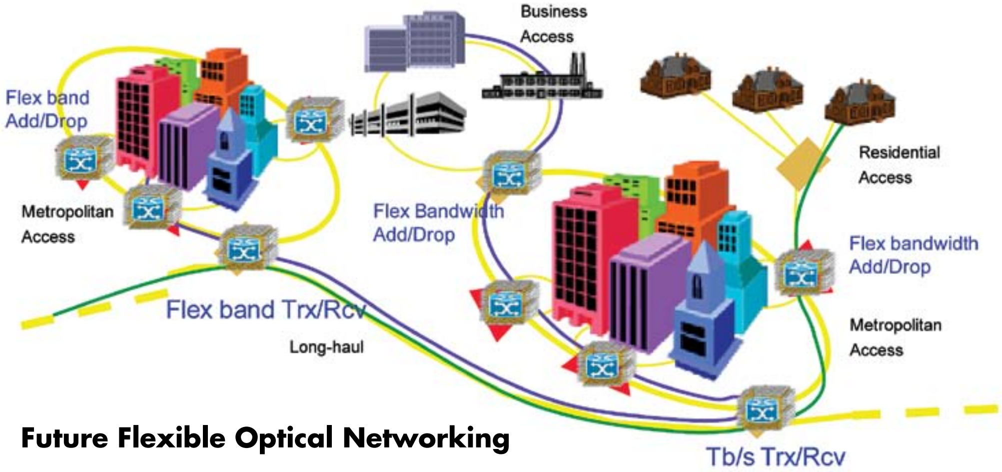
*Certain mixtures of Ga,In,Sn, have a lower melting point than pure Ga.

Next Generation Networking and Systems

(Sponsors: DARPA, DOD, NSF, Industry)

S.J. Ben Yoo

To sustain current exponential traffic increases, future networks will need to fully utilize the benefits of optical networking, so that the massive bandwidths (e.g., 10's of THz) can be manipulated directly in the optical layer without involving electronics in the data plane while supporting future networking technologies like packet-agile optical networking (e.g., packet switching) or flow-agile optical networking (e.g., flexible bandwidth). Next generation networks will also need to further improve spectral efficiency and capacity through advanced modulation format and protocol support and transparency, and dynamic reconfiguration.



Future Flexible Optical Networking

Prof. Yoo's research team pursues many new photonic and networking technologies that will enable the next generation of optical networks. Their work in optical code division multiple access (O-CDMA) networking and optical label switching provides very flexible access to the large communication bandwidth available in optical fiber networks with a capability to conceal the data content. Beyond O-CDMA, they have developed optical arbitrary waveform generation (OAWG) and measurement (OAWM) technologies as part of a $9.5 million project from DARPA DSO. This has led to a new networking technique with ultrahigh capacity and versatile formats and protocols which allows secure and high-sensitivity networking. These technologies make it possible to achieve ultra-high capacity all-optical arbitrary waveform generation covering optical bandwidths of many THz. Other applications include photonic ADC/DAC, ultra-high resolution remote sensing and LADAR.

The team also pursues RF-photonic processing to improve the fidelity and efficiency of electrical-optical (or vise versa) information conversion using optical lattice filters capable of creating reconfigurable filter shapes in the RF/microwave domain without

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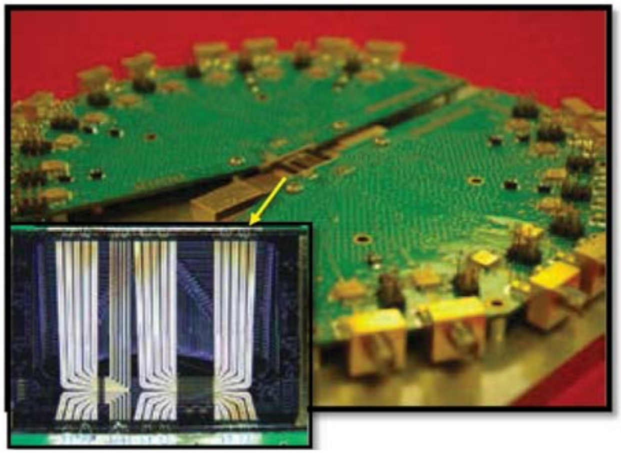
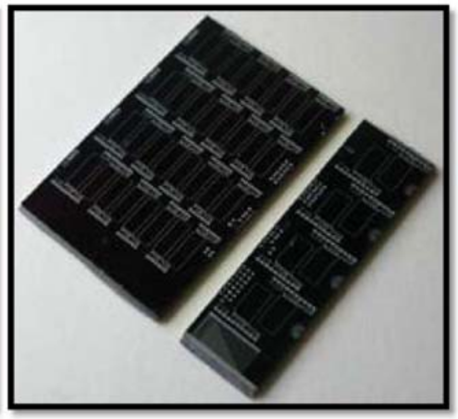
involving power hungry RF electronics. They are also working on further improvements in network spectral efficiency by taking advantage of a type of spatial division multiplexing (SDM) where an optical beam's orbital angular momentum (OAM) state is used as an independent information channel.



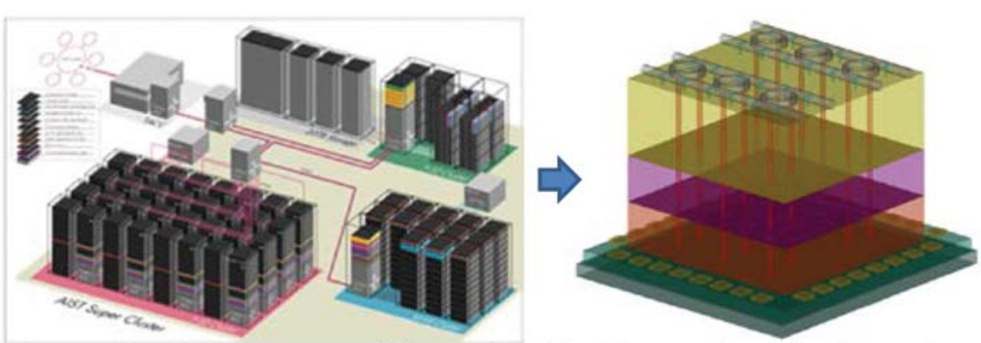
100 GHz OAWG InP device



RF-Photonic Si Lattice Filters

Computing of the Future

The phenomenal advances in computing technology over the past two decades were enabled by Dennard scaling, whereby the exponential improvements in power efficiency and performance and cost- effectiveness of silicon technology tracked Moore's Law improvements in integrating more devices on each chip. As we approach atomic scale lithography, the end of Dennard scaling puts future growth of the computing industry in jeopardy. Photonic interconnects offer a disruptive technology solution that fundamentally changes the computing architectural design considerations. Optics provide ultra-high throughput, minimal access latencies, and low power dissipation that remains independent of capacity and distance.



Conventional data centers will be replaced by 3D nanophotonic-electronic multicore architectures as integrated systems on a chip

Hypergraphs for Complex Networks

(Sponsor: ARL)

Qing Zhao

A graph is a mathematical abstraction for modeling networks, in which nodes are represented by vertices and pairwise relationships by edges between vertices. A graph is thus given by a vertex set V and an edge set E consisting of cardinality-2 subsets of V. A hypergraph is a natural extension of a graph obtained by removing the constraint on the cardinality of an edge: any nonempty subset of V can be an element (a hyperedge) of the edge set E (see Fig 1). It thus captures group behaviors and higher-dimensional relationships in complex networks that are more than a simple union of pairwise relationships. Examples include communities and collaboration teams in social networks, document clusters in information networks, and cliques, neighborhoods, and multicast groups in communication networks.

While the concept of hypergraph has been around since the 1920's, many well-solved algorithmic problems in graphs (such as the shortest path and the minimum spanning problems) remain largely open under this more general model.

As a part of a 10-year ARL project on Network Science, Prof. Zhao and her group are investigating a broad range of algorithmic and topological problems in hypergraphs with applications ranging from discovering latent relationship in social networks, team and coalition formation, document clustering and information dissemination, to secure communications in wireless networks.

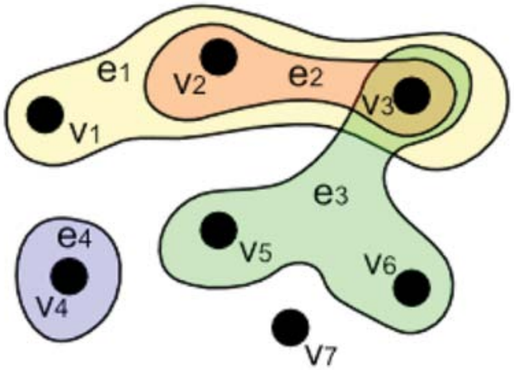
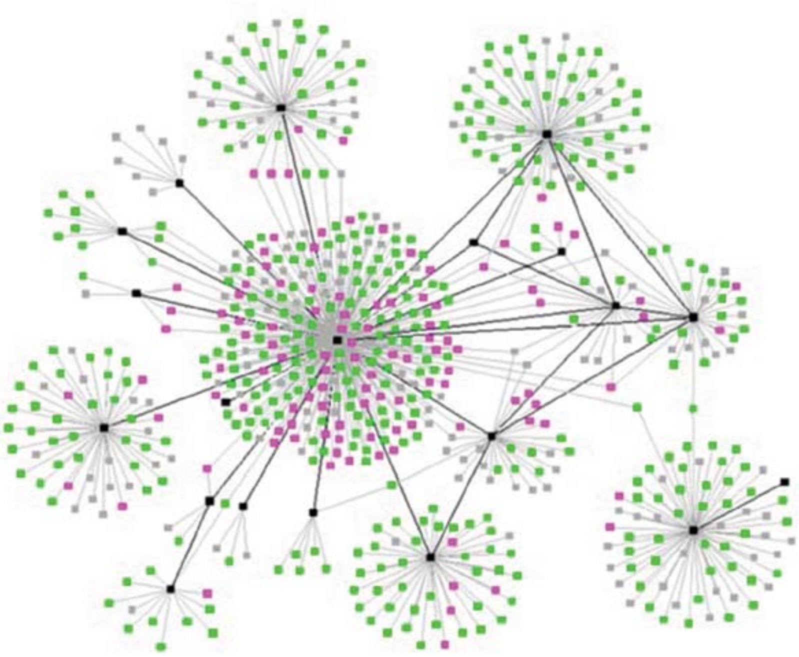


Fig. 1 A hypergraph with 7 vertexes and 4 hyperedges (Source: Wikipedia)

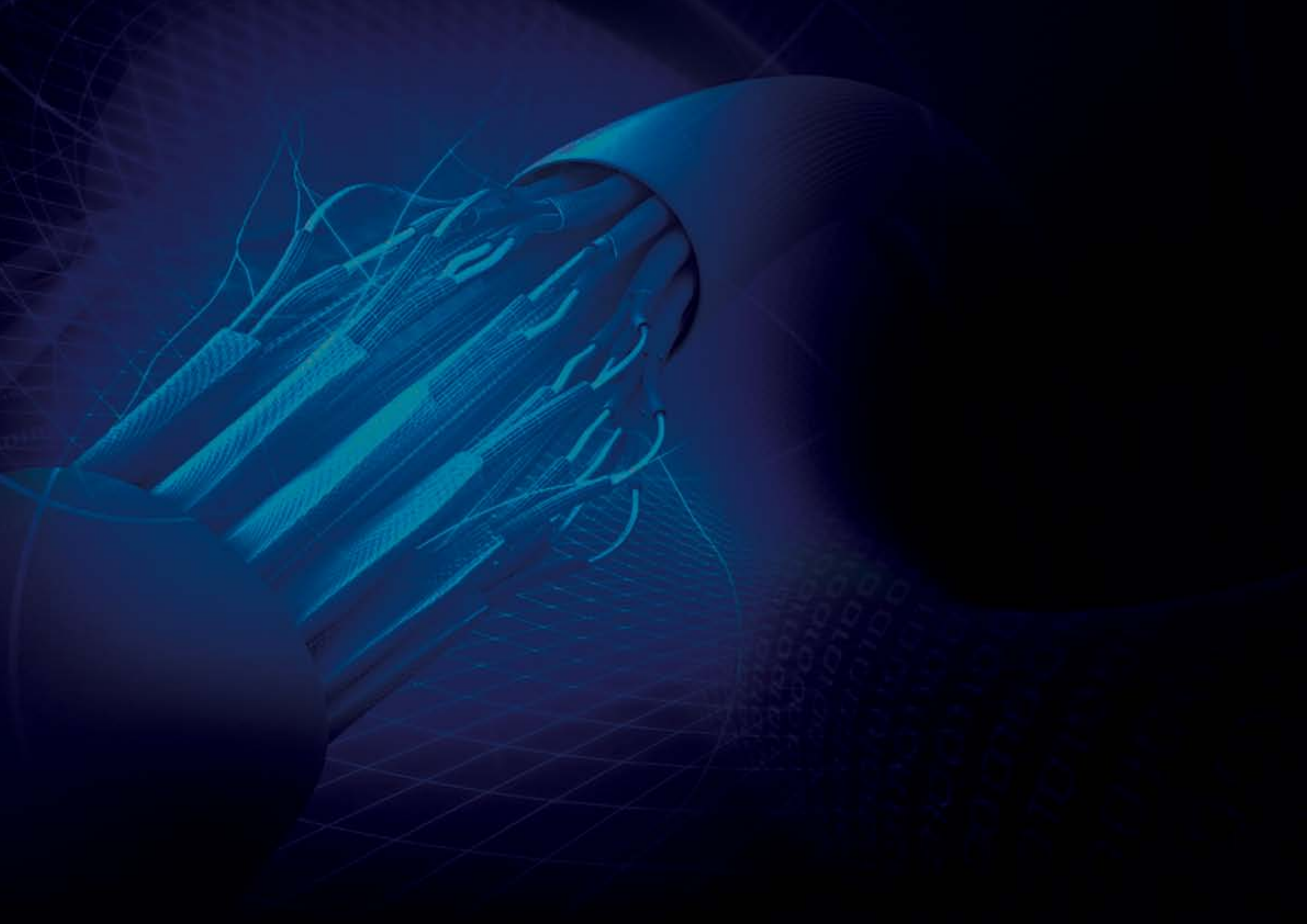


Scholarly Recognitions

Our school continues to attract and to produce leaders in science and technology

- Seventeen IEEE Fellows (Karl Current, Zhi Ding, Richard Dorf, Mohammed Ghausi, Jonathan Heritage, Paul Hurst, Linda Katehi, Richard Kiehl, Brian Kolner, Bernard Levy, Stephen Lewis, Neville Luhmann, Vojin G. Oklobdzija, Anna Scaglione, Richard Spencer, Jerry Woodall, S.J. Ben Yoo)
- Nine IEEE Life Fellows (Robert Bower, Ivor Brodie, William Gardner, Tien Hsia, Shu Lin, David Mayne, Robert Redinbo, Ronald Soohoo, Jerome Suran)
- Six American Physical Society Fellows (Robert Bower, Ivor Brodie, Herman Fink, Jonathan Heritage, Neville Luhmann, Jerry Woodall)
- Four Optical Society of America Fellows (Jonathan Heritage, Andre Knoesen, Brian Kolner, S.J. Ben Yoo)
- American Vacuum Society of America Fellow (Jerry Woodall)
- Electrochemical Society Fellow (Jerry Woodall)
- National Medal of Technology (Jerry Woodall)
- Three National Academy of Engineering Members (Robert Bower, Linda Katehi, Jerry Woodall)
- Four Third Millennium Medal winners (Shu Lin, Linda Katehi, Stephen Lewis, Jerry Woodall)
- Optical Society of America R.W. Wood Prize for Outstanding Discovery, Achievement or Invention in the Field of Optics (Jonathan Heritage)
- Four Alexander von Humboldt Research Prizes (Robert Bower , Mohammed Ghausi, Jonathan Heritage, Shu Lin)
- IEEE John R. Pierce Award (Neville Luhmann)
- IEEE Jack A. Morton Award (Jerry Woodall)
- ISSCC Robert L. Woods Award for “Excellence in Vacuum Electronics” (Neville Luhmann)
- IEEE Jun-ichci Nishizawa Medal (Jerry Woodall)
- American Vacuum Society Founders Medal and Award (Welch Award) (Jerry Woodall)
- Institute of Physics Kenneth J. Button Award for “Recognition of Outstanding Contributions to the Science of Electromagnetic Spectrum” (Neville Luhmann)
- Eight NSF Early Career Development Program winners (Venkatesh Akella, Hussain Al-Asaad, Rajeevan Amitharajah, Bevan Baas, Chen-Nee Chuah, Saif Islam, Anh-Vu Pham, Anna Scaglione)
- One DOE Early Career Principle Investigators (John Owens)
- David and Lucille Packard Foundation fellowship (Brian Kolner)
- ISSCC 50-Year Anniversary Author Honor Roll winners (Paul Hurst and Stephen Lewis)
- Four ISSCC Beatrice Winner Awards for Editorial Excellence (Paul Hurst (2), Stephen Lewis, Richard Spencer)
- Two UC Davis Chancellor’s Fellows (Chen-Nee Chuah, Qing Zhao)
- Three UC Davis College of Engineering Outstanding Junior Faculty Awards (Chen-Nee Chuah, Saif Islam, Qing Zhao)

We continue to welcome talented students who share our enthusiasm and optimism about the future.



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