2006 SUMMARY OF ENGINEERING RESEARCH

A Report of Activities during 2005

This report is part of the larger 2006 Summary of Engineering Research, available on the Web at www.engr.uiuc.edu/research and on CD-ROM. The Summary of Engineering Research represents the extensive engineering research program conducted in 2005 at the University of Illinois at Urbana-Champaign. Detailed statistics about research in the College of Engineering are included in the Directory of Engineering and Engineering Technology Programs and Research, published by the American Society for Engineering Education, Washington, D.C.

How to use the Summary of Engineering Research: Research projects are listed by title, followed by the names of the investigators and the sponsoring agencies. Projects are sorted by major topic areas. Project descriptions are brief. Additional information on each project may be obtained from the investigator in charge (denoted by an asterisk). Mailing addresses are provided on the introductory page.

How to obtain publications: Please consult academic and public libraries for the journal articles, papers, and books listed in this report. Information about technical reports is available from the Engineering Documents Center, Grainger Engineering Library Information Center, 1301 West Springfield Avenue, Urbana, IL 61801, USA. To search the center's collection on the Internet, please visit the website at search.grainger.uiuc.edu/top. Copies of theses can be found at the University of Illinois Library, www.library.uiuc.edu, or may be purchased from University Microfilms, 300 Zeeb Road, Ann Arbor, MI 48106, USA, www.umi.com.

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Please send queries and comments about the 2006 Summary of Engineering Research to the Engineering Communications Office, 303 Engineering Hall, MC-266, 1308 West Green Street, Urbana, IL 61801, USA, or email research@engr.uiuc.edu.

Abbreviation key for College of Engineering departments and major labs:

- Advanced Transportation Research and Engineering Laboratory (ATREL)
- Aerospace Engineering (Aerosp. Engr.)
- Agricultural and Biological Engineering (Ag. & Biol. Engr.)
- Bioengineering (Bioengr.)
- Chemical and Biomolecular Engineering (Chem. & Biomol. Engr.)
- Civil and Environmental Engineering (Civil & Environ. Engr.)
- Computer Science (Comput. Sci.)
- Coordinated Science Laboratory (CSL)
- Electrical and Computer Engineering (Elect. & Comput. Engr.)
- Frederick Seitz Materials Research Laboratory (FS-MRL)
- General Engineering (Gen. Engr.) or Industrial & Enterprise Systems Engineering (Indus. & Enter. Syst. Engr.)*
- Materials Science and Engineering (Mat. Sci. & Engr.)
- Mechanical and Industrial Engineering (Mech. & Indus. Engr.) or Mechanical Science and Engineering (Mech. Sci. & Engr.)*
- Micro and Nanotechnology Laboratory (MNTL)
- Nuclear, Plasma, and Radiological Engineering (Nucl., Plasma, & Radiol. Engr.)
- Physics
- Theoretical and Applied Mechanics (Theoret. & Appl. Mech.)*

*In August 2006, the Industrial Engineering program was merged with the General Engineering Department, which became the Industrial and Enterprise Systems Engineering Department. The Theoretical and Applied Mechanics Department merged with the Mechanical and Industrial Engineering Department, which became the Mechanical Science and Engineering Department. Please check department links at www.engr.uiuc.edu for current faculty lists.
Research in the Department of Electrical and Computer Engineering serves two main purposes. The generation of new fundamental knowledge is a primary function. Of equal importance is the education of graduate students who participate in research and contribute to the advancement of knowledge through their thesis research. The research programs described here provide facilities and support for graduate students and enable them to pursue their advanced study.

Another important function of research is the continuing development of the faculty members. A forward-looking undergraduate program depends upon the existence of a strong graduate program and the presence of excellent faculty members who are leaders in their respective fields.

Research in electrical and computer engineering at the University of Illinois at Urbana-Champaign encompasses a broad spectrum of areas that reflect the wide range of interest and expertise of the faculty, as illustrated by the number and diversity of the research projects denoted in the following pages. Almost all of the faculty members in the department are engaged in research and many conduct research in interdisciplinary programs and hold joint appointments in other departments and interdisciplinary laboratories. More than 550 graduate students and many undergraduates assist in this research effort.

Support for this research is provided by contracts and grants from several agencies of the federal government as well as from industrial sources. Other departments and laboratories in which the department's faculty hold affiliate status and are engaged in interdisciplinary research include Bioengineering; Computer Science; General Engineering; Materials Science and Engineering; Nuclear, Plasma, and Radiological Engineering; Physics; the Coordinated Science Laboratory; the Frederick Seitz Materials Research Laboratory; the Micro and Nanotechnology Laboratory; and the Beckman Institute for Advanced Science and Technology.

Faculty and Their Interests

Ilesanmi Adesida
Electronic and transport properties of ultra-low dimensional semiconductor structures, advanced processing methods for electronic devices, high-speed optoelectronic devices and integrated circuits, radiation effects

Narendra Ahuja
Computer vision, robotics, image processing, sensors, pattern recognition, virtual environments, intelligent interfaces

Jont Allen
Speech recognition based on the articulation index and aspects of information theory

Tamer Basar
Information technology research; control over wired and wireless networks; robust identification and control; dynamic games and stochastic teams; nonlinear and adaptive robust control; decentralized detection and estimation; routing, pricing, and congestion control; modeling and control of communication networks; mobile computing; incentive mechanisms through pricing; neural networks-based identification and control; applications of control and game theory in economics

Tangul Basar
Optimum transmitter-receiver design in communication systems, spread spectrum communication system, jamming problems in information transmission, minima stochastic optimization problems with applications in communication systems, mobile radio systems

James Beauchamp, Emeritus
Use of computers for music synthesis, determination of sound synthesis models based on spectral analysis of musical instrument sounds, musical timbre perception, detection of musical pitch, musical sound source separation, and automatic transcription from acoustic recordings
Jennifer Bernhard
Reconfigurable active and passive antennas, phased array antennas, wireless sensor systems

Stephen G. Bishop
Optical and electrical characterization of crystalline and amorphous semiconductors and semiconductor nanostructures, compound semiconductors: GaAs, InP, AlGaAs, ZnSe, SiC, defects in semiconductors, isoelectronic defects, rare earth-doped chalcogenide glasses and GaN. Experimental techniques: photoluminescence, nuclear magnetic resonance, electron spin resonance, magneto-optics, photoemission, infrared spectroscopy

Richard Blahut
Communications, signal processing, information theory, optical recording

Stephen Boppart
Optical biomedical imaging, molecular imaging, lasers in medicine and biology, optical coherence tomography, image-guided surgery, medical engineering, optical diagnostics of cancer

Yoram Bresler
Biomedical imaging systems; statistical signal and image processing; inverse problems; statistical pattern recognition; sensor-array processing

Donna J. Brown
Asynchronous learning technologies and environments; WWW-based education; VLSI placement and routing; parallel and distributed algorithms and architectures; analysis and design of algorithms, with a particular interest in approximation algorithms; graph theory

Marie-Christine Brunet
Numerical algorithms, parallel computing

Andreas Cangellaris
Numerical techniques for electromagnetic modeling and simulation, microwave circuit design, speed VLSI interconnects, electronic packaging, electromagnetic computer-aided design for high-speed digital and RF/microwave electronics, antenna modeling, optoelectronic interconnects, electromagnetic modeling for nonlinear optics

Scott Carney
Optical physics, including imaging, near-field microscopy, classical and quantum coherence theory, beam propagation, fundamental issues of energy conservation, mathematical methods in inverse scattering and the propagation of light

Nicholas Carter
Architectures that combine programmable processors and reconfigurable logic, computing using nanotech devices, design techniques to integrate computation and sensing

Patrick Chapman
Power electronics, electric drives, vibrations in electromechanical systems, monolithic integrated power circuits, numerical magnetic modeling, biomechanical energy conversion

Keh-Yung Cheng
Molecular beam epitaxy technology, optoelectronic integrated circuits, high speed devices, in situ fabrication of nanostructures, quantum wire lasers, vertical cavity surface emitting lasers, Sb-based IR detectors and electronic devices

Weng C. Chew
Electromagnetics: wave propagation in inhomogeneous media, microwave integrated circuits, microstrip antennas, and fast algorithms for radiation scattering, low frequency electromagnetics, and layered media; parallelization of fast algorithms; inverse scattering, imaging, and physics-based signal processing

Yun Chiu
Integrated circuits, VLSI signal processing, device modeling and CAD, wire-line and wireless communications
Hyungsoo Choi
Precursors for nanoscale materials synthesis, including syntheses and development of tailored organometallic, inorganic, and polymeric precursors; thin film and nanoparticle fabrication, including thin films, micro- and nanoparticles, and nanowires/tubes via sol-gel processing, charged liquid cluster beam (CLCB) deposition, chemical vapor deposition (CVD), chemical solution deposition (CSD), and precision particle fabrication (PPF) technology; electronic and optical materials, including fabrication of electronic, optical, and magnetic materials for various devices involving thin films, micro- and nanoparticles, nanowires/tubes of metals, metal nitrides and oxides utilizing their electronic, optical, optoelectronic, and magnetic properties; bimaterials, including fabrication of micro- and nanospheres/capsules of biodegradable/compatible materials for advances drug delivery and tissue engineering

Kent Choquette
Vertical cavity surface emitting lasers (VCSELs), micro- and nanocavity lasers, optoelectronic devices, selective oxidation of compound semiconductors, hybrid heterogenous integration, nanoprocessing fabrication, photonic crystal materials, Si-based optoelectronics

Shun L. Chuang
Optoelectronics, semiconductor lasers, modulators, photodetectors, photonics, quantum electronics, fiber optical sensors, electromagnetics

Todd P. Coleman
Wireless networks, information theory, operations, research, computational neuroscience

James J. Coleman
Semiconductor lasers, optoelectronics, epitaxial growth

Brian Cunningham
Nanotechnology, photonic crystals, biosensors, micro/nanofabrication methods and materials detection instrumentation

Minh Do
Image and multidimensional signal processing, wavelets, imaging, multiscale geometric analysis, visual information representation

James G. Eden
Ultraviolet and visible lasers and laser spectroscopy, microcavity plasma devices and arrays, micro- and nanophotonic resonators; optical physics, including femtosecond laser spectroscopy and technology, and the interaction of intense optical fields with matter, laser magnetometry

Milton Feng
High-speed devices and ICs for wireless and light emitting transistors for optoelectronics (optoelectronic IC), monolithic microwave and millimeter-wave IC, digital IC, high field transport properties, RF-MEMS for wireless communications, advanced Si-CMOS device physics

Matthew Frank
Computer system architecture, parallel computing, program analysis, concurrency control, online algorithms

Patricia Franke
Atmospheric dynamics, including the dynamics and thermodynamics of the upper atmosphere through data analysis of radar and lidar data and through the numerical simulations of different types of flow; radar and optical remote sensing of the upper atmosphere; computational electromagnetics, application of finite difference time domain techniques to the problems of radar backscatter from turbulent regions of the neutral atmosphere and the ionosphere and application of different numerical methods and parallel computing for computationally demanding problems; computational fluid dynamics

Steven J. Franke
Development and application of radar and signal processing techniques for remote sensing in the middle and upper atmosphere; application of tomographic imaging to the middle and upper atmosphere using arrays of ground-based sensors and low-earth orbit satellites; low-power wireless RF communications; high efficiency linear power amplifiers for RF communications and radar applications

Leon A. Frizzell
Ultrasonic biophysics, ultrasonic bioengineering

Chester S. Gardner
Optical communication, laser altimetry, laser remote sensing and ranging, laser guide stars, adaptive optics
George Gross
Electricity planning and analysis, power system operations, competitive electricity markets and auction mechanisms, transmission services and pricing, ancillary services, congestions management, reliability and security, energy policy and economics, restructuring of the electricity business

Christoforos Hadjicostis
Systems and control, error control coding, fault diagnosis and tolerance in dynamic systems, testing and verification, discrete event systems, algebraic systems, coding and graph theory

Bruce E. Hajek
Communication networks information theory, computer networks stochastic analysis, optimization wireless communication

Mark Hasegawa-Johnson
Acoustic phonetics, audio signal processing and speech recognition, speech and auditory physiology

Karl Hess
Hot carriers in semiconductors, electronic transport in heterojunction structures and superlattices, numerical simulation of semiconductor devices (supercomputing applications), quantum transport in mesoscopic systems, laser diode simulation, molecular and electron nanostructures, theory and simulation, deuterium processing and MOS reliability, quantum computing, theorem of Bell

Nick Holonyak, Jr.
Semiconductors, semiconductor device physics, semiconductor crystal growth and junction formation, diffused Si devices, SCRs, TRIACs, double injection, luminescence, light emitting diodes (LEDs), heterojunctions, lasers, tunnel diodes, compound semiconductors, quantum well heterostructures, superlattices, quantum well lasers, impurity-induced layer disordering, Al-based III-V native oxides and their use in heterostructures devices

Kuang C. Hsieh
Semiconductor materials/devices processing and characterization

Thomas S. Huang
Image processing, image compression, computer vision, human computer interaction, image and video databases

Seth Hutchinson
Robotics, computer vision, artificial intelligence

Wen-Mei Hwu
Architecture, compilation and microarchitecture of high performance parallel computer systems

Ravishankar K. Iyer
Design and evaluation of reliable and secure networks and systems, computer measurement and modeling, dependability and security validation and benchmarking

Kanti Jain
Microelectronic, optoelectronic, microsystem and biophotonic devices; novel micro and nanofabrication technologies

Jianming Jin
Computational electromagnetics, finite element methods, electromagnetic analysis and design in magnetic resonance imaging, wave scattering and propagation, electromagnetic interference and compatibility, microwave and millimeter wave circuits, antennas and electromagnetic theory

Douglas L. Jones
Digital signal processing, time-varying and time-frequency analysis, signal processing for communications, binaural hearing aids, signal processing for MEMS

Farzad Kamalabadi
Remote sensing and imaging, multidimensional signal and image processing, signal reconstruction and tomography, ionospheric and space physics

Kyekyoon (Kevin) Kim
Growth of GaN-based compound semiconductors and fabrication of optoelectronic and electronic devices using plasma-assisted MBE; plasma-arc-driven electromagnetic railgun for fueling of plasma devices; charged liquid cluster beam generation and application to thin film deposition, micropattern generation, and nanoparticle fabrication; generation of solid and hollow, charged and neutral, monodisperse, micro- and nanospheres for biomedical and other applications; plasma display panels; development of novel thin film deposition techniques using plasmas, charged particles, electrostatic spraying, and their combinations with other techniques; MEMS and sensors; ionized source (cluster) beam deposition for low-temperature growth of high-quality films; inertial confinement fusion targets
Ralf Koetter
Practical and theoretical aspects of coding theory, complexity, algorithms, communication systems, networks

Philip T. Krein
Power electronics, electric machinery and electromechanics, electric and hybrid vehicle systems

Erhan Kudeki
Radar remote sensing; atmospheric winds, waves, and turbulence; ionospheric plasma instabilities; incoherent scatter electric field measurements; midlatitude field aligned irregularities and meteor trails

P. R. Kumar
Wireless networks, sensor networks, convergence of control, communication and computation, semiconductor manufacturing, manufacturing systems, machine learning, adaptive systems, control, stochastic systems

Jean-Pierre Leburton
Theory of semiconductor devices, modeling and simulation of nanostructures, electronic and optical properties of heterostructures and low dimensional systems, transport in quantum structures, electronic properties, charging effects in quantum dots and nanocrystals, spin effects in nanostructures, quantum computation and quantum information processing, nano-bio-electronics

Stephen Levinson
Speech processing, language acquisition, natural language understanding, speech synthesis

Zhi-Pei Liang
Magnetic resonance imaging, pattern recognition, statistical learning, bioinformatics

Daniel Liberzon
Nonlinear control theory, analysis and synthesis of hybrid dynamical systems, systems with imprecise measurements and/or modeling uncertainty, stochastic differential equations and control

Chang Liu
MEMS, microsensors, microintegrated fluidics systems, MEMS for nanotechnology, wireless interface for sensors, sensitive skin

Michael C. Loui
Computational complexity theory, ethics in engineering and computing, scholarship of teaching and learning

Steven Lumetta
Optical network architecture, computer architecture, cluster computing, parallel computing, user-level communication, validation and reliability

Joseph W. Lyding
Scanning tunneling microscopy and spectroscopy, STM-based nanolithography and nanofabrication, silicon-based molecular electronics, carbon nanotubes and carbon-based nanotechnology merged with silicon, growth of 3-D silicon nanostructures, deuterium processing and hot electron degradation in semiconductor devices, atomically precise dopant mapping, cross-sectional STM of semiconductor heterostructures, oxide silicon interface mapping, carbon nanotube purification

Yi Ma
Computer vision, including multiple view geometry, structure from motion, dynamic vision, real-time tracking, and active vision; systems theory, including geometric nonlinear control, hybrid systems, vision-based robotic control and navigation

Jonathan Makela
Ionospheric physics, especially irregularities at low- and mid-latitudes and their effects on trans-ionospheric satellite signals, response of the Earth's ionosphere to geomagnetic storms; optical and radio remote sensing techniques from ground- and satellite-based platforms

Sean Meyn
Optimal control, Markov processes (with or without control), stochastic approximation and adaptive control, reinforcement learning and simulation, spectral theory and large deviations, information theory, stochastic networks

Eric Michielssen
Computational electromagnetics, fast integral equation-based solvers algorithms in both the frequency and time domains, and robust design paradigms; analysis and design of electromagnetic and optical systems (antennas, filters, interconnects, platform, terrain, plasmonic devices, and so forth)

Pierre Moulin
Image and video processing, compression, statistical signal processing, information hiding, information theory

David Nicol
Cyber-security, modeling and analysis of computer and communications systems, high performance simulation, parallel processing
Burks Oakley II
Applications of computer-aided learning in the undergraduate engineering curriculum

William D. O'Brien, Jr.
Ultrasonic biophysics and bioeffects, acoustic microscopy, ultrasonic bioengineering, ultrasonic dosimetry, ultrasonic tissue characterization, acoustic imaging techniques

Michael L. Oelze
Ultrasound, including backscatter microscopy, quantitative imaging, computed tomography; use of ultrasound for cancer diagnosis and therapy; bioeffects of ultrasound; sonoporation; coded excitation and ultrasound

Thomas Overbye
Power systems operation and control, power system stability, power system analysis by computer methods, power system visualization

Mangalore A. Pai
Power system stability, dynamic security of power systems, model reduction in power systems, iterative solver techniques in power system computations, voltage stability, impact of distributed generation in power systems

Sanjay Patel
Computer architecture, microarchitecture, high-performance and reliable computer systems, the implications of future generation applications and implementation technologies on systems design

Janak H. Patel
VLSI testing and testability, VLSI design automation

William R. Perkins
Control systems, system theory, sensitivity theory and robust control, large-scale dynamic systems

Constantine D. Polychronopoulos
Parallelizing/optimizing compilers for multithreaded architectures, program restructuring and optimization; code generation and optimization for superscalar processors; parallel programming languages; environments for parallel programming; partitioning, scheduling, and run-time environments for parallel computers; multiprocessor operating systems with multithreading support; parallel computer architectures; performance evaluation of parallel architectures

N. N. Rao
Ionospheric propagation, radiolocation

Umberto Ravaioli
Monte Carlo simulation of high speed electronic devices; numerical methods for semiconductor device simulation; quantum devices; supercomputation and visualization; reliability of MOS devices; micro- and nano-electromechanical systems (MEMS and NEMS); charge transport in biological systems (ionic channels); properties of carbon nanotubes

Elyse Rosenbaum
Design of ESD-protected RFICs, modeling and simulation of ESD protection circuits, silicon-on-insulator, design of very high speed I/Os, gate oxide reliability

William Sanders
Dependability, security, and performance evaluation; intrusion- and fault-tolerant systems; reliable and secure distributed systems

Dilip V. Sarwate
Communications, coding theory, spread-spectrum communications, design of algorithms

Peter W. Sauer
Electric machinery modeling, analysis and control, power system dynamic modeling and simulation, power system stability

Jose Schutt-Aine
Electronic packaging, microwave theory and measurements, and digital circuit modeling, including integration of modeling and simulation tools, high-performance computation for simulation of packages, applications of V-shaped transmission lines

Naresh Shanbhag
Design and VLSI implementation of low-power, high-performance multimedia digital signal processing and communications systems, noise-tolerant deep submicron VLSI systems, fundamental bounds on efficiency of VLSI information processing systems, power-aware reconfigurable DSP systems, low-power DSP and circuits, DSP and communication system design, digital ASIC design

Yoshihisa Shinagawa
Computer graphics, vision, and its applications

Andrew Singer
Statistical signal processing, communications, machine learning, data compression, sonar/lidar/optical signal processing
Mark W. Spong  
Nonlinear control theory, robotics, mechatronics, networked control systems, teleoperation, bipedal locomotion

Rayadurgam Srikant  
Internet, wireless networks, sensor networks, game theory, queueuing theory, information theory

Gary Swenson  
Remote sensing of the atmosphere from ground-based, aircraft, and spacecraft using optical methods; space environment issues with a particular emphasis on spacecraft glows

Gregory Timp  
Fabrication, development, and characterization of the performance of silicon MOS nanotransistors to discover the fundamental limitations of the silicon MOSFET; atomic physics and light pressure forces on single atoms for lithography applications; mesoscopic and nanostructure physics, including measurement of the low temperature transport characteristics of high electron mobility transistors that resemble electron waveguides; Hopping (thermally-assisted tunneling) conductivity of localized electrons in a two dimensional impurity band formed in the inversion layer of a silicon metal-oxide-semiconductor field effect transistor (MOSFET); the effect of superlattices on lattice-dynamical properties of graphite intercalation compounds using Raman scattering, extremely high field magnetoresistors, Schubinkov-deHaas effect (using high resolution microscopy), high resolution x-ray scattering; nanometer-scale lithography to probe biological function

Timothy N. Trick, Emeritus  
Computer-aided analysis and design of circuits, computer-based education

John Tucker  
Metal silicde source/drain MOS transistors at ~10nm gate length, atom-scale electron devices made by STM patterning of donors in silicon, nanoscale architectures

Nitin Vaidya  
Wireless networking, mobile computing, fault-tolerant computing

Venu Veeravalli  
Distributed wireless sensor systems, wireless packet data networks, channel modeling for wideband multiantenna wireless systems, information theory for wireless communications, wireless code division multiple access (CDMA) systems, radio resource management for wireless networks, decentralized dynamic decision making, sequential multihypothesis testing and change-point detection

Pramod Viswanath  
Communication theory, wireless communication, information theory, communication networks

Benjamin W. Wah  
Nonlinear optimization, parallel processing, distributed processing, artificial intelligence, computer networks, multimedia signal processing

Andrew Webb  
RF coil design, functional imaging agents, magnetic resonance microcoils, thermal mapping using MRI, functional magnetic resonance imaging

Bruce C. Wheeler  
Analysis of multichannel neural signals, microminiature sensors for neural recording, algorithms for enhanced hearing aids, patterned growth of neurons

Martin Wong  
Computer-aided design of VLSI, design for manufacturing, routing for high-speed packaging, field-programmable systems, design and analysis of algorithms, combinatorial optimization

Jianhua (David) Zhang  
Lasers and laser spectroscopy, electromagnetics, plasma diagnostics, optics, cryogenics, electric and electronic circuits
Advanced Automation

Acquisition, Compression and Interpolation of Panoramic Stereo Images of a Scene for Remote Walkthroughs
N. Ahuja,* Y. Shinagawa,* M. Maitre, A. Jagmohan
n-ahuja@uiuc.edu
National Science Foundation, ECS 02-25523
Conducted in the Coordinated Science Laboratory
This project is aimed at producing novel images of a scene from arbitrary new viewpoints using a sparse set of panoramic snapshots or sample images of the scene. The samples are taken from a relatively small number of strategically placed cameras. A major application and evaluation testbed of the proposed work is to enable walkthroughs of a 3-D scene by generating the images of the scene along a trajectory chosen by a remote user dynamically.

Automated Visual Learning of Safety Appliances on Railcars
N. Ahuja,* C. Barkan,* J. M. Hart, C. B. Liu
n-ahuja@uiuc.edu
American Association for Railroads
Conducted in the Coordinated Science Laboratory
This project is aimed at the development of visual learning techniques and their implementation for automatic checking of the state of safety appliances on a moving train. This consists of the following stages: acquisition of images of railcars for inspection of the safety appliances located on the railcar sides; identification of image characteristics associated with the health of the safety appliances; identification of types of models useful to represent the railcar appearance when the safety appliances are in satisfactory condition, and if necessary, to represent unsatisfactory condition as well; application of models to learn the descriptions of safe and unsafe appliances; and application of the results of learning to railcar classification.

Globally Coordinated Locally Linear Models
N. Ahuja,* H. Arora, A. Briassouli
n-ahuja@uiuc.edu
Office of Naval Research
This project is aimed at modeling spatiotemporal variations in video sequences such as variations in raw color values, as well as certain functions computed on these values. Since an arbitrary scene consists of distinct objects occupying different parts at different times, making video sequences nonstationary, the goal is local rather than global spatiotemporal modeling. The applicability of the models being developed extends beyond video, to a variety of multivariate, multidimensional data encountered in everyday life.

Machine Vision for Improved Safety Inspection of Railcars
N. Ahuja,* C. Barkan,* A. Kumar
n-ahuja@uiuc.edu
Transportation Research Board
It is vital to rail safety to ensure that critical mechanical components are in good working order at all times. However, currently much of inspectors’ time is expended inspecting items that are in good working order. This project is aimed at the development of a machine vision system for wayside automatic inspection of railcars, using an advanced camera system that images each railcar truck as a train passes by, and then using machine vision algorithms to analyze these images for detecting worn or defective components.

Machine-Vision Based Assessment of Intermodal Railroad Loading Patterns
N. Ahuja,* C. Barkan,* J. M. Hart, S. Todorovic, P. Vemuru
n-ahuja@uiuc.edu
Burlington Northern Santa Fe
Conducted in the Coordinated Science Laboratory
This project is the design and implementation of a computer vision system for automatic assessment of the loading pattern of trains passing by a wayside monitoring station. The research is concerned with the following major areas: development of algorithms for automatic inspection of double stack railcars, identification of advanced imaging sensors to enhance algorithm performance, field testing of the algorithms and sensors, and the development of a field deployable wayside system to demonstrate a proof of concept. The system needs to have the following capabilities: to image parts of a moving train, to identify specific double stack cards in the train, to analyze key portions of these images to detect the presence or absence of loaded containers, and to detect occurrences of double stack loading.

* Denotes principal investigator.
Next-Generation RFID Systems: People and Object Tracking for Homeland Security Applications
N. Ahuja,* J. Bernard, * G. Horn, R. Jaehne,* V. Kindratenko,* S. Patel,* N. Vaidya,* T. Yu, B. Ghanem
n-ahuja@uiuc.edu
University of Illinois

This project is aimed at developing methods for tracking and localization of people in buildings. A central feature of the proposed work is the use of Radio Frequency Identification (RFID) tags. Current RFID technology has inadequate reliability, particularly for homeland security applications. The goal of this project to pursue research on next-generation RFID systems, in collaboration with application domain experts at the Illinois Fire Service Institute, e.g., to help firefighters and other first responders do their jobs more effectively.

Recognition and Contents-Based Retrieval of Hand Gestures from Video
N. Ahuja,* A. Briassouli, A. Sehgal
n-ahuja@uiuc.edu
U.S. Office of Naval Research, N00014-03-1-0107
Conducted in the Coordinated Science Laboratory

This project is concerned with recognition of scenes from the spatiotemporal structure of the video data. Trajectories of scene contents seen in the video sequence are used as the basis for this purpose. Objects are characterized by their spectral properties as well as temporal behavior. Such representations are used for information access as well as for recognition using such methods as support vector machines.

Scale Dependent Processing of Clustered Sensory Signals
N. Ahuja,* A. Feng,* M. Nelson,* C. Gao, H. Arora
n-ahuja@uiuc.edu
National Science Foundation, NSF ISBN 04-22073
Conducted in the Coordinated Science Laboratory

The broad objective of this proposal is to understand the computational algorithms used by animals to extract individual signals that are embedded in a cluster of similar signals. Our major hypotheses are: that characteristics of the received signal and the separability of individual components will vary as a function of distance from the cluster; that computational algorithms for detection, localization, and identification should reflect these scale-dependent changes; and that motor strategies and sensory filtering properties should be adaptively adjusted when processing sensory signals at different distance scales.

Real-Time Path Planning in Changing Environments
S. Hutchinson*
National Science Foundation
Conducted in the Coordinated Science Laboratory

New methods are proposed to generate collision-free paths for robots that operate in environments that change over time. The proposed approach is related to recent probabilistic roadmap approaches. These planners use preprocessing and query stages and are aimed at planning many times in the same environment. In contrast, the preprocessing stage for this research creates a representation of the configuration space that can be easily modified in real-time to account for changes in the environment. As with previous approaches, the proposed approach began by constructing a roadmap in the configuration space, but this roadmap is not constructed for a specific workspace. Instead, it is constructed for an obstacle-free workspace, and the mapping from workspace cells to nodes and arcs in the roadmap is encoded. When the environment changes, this mapping is used to make the appropriate modifications to the roadmap, and plans can be generated by searching the modified roadmap. At the heart of the method is the encoding for mapping workspace obstacles to configuration space obstacles. To make the proposed approach truly viable, a major component of the proposed research will focus on robustness and complexity issues. These issues will be addressed by using tools from the fields of image processing, information theory, graph theory, computational geometry, and incremental algorithms.

Advanced Processing and Circuits

AlGaN/GaN HFET Fabrication and Characterization
I. Adesida,* V. Kumar, A. Kuliev
Triquint Corporation
Conducted in the Micro and Nanotechnology Laboratory

This project involves a collaboration with Triquint Corporation on the fabrication of AlGaN/GaN HFETs. Technologies for the fabrication of the HFETs will be developed.
Gallium Nitride Optoelectronics
I. Adesida,* L. Zhou
Defense Advanced Research Projects Agency,
DAAD19-99-1-0011
Conducted in the Micro and Nanotechnology Laboratory
This project focuses on experimental issues for the fabrication of novel optoelectronic devices and circuits in gallium nitride and related materials. UV detectors, field effect transistors, and heterojunction bipolar transistors will be investigated. Methods for integrating these devices will also be explored.

Porous GaN: Production, Characterization, and Applications
I. Adesida,* P. Bohn,* X. Li,* S. Kim
U.S. Office of Naval Research, N00014-01-1
Conducted in the Micro and Nanotechnology Laboratory
This program involves the generation and characterization of porous GaN and SiC for applications in growth of high quality epitaxial layers. Matrices with dimensions down to 50 nm are to be achieved for the porous materials.

Processing of Gallium Nitride and Related Compounds
I. Adesida,* L. Zhou, F. Khan
ATMI/Air Force
Conducted in the Micro and Nanotechnology Laboratory
This program consists of the development of viable processing methods for gallium nitride and related compounds. A systematic study of etching techniques, ohmic contact formation, and other metallizations will be conducted and applied to devices.

Resonant Enhanced Modulators
I. Adesida,* S. Rommel
Air Force; Sarnoff Corporation
Conducted in the Micro and Nanotechnology Laboratory
This is a collaborative program with Sarnoff Corporation on resonant enhanced modulators in InP-based heterostructures. Waveguides with coupling rings are to be fabricated and characterized in InP-heterostructures. High precision patterning using inductively coupled plasma reactive ion etching and electron beam lithography will be used in fabricating the modulators.

Silicon-Germanium Modulation-doped Field Effect Transistors
I. Adesida,* K. Ismail*
National Science Foundation, ECS 97-10418
Conducted in the Micro and Nanotechnology Laboratory
This collaborative program with IBM Corp. is intended to significantly advance the growth and fabrication technologies for SiGe/Si modulation-doped field effect transistors (MODFETs) needed for low-power, high-speed microwave and digital applications. Specific goals are to study the physics of short gate-length p-type, n-type, and complementary MODFETs and to demonstrate simple circuits.

Ultra-High-Power GaN Power Amplifier at X-Band
I. Adesida,* W. Lu, D. Selvanathan
Air Force; TRW Corporation
Conducted in the Micro and Nanotechnology Laboratory
This collaborative project with TRW Corporation is to fabricate an ultra-high-power GaN-based HFET amplifier on SiC at X-Band. Various processing techniques for GaN will be developed as part of this project.

Aeronomy

Engineering Services and Utilities for ST Radar Operation at the Sidney Field Station
E. Kudeki,* S. Henson
National Science Foundation; SBC Utah State University
Conducted in the Coordinated Science Laboratory
This grant concerns the operation of an ST radar at the university's Sidney Field Station. Tropospheric and stratospheric wind, reflectivity, and aspect sensitivity measurements to be conducted with the Sidney radar will complement similar measurements conducted by similar radars operated at the Urbana Atmospheric Observatory and Bondville Field Station. The three-radar network will be used in correlative studies of atmospheric gravity wave propagation in the troposphere and the lower stratosphere as well as phenomena associated with the evolution and dynamics of weather fronts.

* Denotes principal investigator.
Engineering Services and Utilities for the Bondville Field Station
E. Kudeki,* S. Henson
National Oceanic and Atmospheric Administration, 52 RANR 100075
Conducted in the Coordinated Science Laboratory
Continuous operation of the FLATLAND ST (stratosphere-mesosphere) radar administered by NOAA is maintained at the Bondville Field Station. The FLATLAND radar, operating at a frequency of 50 MHz, has been designed to investigate the dynamics of the atmosphere above a plain area with insignificant orographical forcing. The routinely measured reflectivity profiles and Doppler spectra are collected in a NOAA database. Joint measurements with the Urbana Field Station MST radar are performed to investigate the horizontal scale lengths of atmospheric gravity waves and to follow the transit of weather fronts.

Radar Studies of the Equatorial Ionosphere
E. Kudeki,* E. Chapin, S. Bhattacharyya, J. Urbina
National Science Foundation, ATM 90-22400
Conducted in the Coordinated Science Laboratory
The 50 MHz Jicamarca Radio Observatory located near Lima, Peru, is used to investigate the structure and dynamics of the equatorial ionosphere. In the mesosphere ionospheric D region, investigations aim to resolve the internal structure of narrow echoing layers and determine the relevant scattering/reflection mechanisms. In the higher ionosphere, E- and F-region plasma drifts, instabilities, and turbulence are under study. Current projects include efforts to quantify the anisotropies of equatorial plasma turbulence, obtain interferometric images of plasma irregularity structures, and measure the component of ionospheric drifts in the geomagnetic field direction. Major research effort is dedicated to the refinement of radar techniques suitable for these studies.

Applied Computation Theory
Development of Professional Identities of Engineering Students
M. Loui,* G. Hashemiam
Carnegie Foundation for the Advancement of Teaching
Conducted in the Coordinated Science Laboratory
This project exhibits the development of students' conceptions of themselves as professional engineers, particularly their understandings of engineers' ethical obligations. We have documented the effect of an engineering ethics course on students' understandings of professional responsibility and potential for moral courage.

Ethical Implications of Biases and Errors in Geographic Information Systems
M. C. Loui,* C Graeff
University of Illinois
Conducted in the Coordinated Science Laboratory
Geographical information systems combine traditional maps with additional data. The design and use of a geographic information system (GIS) can introduce a variety of biases and errors. We identified and classified biases and errors in GIS data that arise inevitably from limits on the accuracy of gathered data, from limits on the precision of measuring instruments and display technologies, and from the combination of data in incompatible formats from multiple sources. We explained how designers and users of a GIS can work with these inherent biases and errors in a professionally responsible way.

National Institute for Engineering Ethics Video Project: A Sequel to Gilbane Gold
National Science Foundation, SES-0138309
Conducted in the Coordinated Science Laboratory
We have developed a new video, "Incident at Morales," to dramatize a fictional but realistic case study in engineering ethics. The new video is directed to a broad audience, including engineering students, practicing engineers, and others who work with engineers. It focuses on ethical aspects of engineering decisions. Because of the globalization of the economy, the new video shows a case in an international context. We are assessing the pedagogical effectiveness of the video.

Studies in Algorithms and Complexity Theory
M. Loui,* E. Echevarria, S. Pae, M. Roman, M. Rosulek
University of Illinois
Conducted in the Coordinated Science Laboratory
We studied the optimal generation of random numbers using a discrete random source. When the source distribution is unknown, we characterized the optimal functions and showed that they can be computed efficiently. When the source distribution is unknown, we proved that it is impossible to construct an optimal tree algorithm recursively, using a model based on algebraic decision trees. We proved that no circuit family can

* Denotes principal investigator.
approximate the permanent function unless the polynomial hierarchy collapses. We constructed a set that splits every NP-complete set into subsets that cannot be reduced to each other unless \( P = NP \).

**Student Misconceptions in an Introductory Digital Logic Design Course**  
C. Zilles,* J. Longino, M. Loui  
*University of Illinois*  
*Conducted in the Coordinated Science Laboratory and in the Department of Computer Science*

We are developing a concept inventory in digital logic design. We interviewed students who had taken an introductory digital logic course to determine common student misconceptions. Based on the interviews, we developed and administered a prototype assessment tool.

**Bioacoustics**

**Development of Intelligent Hearing Aid**  
A. Feng* (Physiol.); D. L. Jones, B. C. Wheeler,  
W. D. O'Brien; C. Lansing,  
R. Bilger (Speech & Hearing)  
Phonak, Inc.  
*Conducted in the Beckman Institute for Advanced Science and Technology*

This project aims to refine binaural signal processing algorithms for hearing aids so that they are suitable for real-time implementation in a commercial hearing aid. Also studied is wireless communication between hearing aids and support devices located on the body.

**High-Intensity Ultrasound for Prostate Treatment**  
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frizz@uiuc.edu  
*National Institutes of Health, CA81340; SBC Interscience Research, Inc.*  
*Conducted in the Beckman Institute for Advanced Science and Technology*

In this study, ultrasound phased arrays are being developed for high intensity ultrasound treatment of prostate disease. These arrays will allow electrical scanning of the focus and will replace currently used transducers that must be mechanically scanned. The design will use a cylindrically shaped array with elements larger than a wavelength to keep the number of elements to a reasonable level and thereby reduce the cost and complexity of manufacture. The goal is to determine an optimal design that will minimize the effects of grating lobes by varying the spacing and size of the elements.

**Advanced Hearing Protection**  
W. D. O'Brien, Jr.*, C. R. Lansing, Y. Liu, X. Yin  
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*U.S. Air Force Office of Scientific Research, F49620-03-1-0188*  
*Conducted in the Beckman Institute for Advanced Science and Technology*

The objective is to develop an understanding, based on first principles, of the reception and conduction paths of very-high-amplitude airborne sound levels (about 150 dB) to the inner ear by soft and hard tissues in order to design an advanced hearing protector device. The computational goal is to develop an acoustic propagation model using well understood and documented computational techniques that will model propagated acoustic signals around and inside the human head. Modeling of acoustic diffraction around stationary and moving complex geometries will be accomplished with finite-element analysis (FEA). This model will take into consideration the effects of diffraction of sound around the human head and the direction from which the sound has traveled from the acoustic source to the human head.

**Evaluation of Inertial Cavitation's Role in Sonoporation**  
W. D. O'Brien, Jr.*, J. F. Zachary* (Pathobiol.),  
M. M. Forbes (Bioengr.)  
*Internal Funds*

The objective of this interdisciplinary research project is to examine and characterize how the interaction of a contrast agent with ultrasound alters the cell membrane to large molecules. A significant problem in cancer therapy is the compromised quality of life experienced by the patient due to the side effects of the therapeutic compounds. Delivery of molecular medicine to solid tumors is often inefficient and as a result, the patient’s healthy cells and tissues are subject to the toxic effects of the drugs. Thus, it is important to develop approaches that deliver drugs to the appropriate cells within the patient in a way that is specific, efficient, and safe. One such method involves the use of ultrasound to enhance cell permeabilization. With this method it is possible, by using ultrasound and contrast microbubbles, to deliver therapeutic compounds noninvasively into specific target cells.

* Denotes principal investigator.
**In Vivo Ultrasonic Microprobe for Tumor Diagnosis**  
W. D. O’Brien, Jr.,* J. F. Zachary* (Pathobiol.),  
D. L. Jones, M. A. Haun, M. L. Oelze  
National Institutes of Health, National Cancer Institute,  
CA079179  
Conducted in the Beckman Institute for Advanced Science  
and Technology  
The objective of this interdisciplinary research program is  
to develop the basis for a fundamentally new sensor  
technology for an in situ evaluation of solid tumors with  
the expectation of rapid and accurate detection and  
diagnosis of cancer. The specific goal is to develop an in  
vivo ultrasonic microprobe sensor that operates at  
ultrasound frequencies up to 300 MHz and image  
resolution to 5 micrometers. With these sensor and imaging  
capabilities, research is scheduled to assess differences in  
acoustic cytoarchitectural features of normal tissues from  
neoplastic tissues at the cellular level.

**Inertial Cavitation and Neovascularization**  
W. D. O’Brien, Jr.,* J. F. Zachary* (Pathobiol.),  
M. L. Oelze,  
C. A. Johnson (Biophysics & Computl. Biol.),  
R. J. Miller, J. P. Blue  
Beckman Institute for Advanced Science and Technology  
The objective of this interdisciplinary research project is to  
examine and characterize how the interaction of a contrast  
agent with ultrasound alters the expression of vascular  
growth factor molecules following capillary injury. The  
generation of these data will allow for a more clear  
understanding of the safety issues surrounding the use of  
ultrasound contrast agents to assess blood flow and  
myocardial perfusion in human patients. Microbubble  
ultrasound contrast agents are valuable diagnostic tools for  
physicians, but their use must be considered in the context  
of risk-benefit assessment for each patient. The medical  
significance of and long-term potential benefits from the  
use of ultrasound contrast agents are clear; however,  
concerns related to their “safe use” have been raised  
because of reports of microbubble ultrasound contrast  
agent-induced vascular injury. Currently, the medical  
significance and pathogenesis of such phenomena are not  
clearly understood. Because ultrasound contrast agents are  
poised to be used to assess myocardial and skeletal muscle  
perfusion, the results of our study are an early step in  
developing an understanding of the primary bioeffects  
(injury) of ultrasound contrast agent on capillary beds of  
the heart and circulatory system.

**Novel Methods for Aberration Correction in Medical Ultrasound**  
W. D. O’Brien, Jr.,* D. L. Jones,* M. A. Haun  
University of Illinois Research Board  
Conducted in the Beckman Institute for Advanced Science  
and Technology  
The objective is to develop aberration correction  
techniques for medical ultrasound that will allow imaging  
through any type of biological tissue, in the presence of  
large variations in the sound propagation speed. One  
element of this would be ultrasonic imaging and surgery  
in the brain, which is impossible today because of skull-  
induced distortion. The interdisciplinary project  
icorporates expertise in the areas of medical ultrasound  
and signal processing. The project’s purpose is to conduct  
the preliminary studies of a new ultrasonic imaging  
capability that would yield a significant improvement in  
spatial resolution, an improvement that could be as much  
as a factor of 10 better than what is currently achievable.  
If this were accomplished, the diagnostic capability of  
medical ultrasound would experience a significant  
improvement.

**Temperature Estimates During Diagnostic Ultrasound Exposures**  
W. D. O’Brien, Jr.,* J. F. Zachary (Pathobiol.),  
T. A. Bigelow  
Beckman Institute Research Assistantship to T. A. Bigelow  
Conducted in the Beckman Institute for Advanced Science  
and Technology  
The goal is to develop a quantitative assessment of tissue  
temperature increase under in vivo and in utero ultrasound  
exposure conditions, thereby providing the capability for  
the medical professional to know the temperature increase,  
and hence the risk of the desired diagnostic exposure. Of  
particular importance is the heating near the developing  
cranial bone because heating of the developing brain tissue  
can result in long-term neurological disorders. There is a  
fundamental trade-off between the improved diagnostic  
capability and the resulting increased risk. The risk from  
a diagnostic ultrasound procedure is well understood by  
medical professionals provided that the risk can be  
appropriately identified and quantified.

* Denotes principal investigator.
Ultrasound Contrast Agents; Dynamic Physical Behavior and Bioeffects
W. D. O'Brien, Jr.,* P. Laugier* (Université Pierre et Marie Curie, UMR C.N.R.S. 7623, Paris)
University of Illinois-Centre National de Las Recherche Scientifique Collaborative Research Program

Conducted in the Beckman Institute for Advanced Science and Technology

The objective of the program is to develop a collaborative interaction between the two research groups that will investigate the physical interaction mechanisms between ultrasound and contrast agents. The two research programs are the Bioacoustics Research Laboratory, Department of Electrical and Computer Engineering, University of Illinois and Laboratoire d'Imagerie Paramétrique, Université Pierre et Marie Curie–Paris 6, Paris, France. Both research programs have contributed significantly to the capabilities of diagnostic imaging. During the last decade, ultrasonic contrast agents have provided clinical ultrasonic imaging with a new and powerful capability to image structures not previously possible. These agents are made of small microbubbles (< 5 µm in diameter) that are administered into the vascular system of the body to enhance ultrasound image contrast. Ultrasound contrast agents are used as adjuncts in routine ultrasound evaluations to enhance sonographic contrast and thus increase the opportunity for early detection, diagnosis, and treatment of a variety of disease processes including heart disease and cancer. Concerns about the potential bioeffects of inertial cavitation associated with the interaction of ultrasound with contrast agents in human beings have been reported. The center topic involved in this cooperative program between the two research programs is the connection between bioeffects and the bubbles responses to ultrasonic insonification.

Ultrasound-Induced Lung Damage Assessment
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The objective of this interdisciplinary research program is to evaluate a significant ultrasound-induced biological effect of lung tissue. It is known that diagnostic ultrasound exposure conditions can produce damage to lung tissue in a limited number of animal species. Thus, the emphasis of the program is to conduct both experimental and theoretical evaluations in order to develop a fundamental understanding of the mechanisms responsible for producing lung damage and from this understanding provide a best-case extrapolation to the likelihood of similar damage in humans.

Biomaterials Characterization with High-Frequency Ultrasound Computed Tomography
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3M Corporation

Conducted in the Beckman Institute for Advanced Science and Technology

The objective is to evaluate diffraction tomography algorithms applicable to soft tissue scattering, construct a high-frequency ultrasound computed tomography scanning device, and evaluate model biological systems for scanning. An ultrasound frequency of up to 100 MHz yielding resolution of 12 to 15 micrometers will be used. Elastic properties of cell models, other kinds of tissues, and synthetic biomaterials will be imaged and quantified. The high-resolution, quantitative information that the high-frequency ultrasound computed tomography device can yield will be beneficial for many kinds of research into properties and functioning of materials.

Tumor Diagnosis through Enhanced Ultrasound Imaging
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National Institutes of Health, National Cancer Institute, F32CA96419

Conducted in the Beckman Institute for Advanced Science and Technology

The objective is to develop and refine a fundamentally new approach to enhance ultrasound imaging of biological tissues by the quantification of tissue microstructure through acoustic backscatter. This enhanced imaging technique will then be adapted for real-time in situ clinical diagnosis of solid tumors with the expectation of producing acoustic images that will provide an accurate diagnosis of cancer. Use of enhanced ultrasound imaging is medically significant because it offers a quick and noninvasive means of detecting and classifying tumor types.

* Denotes principal investigator.
Development and Information Processing in 3-D Patterned Neural Circuits
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National Science Foundation
Conducted in the Beckman Institute for Advanced Science and Technology
This is a subcontract from Georgia Tech University under the group title "A 3-D Microfluidic/Electronic Neural Interface System: In Vitro Studies of Neural Networks, Plasticity and Injury," sponsored by the National Institutes of Health Bioengineering Research Partnership Program. The group proposal is to develop an instrumented three-dimensional neural culture system with optical, microfluidic, electrical, and electronic interfacing so that experimenters may develop a more sophisticated model of how the brain works. The University of Illinois effort is to extend currently successful two-dimensional patterning technology to three dimensions and to evaluate the predicted increase in the functionality and health of the neurons.

Information Processing in Designed Neuronal Circuits
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This research aims to design and grow neuronal networks from living neurons in patterns with micrometer resolution. Further, the networks will be grown on microelectrode arrays so that they can be stimulated and recorded electrically. Finally, the coding, computational, and learning principles for these networks will be studied.

Physical Exercise, Mental Activity, and Brain Plasticity
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National Institutes of Health, PHS 2R01 AG10154-07
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Researchers propose to use morphological and morphometric, electrophysiological, immunocytochemical, and behavioral methods in mature adult and aging cerebellar cortex to determine which synapse and neuron types in cerebellar cortex exhibit plasticity in response to learning and to physical exercise; which nonneuronal elements exhibit plasticity; the molecular mechanisms underlying this plasticity; and functional correlates.

A Database System for Neuronal Pattern Analysis
B. C. Wheeler, M. Gabriel,* W. T. Greenough; J. Malpeli (Psychol.); M. Nelson, A. Feng; R. Gillette (Physiol. & Biophys.)
National Science Foundation, DBI 9116763
Conducted in the Beckman Institute for Advanced Science and Technology
Neuronal pattern analysis documents the dynamic brain processes of sensation, perception, learning, and cognition by recording the electrical activity of brain neurons. Recent advances in multiarray recording have greatly expanded the rate at which these data can be obtained, making possible the study of dynamic intercorrelations in neuronal networks. Computational modeling has fostered major increments in data processing requirements, which call for parallel development of adequate database systems for organization, rapid access, and sharing of these data. This work establishes a database system for time series neurophysiological data recorded by the Neuronal Pattern Analysis Group at the Beckman Institute for Advanced Science and Technology, carried out with collaboration from the National Center for Supercomputing Applications.

Novel 3-D Histologic Methodology to Identify Ultrasound Scattering Sites in Tissue
J. F. Zachary* (Pathobiol.), W. D. O'Brien, Jr.,* J. Mamou, M. L. Oelze
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University of Illinois Research Board
Conducted in the Beckman Institute for Advanced Science and Technology
The objective of this interdisciplinary research project is to quantify microscopic tissue structures responsible for ultrasound scattering. It is, in part, these microscopic tissue structures that pathologists use to diagnose disease. Our hypothesis is that tissue microstructure (e.g., size, shape, concentration, and ultrasonic properties) of pathologic tissue (e.g., solid tumors) is measurably different from that of the surrounding healthy tissues, thus providing image contrast. The approach is to construct 3-D microscopic tissue models from normal and pathologic tissues, and from these computational phantoms, compare the theoretical ultrasound scattering from 3-D acoustic impedance maps with experimental scattering results.

* Denotes principal investigator.
Circuits

An Integrated Design Methodology for Low-Power DSP and Communications Systems
I. N. Hajj,* N. R. Shanbhag,* S. Bobba
National Science Foundation, MIP-9710235
Conducted in the Coordinated Science Laboratory
The goal of this project is to develop an integrated computer-aided design (CAD) approach for the design of low-power hardware for digital signal processing (DSP) and communications applications. The approach incorporates high-level (algorithmic) and low-level (circuit) parameters and includes novel capabilities for design exploration and low-power circuit synthesis. The design exploration will be done by developing low-power constrained algorithm design procedures that employ an analytic relation between word-level and bit-level signal statistics. The synthesis effort will incorporate signal statistics, high-level hardware models, and algorithm transformations to generate low-power dedicated implementation of DSP algorithms.

Full-Chip Simulation of Charged Device Model ESD
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The capability to perform circuit simulation of ESD events increases the number of parts that pass ESD Qualification on the first try. The charged device model (CDM) best represents yield reducing events that occur in modern factories. The CDM represents the single pin discharge of a packaged chip that is at a potential hundreds of volts above ground. We are investigating whether sufficiently accurate CDM simulation results can be obtained using only a small simulation netlist that contains macro-models of the multiple discharge paths. The various power domains are linked through the substrate, and an appropriate model of it must be developed.

Highly Reliable Receiver Circuits for High-Speed IO Links
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Semiconductor Research Corp.
Conducted in the Coordinated Science Laboratory
We are applying communication theory to design ESD-protected, high-speed serial links. Links are expected to provide data rates in excess of 10 Gb/s at a BER less than 10^{-15}, per-channel power consumption less than 100 mW, and a 3-KV HBM-ESD protection level.

Algorithms and VLSI Architectures for Joint Equalization and Decoding
N. R. Shanbhag,* A. C. Singer, S. J. Lee
CCR-9979381; CCR-00-85929
Conducted in the Coordinated Science Laboratory
This project explores efficient algorithms and architectures for joint equalization and decoding in high data-rate communications systems. Such systems suffer from intersymbol interference (ISI) and noise. Conventional approaches separate the two functions of equalization and decoding for historical reasons. Significant improvements in bit-error rates are feasible if the two functions are executed jointly. Techniques such as turbo equalization are being explored where the equalizer and the decoder exchange soft information to enhance performance. Application of these new receiver techniques to broadband communication systems such as very high-speed digital subscriber lines (VDSL) and wireless is being studied.

Fluid IP Core Generators
N. R. Shanbhag, B. Lam, M. Zhang, B. Shim
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Defense Advanced Research Projects Agency
Conducted in the Coordinated Science Laboratory
This project seeks to develop design techniques and tools for realizing custom-quality VLSI designs in synthesis quality design cycle times for DOD applications. The focus of our research is on datapath intensive broadband communication subsystems, such as filters and FFT. The design methodology includes an architecture optimizer and a layout synthesizer bypassing logic synthesis. Techniques such as device sizing, noise-tolerance (both at the circuit and algorithmic level), algorithm transforms, power, and delay models are being incorporated into the core generator. The resulting circuit layouts are targeted to meet power, delay, and reliability specifications.

High-Speed Architectures for Iterative Decoders
N. R. Shanbhag,* M. Mansour
CCR-9979381; CCR-0085929
Conducted in the Coordinated Science Laboratory
This research focuses on the design of high-speed iterative decoders. Recently, turbo codes, low-density parity check (LDPC) codes, and related concatenated codes have been proven to be extraordinarily effective in improving the bit-error rates on noisy communication links. Decoders for such codes are iterative and block-based, making high
data-rates difficult to achieve. These decoders are also memory intensive. Our research explores alternative decoding algorithms that might be appropriate for low-power and high-performance VLSI implementations.

**High-Speed IO Signaling**

N. R. Shanbhag,* G. Balamurugan, H. M. Bae, S. Sridhara

*Intel*

*Conducted in the Coordinated Science Laboratory*

The goal of this project is to investigate solutions for data transmission in the range of 5Gb/s–10Gb/s for inter-chip communications. The project involves the application of communications and signal processing theory and techniques to analyze high-speed I/O links. Until recently, design efforts have been focused primarily on transceiver electronics without comprehension of the communication channel. In addition, no rigorous, comprehensive analysis techniques exist to analyze and predict the performance of I/O signaling systems. By viewing the I/O link as a noisy communication channel over which reliable information transfer needs to take place, the project proposes to develop analysis methods and explore design possibilities to accomplish reliable energy-efficient high-speed data transfer over inter-chip links.

**Noise-Tolerant DSP in the Deep Submicron Era**

N. R. Shanbhag,* R. Hegde, L. Wang, G. Balamurugan

*National Science Foundation, CCR-9902745*

*Conducted in the Coordinated Science Laboratory*

This research addresses the design of reliable and energy-efficient DSP systems in deep submicron (DSM) SMOS technology in a unified manner via the development of noise-tolerant algorithmic and circuit design techniques. In particular, circuit design techniques that tolerate leakage, crosstalk, ground bounce, and process variations are being developed. Algorithmic approaches that exploit the statistical structure of multimedia signals to combat DSM noise are also being studied. A design methodology is being formulated that jointly applies circuit and algorithmic noise-tolerance techniques to achieve an overall level of system reliability while minimizing energy.

**VLSI Architectures for Soft Decoding of Reed–Solomon Codes**

N. R. Shanbhag,* R. Koetter, R. Blahut, A. Ahmed

*CCR-0073490*

*Conducted in the Coordinated Science Laboratory*

This project investigates high-performance architectures for soft decoding of Reed–Solomon codes. Reed–Solomon codes are commonly employed to enhance the reliability of broadband communications links. Reed–Solomon decoders used in practice today employ hard-decision decoding. Soft decision decoding of Reed–Solomon codes can provide significant coding gains over hard-decision decoders. Soft decision decoding algorithms are computationally complex and hard to implement in VLSI. This research explores algorithmic and architectural techniques to design soft decision Reed–Solomon decoders for high-data rate communication systems.

**CAD for VLSI Manufacturability and Reliability**

M. D. Wong*

*IBM*

*Conducted in the Coordinated Science Laboratory*

In nanometer-design technologies, computer-aided design software must consider manufacturability and reliability. In this project, we focus on the development of theories and prototype systems for solving problems in the design for manufacturability and reliability area. Research topics include lithography-aware design tools, fast reticle enhancement techniques (OPC, PSM, OAI, and such), and layout optimization for CMP.

**Routing for High-Performance VLSI Packaging**

M. D. Wong*

*IBM*

*Conducted in the Coordinated Science Laboratory*

In this project, we develop a complete routing system for high-performance circuit boards. The type of high-end boards targeted in this project is generally completed using manual methods because of the complexity or density of the design. The goal is to create a system that will either completely remove the need of manual routing or significantly reduce the effort of manual routing. Such a system will dramatically reduce the design time for state-of-the-art, high-performance complex boards.

**Communications**

**Fair Scheduling and Admission Control for Shared-Channel Wireless Packet Networks**

V. Bharghavan,* R. Srikant,* S. Shakkottai, A. Eryilmaz

*National Science Foundation*

*Conducted in the Coordinated Science Laboratory*

Fair scheduling of traffic sources in wireless networks is difficult due to bursty channel errors and location-dependent channel capacity. In this project, researchers study MAC, scheduling and admission control algorithms...
for indoor and outdoor wireless networks that allocate the available bandwidth in a fair manner to competing sources.

**High-Performance Decoding of Algebraic Codes Beyond their Packing Radii**
R. Blahut,* N. Shanbhag, R. Koetter
*National Science Foundation, CCR-0073490

Conducted in the Coordinated Science Laboratory

The objective of this research is to investigate practical and theoretical aspects of interpolation/factorization algorithms that were pioneered by M. Sudan for decoding beyond half the minimum distance of Reed–Solomon, Bose–Chaudhuri–Hocquenghem (BCH), and algebraic geometry codes. The research has two main thrusts. The first is the characterization of the decoding algorithm and its complexity or performance trade-off, together with subsequent improvements in the decoding of BCH and algebraic geometry codes; these are at the theoretical core of this proposal. The second main thrust is the development of efficient computational architectures for implementing the algorithms and the demonstration of the feasibility and practicality of very large scale integrated circuit (VLSI) implementation of decoders that will dramatically outperform the decoding algorithms used in current commercial communications and storage systems.

**Codes on Graphs, Factor Graphs, and Iterative Algorithms**
R. Koetter*
*National Science Foundation Career Award, CCR 99-84515

Conducted in the Coordinated Science Laboratory

The primary focus of this research is the investigation of creative new methods for reliable transmission of information in the context of modern error-control techniques. Error-correcting codes are an essential part of modern communication and storage systems and much of today's technology would not be possible without them. This study is focused on graph-based, iterative decoding algorithms, which, without doubt, are one of the most significant coding-theoretic developments of the last decade. The goal of the investigator's research is to develop a broad, analytical, and constructive approach to research and education, unifying graphical models, coding theory, and iterative algorithms. The interplay between codes on graphs and other areas, like iterative graph-based algorithms, system theory, and network information theory, is in the focus of this investigation with the goal of discovering and utilizing fundamental connections between these fields.

**High-Performance Short Iterative Codes**
R. Koetter*
Motorola, Inc.

Conducted in the Coordinated Science Laboratory

This project aims at developing excellent codes for application requiring short- to moderate-length (64 bits to <1,000 bits) codes. Traditional coding schemes for these lengths rely typically on algebraic constructions or convolutional codes. Researchers strive to make the tremendous gains achievable for long blocklengths (>10,000 bits) by turbo and other iteratively decodable codes available for much shorter code length.

**Unwrapping Phase Images: Theory and Applications Using Probabilistic Inference Techniques**
R. Koetter,* B. Frey, D. Munson
*National Science Foundation, CCR 01-05719

Conducted in the Coordinated Science Laboratory

Phase unwrapping in two-dimensional topologies is a signal processing problem that has been studied extensively over the past 20 years and has important applications, such as medical imaging and synthetic aperture radar. However, despite its importance in science and engineering, to date, phase unwrapping in two-dimensional grids has remained an essentially unsolved problem. This research takes a fresh approach to the problem using methods from probabilistic inference. The work not only holds the promise of resulting in powerful phase unwrapping schemes based on the sum-product algorithm and structured variational methods, but also has the potential to provide deep theoretical insight into the ill-posed nature and solvability of the phase unwrapping problem. Such an insight is extremely important for guiding the development of practical algorithms.

**Design Principles for Wideband Wireless Communications**
V. V. Veeravalli,* A. Mantravadi
*Cornell University, NSF CCR-9980616

Conducted in the Coordinated Science Laboratory

This research is aimed at enhancing the performance of wideband wireless multi-access systems by optimizing tradeoffs between coding and spreading, capitalizing on advantages afforded by spatial diversity, and developing techniques for accommodating multirate users.

* Denotes principal investigator.
New Techniques for Optimizing the Quality and Capacity of Wireless Communication Systems
V. V. Veeravalli,* J. F. Chamberland, Y. Liang, N. Wang
* National Science Foundation, Faculty Early Career Development, Presidential Early Career Award for Scientists and Engineers, CCR-0049089
Conducted in the Coordinated Science Laboratory
The research in this project is directed toward the development of future generation multimedia wireless communication systems. Specifically, the research spans the following four areas: wireless channel modeling and analysis; information theory for wireless systems; wireless CDMA systems; and dynamic radio resource management.

Research at the Frontier of the Physical Layer
V. V. Veeravalli,* R. Prakash, K. C. Reddy
National Science Foundation, CCR-0049085
Conducted in the Coordinated Science Laboratory
The research conducted under this grant has a broad perspective from the viewpoint of the physical medium in that it covers wireline (twisted pair or a coaxial cable); wireless (satellite, cellular/PCS, or wireless local area network, WLAN); and recording, (magnetic or optical disc) media. The research has a narrow focus in that the problems addressed all involve some form of forward error control (FEC). A major component of the project is on coding and information theory for wireless CDMA systems.

Computer Engineering
Ad Hoc Wireless Networks Utilizing Multirate and Power-Save Capabilities
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National Science Foundation, ANI 01-25859
Conducted in the Coordinated Science Laboratory
Wireless communication technology has gained widespread acceptance in recent years. Wireless local area networks have come into greater use, with the advent of the IEEE 802.11 standard and availability of several commercial products based on this standard. An ad hoc network can be formed by wireless, potentially mobile hosts, without requiring the use of any fixed infrastructure, such as base stations. Such networks have many applications, including home networking, personal area networking, sensor networking, search-and-rescue missions in remote areas, and other civilian as well as military operations. Modern wireless devices are often designed with the capability to transmit at different bit rates using different modulation schemes and to operate in a power-save mode to conserve energy. While such wireless devices can be built, there is not adequate research on performance of ad hoc networks utilizing such devices. This project will, therefore, attempt to answer two broad questions: How do we design wireless medium access control (MAC) protocols that exploit multirate and power-save capabilities in ad hoc networks? While there has been some work on such protocols, this project is expected to develop new techniques to utilize multirate and power-save capabilities. What is the impact of multirate and power-save capabilities on performance on network layer and transport layer? The project will study the interaction between wireless device capabilities and upper layer performance, and develop mechanisms to improve performance of the various layers.

Protocols for Mobile Ad Hoc Networks
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Mobile ad hoc networks are multihop wireless networks, with dynamically changing network topology. In this project, we investigate several protocol design issues corresponding to routing, medium-access control, and transport layers in mobile ad hoc networks. The focus is on performance issues related to individual layers as well as interlayer interactions.

TCP-Unaware Approaches to Improve Performance of TCP Over Wireless Links
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The focus of this project is on TCP-unaware techniques to improve TCP performance over paths that include wireless links. The path from a TCP sender to a TCP receiver usually includes several intermediate nodes that may drop TCP packets if congestion occurs. TCP makes the implicit assumption that all packet losses are due to congestion. Since wireless links are prone to transmission errors, this assumption is not accurate for TCP over wireless links. Nevertheless, TCP reduces its congestion window when packet losses due to transmission errors occur. This phenomenon is known to result in poor throughput for TCP

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over wireless links. This project investigates TCP-unaware mechanisms to avoid such TCP performance degradation.

**Wireless Wind Tunnel: A Testbed for Experimental Evaluation of Wireless Networks**
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This project, evaluating protocols for wireless networks and developing scaling techniques for physical environments, aims at deploying an anechoic chamber for interference control, forming a testbed, referred to as the wireless wind tunnel (WWT). The uses of the testbed focus on: evaluation of wireless protocols (WP) in controlled environments, development of channel models suitable for simulation-based evaluation of WPs, and evaluation of techniques for scaling the physical environment to facilitate realistic wireless experiments. The WWT addresses some of the limitations based on computer evaluations resulting from the present insufficient understanding of channel and system models for wireless networks. These are not well understood and brute force accurate simulation of the wireless environment are at present too complex. Existing hardware testbeds suffer from one or both of the following shortcomings: experiments often cannot be repeated due to interference by other wireless devices operating in the same frequency range, and the parameters of the experiment (such as the mobility patterns of the mobiles and scatterers in the environment) are not fully controllable. This work impacts the education mission, including coursework, laboratories, and student projects. The testbed will serve as a demonstration tool. New educational opportunities will open involving experimental research providing better training and motivation. Facilities will be made available to a larger pool of researchers. Additional impact is expected on communications systems in practice. 

**Decision and Control**

**Dynamic Team and Game Theory for Congestion Control in High-Speed Networks**
T. Basar,* R. Srikant,* D. Wiedenheft

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**Conducted in the Coordinated Science Laboratory**

This project is related to NSF 98-13710, and involves research for undergraduate students on various aspects of communication networks, particularly in the area of congestion control.

**Objective-Oriented Model Heterogeneous Sensor Networks for Coordinated Control**
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This is a multi-university research effort that focuses on a comprehensive study of large, mobile ad-hoc reconfigurable networks for coordinated control. It draws on elements from coordinated control, dynamic state estimation, ad-hoc network management, resource assignment, and fault tolerance. Its aim is to provide a formalism in which the methods of sensor networking may be integrated as part of a systematic design process focused on achieving a specific control objective. Particular topics of study at the present are robust H-infinity and risk-sensitive control and filtering in a receding horizon framework, performance-and utility-driven resource allocation in networks, and control over networks using decentralized and distributed sensor information.

**Smart Icing Systems**
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**Conducted in the Coordinated Science Laboratory**

This part of the larger interdisciplinary/interdepartmental research program addresses the identification and control research required to develop a smart icing system for aircraft. A smart icing system would sense the effect of ice accretion on the aircraft performance and handling qualities and provide information to the flight crew, operate ice protection systems, provide envelope protection, and possibly adapt the flight controls. The research conducted here involves in-flight parameter identification of aircraft flight dynamics utilizing excitation generated by only natural (and not forced) maneuvers of the aircraft and turbulence. Subsequently, this information would be fed (along with other sensor-based data) into an appropriate neural network that would, in turn, lead to an accurate detection of the level of severity of ice accretion on the flight surfaces of the aircraft. The ultimate goal of this effort is to provide both the pilot and the autopilot with needed information to improve the safety of aircraft operating in icing conditions.
Cooperative Networked Control of Dynamical Peer-to-Peer Vehicle Systems
G. Dullerud,* F. Bullo, E. Frazzoli, P. R. Kumar, D. Liberzon, B. Reznick, M. Viswanathan
Conducted in the Coordinated Science Laboratory
The goal of this project is to develop systematic methodologies for the reliable construction of cooperative networked multivehicle systems.

Architectures for Secure and Robust Distributed Infrastructures
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U.S. Air Force Office of Scientific Research; Department of Defense, URI Award F49620-01-1-0365URI (subcontracted from Stanford University)
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Within the context of a much larger project, this work focuses on addressing the challenges that arise in regards to distributed or hierarchical coordination, fault tolerance, safety, and scalability in emerging dynamic systems and networks. The initial goal of this project has been to develop distributed estimation algorithms that can be used in network monitoring.

Designs of Robust Encoded Dynamic Systems
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Air Force Office of Scientific Research, DoD URI Award F49620-01-1-0365URI
This work analyzes the effects of roundoff noise on our ability to nonconcurrently detect and identify transient faults that corrupt state variables during the operation of a fault-tolerant discrete-time LTI dynamic system. The analysis provides insights that allow us to evaluate the performance of established decoding algorithms using analytical techniques. It also leads to explicit bounds on the precision needed in order to guarantee the correct identification of the number of faults that have affected the system.

Diagnosis and Assessment of Faults, Misbehavior, and Threats in Distributed Systems and Networks
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National Science Foundation, ECS 04-26831 ITR
This project addresses the problem of state estimation in discrete event systems (DES) that are modeled by labeled Petri nets that may have both nondeterministic transitions (i.e., transitions that share the same label) and unobservable transitions (i.e., transitions that are associated with the empty label). These techniques are promising because they show that one can compute the set of consistent markings with complexity that is at most polynomial in the length of the observed label sequence.

Enabling Diagnosis of Faults and Misbehavior in Heterogeneous Networked Systems via Structured Redundancy
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Boeing Corporation
This project aims to evaluate how the use of redundant sensors, actuators or, more generally, redundant information can enable efficient and gracefully degradable diagnosis algorithms for large networked systems. Instead of focusing on how diagnosis can be performed for a given system or network, this project is interested in finding out how small modifications in the system structure (e.g., sensor or actuator allocation) or the communication links and protocols can result in more efficient and robust diagnosis algorithms.

Enabling Novel Digital Sequential Circuit Designs through Error Control and Noise Tolerance Techniques
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National Science Foundation, ECS 02-18939 ITR
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This project is developing a framework for fault-tolerant convolution using a polynomial residue number system with non-coprime moduli. These techniques are promising in terms of the simplicity of the corresponding error detecting and correcting mechanisms. We are specifically investigating how these techniques, together with nonconcurrent error detection and correction techniques, can offer advantages in terms of hardware and time complexity.

Error Control in Switched Linear Controllers
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This project develops protection schemes for linear time-invariant (LTI) controllers in switched systems. Tolerance against internal controller faults is achieved via

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embeddings that preserve the state evolution of the original controller in some encoded form, but enable error detection and correction through nonconcurrent (e.g. periodic) checks.

Operation and Control of Energy Processing Systems: Economic and Environmental Considerations
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National Science Foundation, ECS 02-24729 EPNES
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The goal of the proposed research project is to develop a comprehensive framework for studying reliability and sustainable operation of energy processing systems in regulated economic markets. The successful completion of this project can have potentially significant implications in characterizing and evaluating the economic and environmental consequences of reliable designs for future commercial power generation and distribution systems.

Operation and Control of Energy Processing Systems: Fault Tolerance Considerations
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National Science Foundation, ECS 02-24729 EPNES
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The main goal of this research project is to develop a comprehensive framework for dynamical state estimation, fault detection, and fault accommodation in energy processing systems. This includes terrestrial and autonomous power systems, as well as electric drives and power electronic systems, as found in civilian and military sectors. In particular, this project aims at making connections with traditional fault tolerance techniques by developing distributed monitoring/correcting schemes and by explicitly accounting for the system dynamics before overcoming faults that affect the functionality of the system.

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National Science Foundation, ITR 02-24729 EPNES
This research project deals with issues arising in controlling and monitoring real-time systems over heterogeneous communication networks. The project aims at studying the performance of variants of state feedback control schemes in a network setup where packets can be lost or delayed due to deteriorating network performance.

In particular, the project studies the tradeoffs that arise between system instability, noise level, link delay, and packet dropping probability.

Operation and Control of Energy Processing Systems: State Estimation in Switched Linear Systems
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National Science Foundation, ITR 02-24729 EPNES
This project develops observer methodologies for switched linear systems that are driven by unknown inputs. The methodologies are based on using (possibly delayed) outputs, and knowledge of the switching sequence and the system dynamics in order to decouple the unknown inputs from the observer error.

An Integrated Approach to Fault Tolerance in Discrete-Time Dynamic Systems
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National Science Foundation, ECS 00-92696 CAREER
Conducted in the Coordinated Science Laboratory
This project develops systematic approaches for modeling, detecting, identifying, and correcting faults in order to ensure the proper functionality of discrete-time dynamic systems or networks. The project takes a system-theoretic viewpoint and aims to characterize the fundamental limitations of fault-tolerant designs by jointly exploiting system-, coding-, and information-theoretic techniques.

A Robust Control Approach to Digital Communications
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National Science Foundation, CCR 00-85917 ITR
Conducted in the Coordinated Science Laboratory
This project develops a deterministic worst-case framework for reconstruction of discrete (source) data transmissions through dispersive communication channels. This framework can be explored based on robust control ideas and formulations and serves as a complement to existing approaches that reconstruct data by optimizing probabilistic criteria.

Data Centric Sensor Networks
J. Hou,* P. R. Kumar, L. Sha
National Science Foundation, ANI 02-21357
Conducted in the Digital Computer Laboratory and the Coordinated Science Laboratory
This project investigates sensor networks.

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Communicating Networked Control Systems
P. R. Kumar*
U.S. Army Research Office, Multidisciplinary Research Program of the University Research Initiative, DAAD19-01010-465

Conducted in the Coordinated Science Laboratory

The goal of this project is to investigate the modeling, analysis, design, and control of communicating networked systems of sensors and actuators on fixed and mobile platforms.

Data Centric Sensor Networks
P. R. Kumar*
National Science Foundation

Conducted in Coordinated Science Laboratory

This project addresses issues related to sensor networks, formed by nodes that can sense, wirelessly communicate, and compute.

Efficient Resource Management for Controlled Mobility Wireless Networks
P. R. Kumar*
National Science Foundation

Conducted in the Coordinated Science Laboratory

This project addresses the design, development and operation of networks that are mobile.

Quality of Surveillance and Control
P. R. Kumar*
Defense Advanced Research Projects Agency, Multidisciplinary Research Program of the University Research Initiative, N00014-01-1-0576

Conducted in the Coordinated Science Laboratory

The objective of this proposal is to create a scientific foundation for the distributed optimization problem of surveillance and control.

Towards a Theory of In-Network Computation for Surveillance and Monitoring in Wireless Sensor Networks
P. R. Kumar*
National Science Foundation

Conducted in the Coordinated Science Laboratory

This project addresses the development of a theoretical foundation for sensor networks.

A Network Virtual Machine for Real-Time Coordination Services
P. R. Kumar*
Defense Advanced Research Projects Agency, F33615-01-C-1905

Conducted in the Coordinated Science Laboratory

The goal of this proposal is the creation of a real-time network coordination and control layer (middleware) that abstracts, controls, and ultimately guarantees the aggregate behavior of large unreliable networks such as those composed of sensors and actuators.

Scalable Multilayer Control of Joint Battlespace Networks
P. R. Kumar*
U.S. Air Force Office of Scientific Research, F49620-02-1-0217

Conducted in the Coordinated Science Laboratory

This project addresses issues relating to communication networks, both wireless radio and free-space optical.

Hybrid Supervisory Control of Uncertain Nonlinear Systems
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Hybrid systems are systems that combine continuous and discrete dynamics. This research is concerned with problems of the following kind: given a process, typically described by a continuous-time system, find a hybrid controller such that the closed-loop system displays some desired behavior. An important situation in which such a control paradigm is useful arises when the model of the system contains large-scale uncertainties. Logic-based switching introduced together with, or even instead of, more traditional continuous tuning has been shown to improve performance and has become quite popular in the recent adaptive control literature. Such control techniques are also much more amenable to computer implementation. However, a vast majority of the results available on this subject are limited to linear systems. The primary goal of the proposed research is to develop systematic tools for hybrid control design, applicable to useful classes of nonlinear uncertain systems.

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Hybrid Control of Nonlinear Systems
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The research and educational development plan proposed here is aimed at designing hybrid control algorithms. In this framework, a continuous-time process is controlled by means of logic-based switching among a family of regulators. The closed-loop system is then called hybrid because it combines continuous and discrete dynamics. We study several situations in which such a control paradigm is natural and helps overcome various shortcomings of more traditional control methodologies. The primary focus of this research is on systematic development of tools for hybrid control design, applicable to general and useful classes of nonlinear dynamical systems.

Multiple View Geometry
Y. Ma*
University of Illinois
Conducted in the Coordinated Science Laboratory
The goal of this project is to unify the study of geometry of multiple images into a simple and clean mathematical framework where efficient algorithms and systems can be developed for applications in computer vision, robot vision, computer graphics, cognitive science, and so forth.

Adaptive Methods for Heterogeneous Wireless Services
S. Meyn,* M. Medard, J. Huang
National Science Foundation, NSF CCR 99-79381, NSF ITR 00-85929
Conducted in the Coordinated Science Laboratory
With communication and computing systems becoming increasingly pervasive, future systems will require the ability to accommodate, in real time, wireless services to support a variety of applications ranging from traditional voice and paging services to nomadic computing applications. Different services such as voice, or data, may have vastly different requirements in terms of burstiness, or rate and quality of service (QoS) requirements. We consider coding, routing, and traffic rate mechanisms to provide smooth heterogeneous services to a variety of users via wireless access to a network.

Control Techniques for Complex Networks
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National Science Foundation, ECE-02-17836
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In many application areas and in many scientific disciplines, one seeks methods for managing complexity of man-made or real-world systems. Famous application areas include network management in production systems and wireless networks; analysis of the stability of candidate pharmaceutical compounds; and the relationship between chromosomal and protein structure. This project concerns several interrelated approaches to managing complexity in large interconnected systems. Specific application areas addressed in the proposal include phase transitions in molecular models and resource allocation in large network models.

Large-Scale Simulation of Manufacturing and Communication Systems
S. Meyn,* S. Henderson (Cornell University)
National Science Foundation, DMI-0085165
Conducted in the Coordinated Science Laboratory
In the past decade, we have seen astonishing growth in both the theory and application of queuing networks. Industry is driving research in communication and data networks, computer systems, and manufacturing systems. Semiconductor manufacturing plants and the Internet are two infamous examples of networks of almost unimaginable complexity. A powerful need exists for methods for deriving and evaluating operational policies that may be used to effectively drive these systems. This project sets out to develop methods for control synthesis and evaluation for truly complex networks.

Visualization and Optimization Techniques for Analysis and Design of Complex Systems
S. Meyn*
National Science Foundation, ECS-0228251
Conducted in the Coordinated Science Laboratory
This project concerns several interrelated approaches to managing complexity in large interconnected systems. The focus of this project is resource allocation in large network models. A related project concerns phase transitions in molecular models. This research will provide new design methodologies and efficient approaches to simulation and online tuning of control algorithms.

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An Integrated Exploration of Wireless Network Communication
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This research studies the design of agile wireless networks that accommodate time variations in the communication channels, the information sources, and the network topology. The research will lead to design principles that, in addition to enabling more efficient use of the current cellular and PCS bands, will allow exploitation of frequency bands in the 10-100 GHz range to provide high-speed multimedia services for both indoor and outdoor applications.

Passivity-Based Control in Bipedal Locomotion
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National Science Foundation Grant 0510119
Conducted in the Coordinated Science Laboratory
The project explores bipedal locomotion in the context of passivity based hybrid nonlinear control. We are investigating speed regulation, the use of alternate potential functions to increase the basins of attraction of stable limit cycles, the effect of control saturation and underactuation in passivity based control, and the efficiency of passivity based control methods compared to true energy optimal control. The goal is to help solidify the foundations of the field through analysis, development of new concepts, and the design of provably correct control algorithms.

Telemanipulation in Multi-Robot Networks
Office of Naval Research, Grant N00014-05-1-0186
Conducted in the Coordinated Science Laboratory
In this project, we are addressing fundamental issues in communication, coordination, and teleoperated control of multiple agents in coordinated manipulation tasks. While multiagent coordination and control problems such as swarming, flocking, and rendezvous have been studied by several researchers, much less work has gone into the teleoperated control of multirobot networks, especially when the multirobot network is expected to engage in tasks involving both manipulation and motion coordination. Manipulation tasks require haptic and force feedback that introduce significant stability and transparency problems with respect to communication delay, packet loss, and other communication effects.

U.S.-France Cooperative Research: Passivity Based Control of Networked Control Systems
M. W. Spong,* R. Ortega (CNRS, France)
National Science Foundation Grant 0128656
Conducted in the Coordinated Science Laboratory
This award supports U.S.-France collaboration in control systems between Mark W. Spong of the University of Illinois and Romeo Ortega of the Signal and Systems Laboratory at SUPELEC, a French center for research in electrical engineering. The objective is to investigate passive nonlinear control of networked control systems, in particular, systems involving bilateral remote operation (teleoperation) over unreliable communication networks. The problem is motivated by interest in wireless communication in imbedded real time control systems and the use of the Internet as a communication medium in teleoperated and networked control systems.

Reliable and Robust Control of Formations of Unmanned Vehicles
D. Stipanovic,* M. W. Spong, P. Hokayem, C. Burns, J. Mejia
The Boeing Company
Conducted in the Coordinated Science Laboratory
This project is to develop reliable and robust control architectures for networks of autonomous aerial and ground vehicles. The aim is to develop control laws that have low sensitivity to noisy and lossy data communication among vehicles, that are scalable in terms of number of vehicles, and that have the ability to handle discrete transitions in the network, such as formation reconfiguration, addition or loss of vehicles from the formation, and so forth. Applications of this work include undersea and planetary exploration, search and rescue, air traffic control, and control of sensor networks. Both theoretical and experimental issues are being investigated.

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Digital Signal and Imaging Processing

Efficient Algorithms for Lossless Data and Image Compression
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National Science Foundation, CCR-0122293

Conducted in the Coordinated Science Laboratory

In spite of the focus in recent years on lossy compression of audio, images, and video, lossless data compression remains crucial in applications such as text files, facsimiles, software executables, and medical imaging. Universal source coding algorithms, which deal with sources whose statistics are unknown, are of particular importance. The main goal of this research is to develop algorithms featuring fast computation and low memory use, while providing compression quality near the fundamental theoretical bounds. The resulting algorithms will have linear complexity and will be better than any current algorithm with comparable asymptotic compression performance, in terms of computation and/or memory use. Some versions of these algorithms will also have simple structure, admitting fast hardware implementations. A special focus of this research is also on parallel algorithms that allow arbitrary speedup while maintaining the same compression quality.

Fast Algorithms for 3-D Cone-Beam Tomography
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National Science Foundation, CCR-0209203

Conducted in the Coordinated Science Laboratory

In cone-beam tomography, projections are acquired by an area detector, using a source of divergent rays traveling on one of several possible trajectories. It is already used in current PET and SPECT scanners and in nondestructive evaluation (NDE) in manufacturing, and it will be the basis for the next generation of diagnostic CT scanners. This will allow use of CT as a dynamic imaging modality for cardiac imaging, or for real-time surgical guidance in medicine, or as a high-throughput NDE system in manufacturing, or as a high-accuracy security baggage scanner in airports. Unfortunately, the high computational cost of current cone-beam reconstruction algorithms constitutes a major barrier to their applications. We are developing new image reconstruction techniques that require only computations for an image. These techniques can be 100 times faster than current methods for typical images and promise to overcome the computational bottleneck in 3-D cone-beam CT, helping to make it a feasible and commercially viable technology for wide use.

Fast Algorithms for Tomography
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National Science Foundation, CCR-9972980

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Computerized Tomography (CT) is the principle underlying most of the key diagnostic imaging modalities and many other imaging techniques, including synthetic aperture radar. We are developing new image reconstruction techniques that require only computations for an image, as compared to computations for the current method of choice, the filtered backprojection (FBP). These techniques are orders of magnitude faster than FBP for typical images and promise to overcome the computational bottleneck created by new imaging technologies that acquire large quantities of data in real time. Similar developments are pursued for iterative and for 3-D reconstruction.

Minimum-Redundancy Spatiotemporal MRI
Y. Bresler,* Z. P. Liang,* N. Aggarwal
National Science Foundation, BES-0201876

Conducted in the Coordinated Science Laboratory

Since its inception in the early 1970s, magnetic resonance imaging (MRI) has become a premier diagnostic imaging tool. Although its early applications were largely limited to stationary objects, MRI has also proven extremely useful in recent years for dynamic imaging applications, such as cardiac, functional, or interventional imaging. An important challenge confronting dynamic MRI (D-MRI) is to obtain both high spatial and high temporal resolution, with three dimensional imaging capability. The goal of this research is to develop, implement, and test rigorously a new unified theoretical framework for minimum-redundancy D-MRI data acquisition and image reconstruction. In this framework, dynamic imaging is treated as a higher-dimensional image reconstruction problem, with time being an independent axis. Instead of attempting to freeze all motion by sufficiently fast acquisition, time variation during acquisition is explicitly accounted for in the steps of MRI sequence design, data acquisition, and image reconstruction. The approach draws on and extends theories and algorithms introduced by the researchers over the past few years and offers the potential for significant speedups of the imaging process. Furthermore, combination of the theory and techniques developed in this project with fast-scan methods and with

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methods based on phased-array RF coils will produce combined speedups, greater than any one of the individual approaches.

**Unwrapping Phase Images**
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National Science Foundation, CCR 01-05719  
Conducted in the Coordinated Science Laboratory  
The primary goal of the project is to develop optimal algorithms for the long-standing problem of unwrapping phase images from various imaging modalities such as SAR and MRI. Probabilistic inference algorithms will be developed and tested using SAR and MRI as testbeds. Prof. Liang is responsible for phase unwrapping of MRI data.

**Brain Image Segmentation by Integrated Multiscale Analysis and Shape Deformation**
Z. P. Liang,* S. Wang  
NEC Research Lab; University of Illinois Research Board  
Conducted in the Beckman Institute for Advanced Science and Technology  
Brain image segmentation is an important and challenging engineering problem confronting brain mapping. By accurately segmenting gray-scale brain images into various brain structures, we will be able to effectively visualize three-dimensional brain structures and carry out meaningful neuromorphometric studies. The long-term goal of this project is to develop and implement a unified processing software platform to effectively support various information processing tasks in neuroimaging or brain mapping. The specific aim of the project is to capitalize on our recent, novel work on graph-based multiscale image analysis and shape deformation to produce an efficient, accurate, and reliable algorithm for identifying brain structures from MR images. We expect to accomplish three specific tasks during the project period: complete the development of a novel graph-theoretic algorithm for multiscale analysis of MR brain images; further develop, perfect, and validate a topology-preserving shape deformation algorithm so that prior shape information of brain structures can be incorporated into the image segmentation process effectively; and integrate multiscale analysis with shape deformation for accurate segmentation of brain images and develop a prototype software system to facilitate the application of the developed algorithms for practical applications in brain mapping.

**Model-Based Tomographic Imaging Methods**
Z. P. Liang,* J. Ji, Y. Bresler*  
National Institutes of Health, R21 HL62336  
Conducted in the Coordinated Science Laboratory  
The mathematical basis of tomographic imaging is conventionally rooted in the well-established Fourier or radon transform theories, so that image quality is mainly dependent on how the data space is sampled. In practice, physical and temporal constraints often prevent a sufficient coverage of the data space, resulting in various image artifacts, such as Gibbs ringing, resolution degradation, and various motion effects. This project is aimed at overcoming these problems by developing new model-based imaging techniques that can incorporate a priori information into the imaging process effectively. Application of these techniques to cardiac imaging and functional brain mapping is also addressed.

**Multisensor Information Fusion**
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Defense Advanced Research Projects Agency, MDA972-00-1-0020  
Conducted in the Micro and Nanotechnology Laboratory  
This project is a component of research conducted in the Center for Bio-Optoelectronic Sensor Systems (BOSS). The primary mission of this center is to develop sensor and processing technology for detection of biochemical agents in battlefield situations. Prof. Liang is responsible for developing statistical algorithms for multisensor information fusion.

**Statistical Image Reconstruction**
Z. P. Liang,* C. Potter, B. Carragher  
National Institutes of Health, RO1 GM61939  
Conducted in the Beckman Institute for Advanced Science and Technology  
The primary goal of the project is to develop practical image reconstruction methods for high-resolution imaging from electron microscopy data, particularly in the presence of uncertainties in data acquisition parameters (a projection angle for example). We formulate the problem as a statistical parameter estimation problem by introducing a proper model for the object (for instance, a virus) to be imaged. This research effort promises to provide a brand-new solution to the long-standing problem in electron microscopy.

* Denotes principal investigator.
Electromagnetic Communication and Electronics Packaging

CAD Tools for Communications Microsystems
J. Schutt-Ainé,* D. Lambalot, L. Jiang
Defense Advanced Research Projects Agency, AF ECE0849

Recent developments in the area of wireless communication systems and microelectromechanical systems (MEMS) have enabled the networking of distributed transducers in a wireless mode. It is now possible to integrate monolithic microwave integrated circuit (MMIC) front-end modules with MEMS components such as antennas, switches, and filters. Our objective is to supply the necessary CAD tools to improve first-pass success and reduce design iterations for such systems. In particular, electromagnetic techniques are used to model various MEMS switch structures. These are combined with simulation techniques to predict the transient and steady state response of these components. The goal is to reduce the design cycle from several years to one week in the successful implementation of these MEMS structures.

Design and Fabrication of MEMS Probe Station
J. Schutt-Ainé,* C. Liu, D. Lambalot
University of Illinois Research Board

Recent advances in microelectronics have led to considerable reduction in size of components in integrated circuits (ICs). Typical VLSI circuits have dimensions in the submicron range and feature size that can be as low as 0.25 microns. This reduction is a result of several requirements for higher density and shorter interconnection delays. Future state-of-the-art microprocessors will accommodate more than a million transistors in an area of a few hundred squared millimeters. Along with these trends, several issues related to signal integrity and testing have moved to the forefront. With submicron dimensions, interconnect resistance has become a major bottleneck in circuit performance, leading to signal degradation and delays. In addition, measurement and testing in submicron geometries, which allows for determining the performance of the structure, is a challenging task. Nowadays, the methods employed consist of fabricating special-purpose test vehicles for evaluation, which often require expensive mask processes and complex de-embedding schemes. This investigation proposes to implement a nondestructive testing methodology for submicron integrated circuits using the recent advances in microelectromechanical systems (MEMS). More specifically, we intend to fabricate and test a microprobe structure that will permit the high-frequency characterization of submicron interconnects and devices in integrated circuits.

Development and Modeling of Flip Chip and Interconnect Package Technology for Ka and W Band
J. Schutt-Ainé,* F. Liu
National Science Foundation, E-21-N50-G5

In collaboration with the National Science Foundation Package Research Center, Georgia Institute of Technology

The electrical performance of mixed-signal integrated circuits strongly depends on the electromagnetic behavior of the components within the system. Future wireless and personal communication links will be strongly influenced by these considerations. Currently, millimeter-wave monolithic ICs (MMICs) chip sets are under development in the 24-94 GHz range. In recent years, power distribution and parasitic noise control have become critical issues in the design of these MMICs. Nowadays, with increased frequencies, interconnect schemes, layout, and power distribution have become mainstream design issues. It is now recognized in the CAD community that electromagnetic effects will generally take place at the forefront and will represent the critical limiting factor of MMICs performance. The collaborative effort between Georgia Institute of Technology and the University of Illinois focuses on developing the technology support for the implementation of low-cost packaging solutions for MMICs. This is to be achieved by harnessing the modeling, simulation, design, fabrication, and measurement infrastructure built over the past decade at these two institutions.

Hardware Acceleration of Newton Solver
J. Schutt-Ainé,* M. Das Gupta, D. Prasanna, R. Gao, Y. Mekonnen
Demaco/SAIC

In this project, we plan to demonstrate the effectiveness of implementing a Newton solver in hardware on a PCI bus card. The effort focuses on the use of the TI-TMS320C family of digital signal processor for the implementation of the solver. The implementation of fast Newton solver is to be first realized and tested before being implemented into a digital signal processor. We plan to provide documentation and interface requirements to allow users to install the hardware card and utilize it from programs.

* Denotes principal investigator.
High-Frequency Measurements and Validation of Electromagnetic Models in Scattering, Interconnects, and Optoelectronics
J. Schutt-Ainé*
U.S. Air Force Office of Scientific Research, AF JS 1660

There is tremendous demand for increased capacity in high-speed communication networks and novel applications in optical control of antenna phased arrays. With clock rates in the GHz range, interconnect considerations and electromagnetic phenomena have moved to the forefront in the design of high-speed computers. Microwave modulation of optoelectronic devices, such as semiconductor lasers and modulators, plays an important role in determining the high-speed performance of these devices. Continuing development of high-speed optical communication systems is contingent upon advances in high-speed sources and wavelength conversion devices. While numerous theoretical models have been developed to predict ways to improve these devices, much experimental work remains in order to verify these models and characterize devices based on new designs. This project proposes the experimental validation of various computational models in inverse scattering, wave propagation, interconnects, and optoelectronics. Most of the emphasis will be on the higher frequency range where measurement information is nonexistent. In recent years, computational electromagnetics has received growing interest due to the availability of fast computers and the recent development of fast algorithms. Models that allow the prediction of the most complex problems in scattering and wave propagation have been implemented. Unfortunately, the experimental verification of these models is seriously lagging, especially at higher frequencies where measurement accuracy and repeatability are more difficult to achieve. This project will allow us to determine the frequency range of validity of the computational models and generate useful information for high-frequency operation of radiating, optoelectronics, and waveguiding systems.

Low-Cost Fully Monolithic RF Integrated Circuits for Wireless Applications
J. Schutt-Ainé*
National Science Foundation, ECS-9979292

The performance of radio frequency (RF) integrated circuits will strongly influence the versatility and portability of future wireless communication systems. With the ever-increasing demands for higher bandwidth and capacity as well as reductions in size, weight, and cost, the need for more robust and efficient RF circuits is expected to increase. Currently, millimeter-wave monolithic ICs (MMICs) chip sets are under development in the 24-94 GHz range and will represent the platform for the RF components of most wireless systems. With the recent advent of microelectromechanical systems (MEMS), new potentials are being discovered for applications in the RF/millimeter wave ranges. In order to implement RFICs for future wireless communication systems, several fundamental issues must be resolved. First, a design methodology must be devised and tested. Next, a low-cost solution for the integration of MEMS technology into existing MMIC processes must be developed as well as a reliable packaging scheme. Finally,

* Denotes principal investigator.
a robust platform of design guidelines, tools, and characterization techniques must be made available to ensure reliable implementation of these communication systems. More specifically, the effort will focus on these tasks: developing a computer-aided design environment for the robust implementation of MMICs and MEMS as well as the generation of reliable design guidelines; implementing a robust MEMS process for the fabrication of switches, filters, and tunable capacitors; integration of MEMS components into a reliable and well-established MMIC process; devising a low-cost and reliable packaging solution for RFICs. Executions of these tasks will make use of the existing infrastructure and expertise of the principal investigators in the related areas. These will define several design-build-test cycles that will be optimized through several iterations during the course of the project. Special attention will be devoted to demonstrating the feasibility of these various tasks. Moreover, a testbed prototype will be implemented to validate the proposed flow and assess the hardware advantages of the designed RFICs.

Measurement and Test of Components for Optical Communication Applications

J. Schutt-Ainé,* M. Angert, Z. Deng
Xindium Technologies, Inc.

High-speed optical communication systems are presently improving in speed in response to ever-increasing bandwidth requirements of users. Demand for high-speed digital access will dramatically increase in the future, leading to many opportunities in this area. In order to economically meet the needs of future high bit rate systems, significant changes to component and system architectures will be required. Current commercial systems operating at 2.5 Gb/s (OC-48) data rates are implemented at present using discrete InGaAs photodetectors wirebonded to electronic integrated circuits for signal processing. At bit rates of up to 2.5 Gb/s, an InGaAs photodetector or APD is coupled to sophisticated Si-based electronics with high levels of functional integration to realize photoreceiver modules that incorporate logic thresholding, clock and data timing recovery, and demultiplexing functions in a single package. Advanced signal processing, including coding and decoding for error correction is also implemented in the transceiver circuitry. The objective of this project is the measurement of high-speed components to 50 GHz. The measurements are performed in the Electromagnetics Laboratory, where high-frequency and high-speed testing instruments are available.

Modeling and Simulation of Embedded Transmission Line Structures

J. Schutt-Ainé,* F. Liu
Raytheon Systems

Embedded transmission line (ETL) structures have become very commonplace in many high-frequency and high-speed electronic systems; however, the analysis and design tools needed for their design are not readily available. The objective of this effort is the modeling, extraction, and simulation of three-dimensional complex interconnect structures embedded in multilayer structures. The focus of the work will be on the development of software tools that facilitate and automate the designer’s task. The tools will be based on recently developed electromagnetic parameter extraction techniques to determine the electrical parasitic capacitance and inductance coefficients of these structures. These parameters can next be used with efficient simulation algorithms to predict the signal response of ETL structures and provide information about noise immunity and high-speed performance. This will permit the generation of reliable design guidelines as well as a significant reduction in the time to market.

National Course in Signal Integrity

J. Schutt-Ainé*
IEEE CPMT; National Science Foundation

Signal integrity has become a critical area in the design of high-speed communications systems and fast computers. Many research areas have emerged from industry and universities to address issues related to electrical performance. However, the educational infrastructure is seriously lagging. The goal of the National Course in Signal Integrity project (http://natcsi.ece.uiuc.edu) project is to establish a web-based educational platform that will provide the education necessary for aggressive packaging schemes in the area of signal integrity. This is achieved by providing a better understanding of electromagnetics problems and through the use of modeling and simulation tools. With the emergence of visualization tools and online simulation packages, access to both qualitative and quantitative answers is immediate. In addition to the standard components of web-based courses, we have focused our attention on two major components. In the first part of the project, a Movie Creator was implemented to allow the incorporation of taped lectures into a website with synchronization between the audio and video components. In the second part of the project, an efficient Perl/Java interface was created that permits the execution of signal integrity modeling and simulation CAD tools in the web server. The study of signal integrity issues is

* Denotes principal investigator.
strongly dependent on the ability to simulate and model signal propagation. This task seeks to supply circuit modeling and simulation capabilities using state-of-the-art techniques and analysis tools that were previously developed. A combination of visualization tools and the ability to perform online simulations can provide students with immediate access to both qualitative and quantitative answers. Using our newly developed tool, simulation results can be displayed and examined in a web browser shortly after execution. This unique feature of executing CAD software via the Web will be a major asset in learning environment.

Electromagnetics

Antennas for Wireless Sensors
J. T. Bernhard*
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U.S. Office of Naval Research through the NCASSR Program/NCSA

The emergence of wireless sensor systems promises to change the way we control our environments, make decisions, and promote health and safety. While numerous research projects on wireless sensors exist, very few address the critical technology of antennas that enable wireless communication. Several projects in this area propose to use standard off-the-shelf antennas, but this choice often limits the capabilities of the system by ignoring the unique requirements and environment of the application. In this project, we are developing both a general methodology for the development of antennas for wireless sensor systems as well as several designs for specific applications.

Electromagnetic Study of Integrated Hearing Aid Antennas
J. T. Bernhard*
jbernhar@uiuc.edu
Phonak Communications

Coordinated signal processing between hearing aids allows hearing-impaired individuals to focus on conversations without having to listen to background noise. A wired connection between the hearing aids and a central processing unit makes the system more obtrusive than traditional hearing aids. This research project clarifies and predicts performance with both in-the-ear and behind-the-ear hearing aid antennas.

Intelligent Portable Antenna Systems for High-Speed Wireless Communication
J. T. Bernhard*
jbernhar@uiuc.edu
National Science Foundation CAREER Award, ECS 99-83460

High-speed wireless data communication faces two challenges: high error rates caused by interference and unpredictable environments, and limited functionality and battery life at the portable unit. "Intelligent" or "smart" antenna systems that respond to changing operating conditions can help meet these challenges. This research develops intelligent portable antenna systems to improve the reliability, throughput, and noise immunity of high-speed wireless communication networks. Specifically, this project implements new compact radiation-tunable antennas with a performance-driven fuzzy controller. This novel approach views portable antennas as dynamic components of the communication system, creating a new paradigm for antenna design and control.

Low-Profile Radiators in Aperiodic Wideband Arrays
J. T. Bernhard,* P. Mayes, E. Michielssen
jbernhar@uiuc.edu
U.S. Army Research Office, DAAD 19-02-1-0398

This project develops a family of low-profile antennas and associated array methodologies for wideband applications where traditional periodic patch arrays severely limit performance. The work includes the development of specialized simulation tools as well as extensive measurements to characterize both individual and arrayed elements.

Miniaturized Antennas in Random Sensor Arrays for Planetary Surface and Atmosphere Exploration
J. T. Bernhard,* A. C. Singer, P. E. Mayes, E. Michielssen
jbernhar@uiuc.edu
National Aeronautics and Space Administration, NAG3-2840

In this project, we are developing size-appropriate, electrically small (miniaturized) antennas with moderate bandwidths for such sensors as well as processing algorithms for random arrays that enable the sensors to work together to communicate their data to remote collection sites regardless of their relative positions or orientations. The array will configure itself to form a beam in a general direction that can be intercepted by a passing orbiter or directed to a particular satellite- or surface-based receiver. The project will culminate with a testbed

* Denotes principal investigator.
demonstration using the developed antennas and processing algorithms.

**Reconfigurable Antennas for High Data Rate Multibeam Communication Systems**
J. T. Bernhard,* E. Michielssen
jbernhar@uiuc.edu
*National Aeronautics and Space Administration, NAG3-2555*

This research develops new, individually reconfigurable planar antenna array elements that can be adjusted to provide multiple beams while providing increased scan angles and higher aperture efficiencies than traditional diffraction-limited arrays. With the help of powerful simulation capabilities developed under the project, these antennas will be potential candidates for use in both large and small arrays for forward inter-satellite communication as well as tracking of multiple mobile surface-based units.

**Wideband Conformal Antennas and Arrays**
J. T. Bernhard*
jbernhar@uiuc.edu
*U.S. Air Force Research Laboratory, FA8718-04-C-0060*

This project investigates the fundamental characterization of suitable wideband conformal microstrip-based antennas as single elements and in arrays and explores possible approaches to expand the operating frequency bands and performance of planar and conformal arrays. These approaches encompass the use of novel substrates and antenna designs, array designs that allow wideband performance, such as random and connected array topologies, and implementation of antenna reconfiguration to enable wideband operation of planar and conformal arrays.

**A Wireless Embedded Sensor System to Monitor and Assess Corrosion in the Tendons of Prestressed Concrete Girders**
J. T. Bernhard,* D. A. Kuchma, H. Reis
jbernhar@uiuc.edu
*National Science Foundation, CMS 02-01305*

A multidisciplinary team of three researchers with expertise in the areas of nondestructive evaluation, wireless communication, and structural modeling are developing a wireless embedded sensor system to examine corrosion of tendons in prestressed concrete girders. The project illustrates the importance of integrating technologies and expertise from several fields in solving complex information flow problems.

**Fast Algorithms for Cross Talk Analysis**
W. C. Chew,* Z. G. Qian, J. Xiong, L. Sun
w-chew@uiuc.edu
*SRC 2003-TJ-1123*

This project proposes to use fast algorithms to analyze cross talk in circuits. It will use low-frequency fast multipole algorithm, together with low-frequency method of moments, together with a basis-rearrangement preconditioner to accelerate the solution in the long-wavelength limit. It hopes to tackle large problems encountered in computer chip design.

**Modeling of Well-Logging Tools**
W. C. Chew,* Y. Liu
w-chew@uiuc.edu
*Schlumberger-Chew*

This project proposes to use fast integral equation solvers at low frequencies to model the physics of well-logging tools. There are challenges due to conductive losses as well as low-frequency breakdown of integral equations.

**Modeling with Equivalence Principle Algorithm**
W. C. Chew,* M. K. Li
w-chew@uiuc.edu
*SRC 2006-KJ-1401*

This project collaborates with Intel to study the modeling of complex structures in circuits for computer design using the equivalence principle algorithm. Huygens-like equivalence principle is used to reduce the unknown counts for mutual interactions between complex structures.

**Parallelization of Preconditioners**
W. C. Chew,* A. Hesford
w-chew@uiuc.edu
*SRC 2006-KJ-1412*

This project collaborates with IBM to study the used of parallel algorithms to expedite the calculation of the reduced-coupling preconditioner. The preconditioner is then used in an iterative solver to accelerate the solution, and optimize its memory efficiency.

**Sound Mitigation of Noise Source**
W. C. Chew,* M. S. Tong
w-chew@uiuc.edu
*U.S. Army, W9132T-06-2-0006*

This project studies the use of complex structures to mitigate sound waves produced by army proving ground facilities. We will model complex structures with integral equations for acoustic and elastic waves. The integral equations solutions will be accelerated with fast solvers.

* Denotes principal investigator.
Then the solutions will be used to design sound mitigation structures.

**Subsurface Navigation Algorithm**
W. C. Chew,* C. P. Davis, P. Atkins, W. Tucker
w-chew@uiuc.edu
AF Sub Raytheon 2600

This project studies the possibility of geographically locating an underground personnel, such as a coal miner, using radio location method. It involves forward and inverse modeling of radio wave field at low frequencies in inhomogeneous media.

**Advanced Integral Equation Computer Program**
J. Jin,* M. Kowalski, B. Singh
Mission Research Corp.

The objective of this project is to develop advanced physics-based basis functions for the integral equation solution of electromagnetic scattering problems. Such basis functions would increase the maximum electrical dimension of structures analyzed using method-of-moments-based computer programs. The simulation capability will be further enhanced by utilizing a multilevel fast multipole iterative solver.

**Fast Frequency-Sweep Analysis of Electromagnetic Problems**
J. Jin,* D. Jiao, F. Ling
U.S. Air Force Office of Scientific Research, Multidisciplinary Research Program of the University Research Initiative

This project applies the asymptotic waveform evaluation method to a variety of electromagnetic problems for a fast frequency-sweep analysis. These problems include scattering by a perfectly electric conducting (PEC) body, radiation of wire antennas on a PEC body, scattering by a dispersive dielectric body, scattering and radiation of conformal cavity-backed microstrip patch antennas, and microstrip circuits in a multiplayer medium. The use of AWE can speed up the analysis by more than an order of magnitude.

**High-Order Computational Electromagnetics Techniques**
J. Jin, K. Donepudi, Z. Lou, X. Wang
Air Force Research Laboratory/SAIC, AF SAIC 4400041703

The objective of this project is to develop high-order computational electromagnetics methods for a variety of electromagnetic problems such as antennas, scattering, and circuits. The high-order methods include the partial differential equation based (such as the finite element method) and the integral equation based (such as the method of moments). These methods are characterized by their high-order convergence and can provide much more accurate modeling of problem geometry as well as more accurate representation of electromagnetic fields and currents than traditional low-order numerical methods.

**High-Order Hybrid Finite Element Technology for Simulation of Large-Scale Array Antennas Embedded in Inhomogeneous Media**
J. Jin,* T. Rylander, Z. Lou
U.S. Office of Naval Research, N00014-01-1-0210

The objective of this project is to develop a high-order hybrid finite element technique that is capable of simulating large array antennas embedded in inhomogeneous media. This includes the development of a novel hybridization technique that combines the finite element and boundary integral methods for efficient and accurate analysis of electromagnetic problems and the analysis of dielectric-embedded antennas on a large, complex platform, a problem that is of significant importance to the Navy. It is well known that deploying antennas on a platform, such as a ship’s topside, inevitably introduces distortion in their radiation patterns and causes mutual coupling. The distortion in the radiation patterns may reduce the desired coverage for effective communications and compromise the accuracy for isolating and locating targets. The existence of mutual coupling, caused by space waves, surface waves, and scattering by the platform, reduces the electromagnetic isolation between the antennas and consequently makes it difficult to operate the antennas simultaneously. Therefore, it is important to develop accurate numerical prediction tools to characterize the radiation patterns and mutual coupling of the antennas mounted on a complex, often large, platform.

**Hybrid Methods for Electromagnetic Scattering**
J. Jin*
U.S. Air Force Office of Scientific Research, Multidisciplinary Research Program of the University Research Initiative

In this project, researchers develop hybrid numerical methods to compute electromagnetic scattering from realistic three-dimensional targets. These hybrid methods combine high-frequency techniques (such as the shooting-and-bouncing-ray technique) and low-frequency techniques (such as the finite-element and integral equation methods) to capitalize on the advantages and eliminate the disadvantages of both. As a result, they are

* Denotes principal investigator.
accurate and efficient and can be applied to large, complex
targets.

**Numerical Analysis of Electromagnetic Scattering by**
**Jet Engine Inlets**
J. Jin,* K. Mao
*Air Force Research Laboratory/SAIC, AF SAIC
4400041703

The objective of this project is to develop an accurate and
efficient numerical technique to characterize the scattering
properties of jet engine inlets. This program is considered
a grand challenge in computational electromagnetics,
which is critical for designing low-observable air vehicles
and for developing reliable automatic target recognition
techniques. New solution algorithms will be developed to
deal with huge numerical matrix systems and to suppress
numerical dispersion errors.

**Optimal Design of MRI-Guided Electromagnetic**
**Hyperthermia**
J. Jin,* M. Kowalski
*National Science Foundation Graduate Fellowship

This project concerns with the use of RF electromagnetic
power for oncological hyperthermia of deeply seated
cancerous tumors. It is widely recognized that achieving
effective hyperthermia treatment of deep-seated tumors
within the body without the formation of undesired hot
spots is a difficult problem, requiring automatic
optimization procedures. We will deal with this problem
by developing an integrated approach that combines
electromagnetics, thermodynamics, and feedback control
to develop a design/optimization software. The
approach will utilize the cutting edge technology (MRI) for
guiding the hyperthermia process.

**Three-Dimensional Finite-Element Method for**
**Electromagnetic Field Computation**
J. Jin*
*National Science Foundation, ECS 94-57735

The goal of this project is to develop a finite-element
method using vector elements for electromagnetic analysis
of electronic devices, circuits, antennas, and radar
scattering. Special emphasis is on the method's accuracy,
efficiency, and versatility. Both frequency and
time-domain methods will be investigated and evaluated.
Specific applications will be demonstrated.

**Time-Domain Simulation of Electromagnetic**
**Phenomena**
J. Jin, A. Yilmaz, T. Rylander
*Defense Advanced Research Projects Agency,
F49620-01-1-0228

The objective of this project is to develop novel numerical
techniques to simulate electromagnetic phenomena in the
time domain. The focus is directed toward the FFT-based
time-domain integral equation solvers and the robust time-
domain finite element solvers. In the time-domain integral
equation solvers, the goal is to reduce the computational
complexity by utilizing the FFT technology. In the time-
domain finite element solvers, the emphasis is on the mesh
truncation techniques using either perfectly matched layers
or boundary integral equations.

**High Frequency Devices**

**38-GHz Ion Implantation GaAs MESFET Technology**
**Transfer Program**
M. Feng,* J. Middleton, S. K. Hsia
*Northrop Grumman Corp.; M/A-Com/Amp

**Conducted in the Micro and Nanotechnology Laboratory**

This project is aimed at the technology transfer of the
University of Illinois 0.25 μm gate GaAs MESFET for 24-
GHz and 38-GHz MMICs for LNA and VCO to M/A-Com.
for low-cost production.

**50-GHz Ion Implanted GaAs MESFET**
*TriQuint Semiconductor

**Conducted in the Micro and Nanotechnology Laboratory**

This program is to study the 50 GHz to 100 GHz ion
implanted GaAs MESFET for millimeter-wave integrated
circuit application.

**50-GHz Ion-implanted Enhanced/Depletion/Power**
**GaAs MESFETs**
M. Feng,* H. Hsia, D. Beecher, Z. Tang, J. J. Hwang,
S. Shen
*Network Device Inc.

**Conducted in the Micro and Nanotechnology Laboratory**

This project is to develop enhancement mode, depletion
mode, and power mode (E/D/P) GaAs MESFETs operated
at 50 GHz.

* Denotes principal investigator.
50-GHz Self-Aligned Gate MESFETs
M. Feng,* D. Becher, D. Caruth
Vitesse Semiconductor Corp.

Conducted in the Micro and Nanotechnology Laboratory

We have investigated Vitesse self-aligned gate MESFET for the analog applications in terms of noise gain and power. We have compared performance with the University of Illinois realigned gate FET with Vitesse and to understand device improvement issues.

ADC Circuit Design on a Sigma-Delta Modulator
M. Feng,* M. Heins, D. Barlage
U.S. Army Research Office, DAAH04-96-0218 (Intel Fellowship)

Conducted in the Micro and Nanotechnology Laboratory

This project is aimed at the design of 3 Gbit/s for an 8-bit ADC. Our first goal is to design the subcircuits library of comparator, sample, and hold circuit and OA design of an ADC.

AlGaAs/GaAs HBT Modeling
M. Feng,* P. Mares, M. Hein
Rockwell Microelectronics, Inc.

Conducted in the Micro and Nanotechnology Laboratory

This project aims to establish a useful SPICE model for HBT integrated circuits applications. Our approach is based on 45-MHz to 50-GHz bias-dependent microwave data collection on an HBT device using HP-ICCAP. Temperature-dependent microwave data collection will be included in the model.

CAD Design Tools for an Integrated Millimeter-Wave Wireless Communication Microsystem
M. Feng,* S. C. Shen, J. J. Hwang, M. Heins
Defense Advanced Research Projects Agency, F30602-97-2-0328

In collaboration with C. Liu. Conducted in the Micro and Nanotechnology Laboratory.

We are developing CAD capabilities for a gigahertz wireless communication and distribution microsystems. We are also developing scalable MMIC modules with integrated MEMS components.

Center of Hyper Uniform Nanophotonic Technologies for Ultrafast Optoelectronic Systems
M. Feng,* R. Chan, K. Cimino, W. Hafez, F. Dixon
mfeng@uiuc.edu
Defense Advanced Research Project Agency HUNT Program

Conducted in the Micro and Nanotechnology Laboratory

The goal of this project is to develop new optical source laser and LED using light emitting transistors modified by quantum well base and DBR to achieve high speed modulation of optical interconnect.

Development Materials for GaN-based Minority-Carrier Power Electronic Devices for Advanced DoD Systems
M. Feng,* J. Lai, K. Price
Defense Advanced Research Projects Agency, GaN Power Program (under UTA team-Prof. Russel Dupuis)

Conducted in the Micro and Nanotechnology Laboratory

This program is to study material interface of heterjunction, minority carrier transport property in GaN HBT system, since HBT provides high linearity and high efficiency power amplification.

Digital Radar Receiver
M. Feng,* J. Fendrich
Mayo Foundation; Defense Advanced Research Projects Agency

Conducted in the Micro and Nanotechnology Laboratory

This project performs the design and fabrication of an RF front end (400-700 MHz) fully tunable receiver system. We are working closely with the Mayo Foundation MIT-Lincoln Lab and Defense Advanced Research Projects Agency to build two brassboard RF receiver front ends for digital radar applications.

Direct Ion Implantation GaAs MESFETs
M. Feng,* H. Hsia, Z. Tang, D. Becher, S. Shen
GaAstronics Co.

Conducted in the Micro and Nanotechnology Laboratory

This project is to develop low-cost ion-implanted GaAs MESFETs for 5.8-GHz MMICs.

GaAs- and InP-based HBT Reliability
M. Feng,* D. Barlage, M. Heins
U.S. Army Research Office, DAAH04-94-0369

Conducted in the Micro and Nanotechnology Laboratory

This project is to set up an HBT reliability test. HBT reliability has become a major issue because of

* Denotes principal investigator.
heterostructure interface and fast diffuse p-type impurities in both InP- and GaAs-based HBTs. We will test HBT devices from Rockwell, Hughes, and TRW for the basic failure mechanism.

**GaN HBT Technology**
M. Feng,* J. J. Huang
U.S. Navy, UTA 99-0302

*Conducted in the Micro and Nanotechnology Laboratory*

GaN has great potential to be a power source in millimeter wave ICs and high-speed electronics due to its large breakdown voltage and higher saturation velocity. In collaborate with Prof. Dupuis at the University of Texas at Austin, we have fabricated GaN HBT with beta >100. There are many problems to be solved in terms of current and power efficiency issues at millimeter wave frequency.

**High-Frequency Measurement Project on High-Tc Superconductor**
M. Feng,* J. Fendrich, H. S. K. Hsia
National Science Foundation, DMR 89-20539

*In conjunction with the Science and Technology Center for Superconductivity. Conducted in the Micro and Nanotechnology Laboratory.*

This project has contributed to the study of BKBO and YBCO film characterization at microwave and terahertz frequencies. A parallel-plate resonator (10 GHz) was built to characterize sheet resistance in the microwave frequency. A noncontact coherent time-domain spectroscopy (THz) was used to characterize real and imaginary parts of conductivity. An on-wafer cryogenic microwave probing technique (1-40 GHz, 15-300K) is employed to establish patterned film scattering parameter. This work also aims to develop engineering model parameters using a GHz on-wafer probe technique.

**Hybrid and Monolithic OEIC Receivers**
M. Feng*

*Defense Advanced Research Projects Agency, Center for Optoelectronics Science and Technology*

*Conducted in the Micro and Nanotechnology Laboratory*

This project is aimed at hybrid integration of a PIN/GaAs transimpedance amplifier at 20 GHz operation. The monolithic IC is involved in design and fabrication of 4-channel OEIC receivers using GaAs MESFET technology.

**InGaAs/InP BiFET for ADC Applications**
M. Feng,* D. W. Seo, H. Hsia, Z. Tang

*Defense Advanced Research Projects Agency, N66001-97-C-8618*

*Conducted in the Micro and Nanotechnology Laboratory*

We have developed a 200-GHz InGaAs/InP HFET and integrated it with a 200-GHz HBT. Using this technology, we will construct a fifth-order Sigma-Delta ADC for a 16-bit and 3 FDR > 100 dbc.

**InGaP HBT for ADC Applications**
M. Feng,* D. W. Seo, J. Mu, M. Heins

*Defense Advanced Research Projects Agency, N66001-96-C-8615*

*Conducted in the Micro and Nanotechnology Laboratory*

We are developing an InGaP HBT device model (thermal and electrical model) for implantation into MDS and HSPICs. The second-order Sigma-Delta ADCs with 5 Gbits and 8-bit resolution has been designed, simulated, and fabricated.

**Intelligent Vehicle Highway System Chip Sets (II) (IVHS)**
M. Feng,* P. Apostolakis, J. Middleton
Northrop Grumman Corp.

*Conducted in the Micro and Nanotechnology Laboratory*

This project is a follow-up of the TRP/DARPA contract based on the success of the University of Illinois 24-GHz and 38-GHz GaAs MESFET MMIC for LNA and VCO. The new contract is aimed at low-cost implementation of a 0.1 μm gate GaAs MESFET and MMIC by direct ion implantation for 77-GHz LNA and VCO collision avoidance radar.

**Intelligent Vehicle Highway System Chip Sets (IVHS)**
M. Feng,* H. Hsia
Northrop Grumman Corp.

*Conducted in the Micro and Nanotechnology Laboratory*

This project is a joint development effort between the University of Illinois and Northrop Grumman Corp. on millimeter-wave IC chip sets for IVHS. We will design transmitter, receiver, mixer, and oscillator millimeter-wave ICs using co-planar technology. The mask and fabrication will use University of Illinois ion implanted, super-low-noise GaAs MESFETs, and a monolithic IC process.
Millimeter Wave Technology HBT and HFET
M. Feng*
Sumitomo Chemical America, Inc.
Conducted in the Micro and Nanotechnology Laboratory
We will design and fabricate MOCVD-grown, doped channel HFETs and InGaP and AlGaAs HBTs. We will characterize these devices and optimize their performance for 24- to 77-GHz applications.

Millimeter-Wave ICs and Packages
M. Feng*
Georgia Institute of Technology, NSF Package Research Center
Conducted in the Micro and Nanotechnology Laboratory
This project is to develop 38-GHz and 77-GHz coplanar MMICs for flip chip packages.

MOCVD HEMT Technology
M. Feng,* Z. Tang
Sumitomo Chemical America, Inc.
Conducted in the Micro and Nanotechnology Laboratory
We will investigate the performance of MOCVD grown P-HEMT and HEMT technology and its performance comparison between MESFETs and MBE-grown HEMTs.

Modeling of Flip Chip Interconnects for RF/Wireless
M. Feng,* J. Schutt-Aine
Georgia Institute of Technology, NSF ERC Package Research Center, SBC GIT E21-N50-G5
Conducted in the Micro and Nanotechnology Laboratory
The next generation of wireless personal communication links and wireless LAN and WAN will be focused in the millimeter wave range due to wide bandwidths and less interference effects. This work is to develop a low-cost solution of millimeter-wave MMICs flip chip technology. This work will provide the design, simulation, and process of MMICs operating at 38 GHz for a real application in point-to-point communication links. The Georgia Tech PRC will provide the flip chip package technology.

Monolithic Millimeter-Wave Integrated Circuits Technology
M. Feng*
Northrop Grumman Corp.
Conducted in the Micro and Nanotechnology Laboratory
This project is a joint effort with Northrop Grumman Corp. for developing 0.25 μm gate and 0.1 μm gate GaAs FET-based technology for the application in monolithic millimeter wave ICs (MMWICs). Based on the high-frequency device characterization, an equivalent circuit model will be generated. This model will then be used for MMWIC design. The fabrication of the MMWICs will be demonstrated.

Noise Characterization of Self-Aligned Gate GaAs MESFETs
M. Feng*
ITT Corp.
Conducted in the Micro and Nanotechnology Laboratory
This project aims to reduce the minimum noise figure on the direct ion-implanted self-aligned GaAs MESFETs based on the design of experiments in terms of dose and gate overlap.

Novel Giga Sampling Analog-to-Digital Conversion for Direct Digital Receiver
M. Feng,* D. W. Seo
National Science Foundation, ECS-9979341
Conducted in the Micro and Nanotechnology Laboratory
We proposed novel GHz ADC architecture, the folding and interpolation-based 15-bit subrange A/D converter, will reduce the transistor count by one-third and the area by 60%. The subrange ADC requires a very precise and wide-band track and hold amplifier to maximize input bandwidth to greater than 2 GHz and converter resolution to greater than 15 bits.

Optical Correlation Spectroscopy Using Reconfigurable Diffraction Grating
M. Feng,* Q. He, K. F. Chen, J. J. Huang
Defense Advanced Research Projects Agency Center (DARPA) BOSS Program, MDA972-00-1-0020

Sponsored by DARPA, the goal of this program is to develop a nano spectrometer for biological and chemical agents detection. Our group is to design and fabricate re-configurable grating using novel MEMS switch. It is capable of detecting 3-10 μm wavelength.

* Denotes principal investigator.
Technology for Efficient, Agile Mixed Signal Microsystems
M. Feng,* R. Chan, K. F. Chen, W. G. Ho
Defense Advanced Research Projects Agency, TEAM Program

Under BAE Systems and collaboration with Greg Timp. Conducted in the Micro and Nanotechnology Laboratory.
The goal is to develop silicon RF CMOS with Ft and Fmax > 400GHz with 20 nm gate. The RF mixed signal circuits will be developed based on the fastest RF CMOS technology.

Technology for Frequency Agile Digitally Synthesized Transmitter
M. Feng,* J. Lai, M. Hafez, M. Hampson, D. Chan, B. Chu-Kung
Defense Advanced Research Projects Agency TFAST Program

Under BAE Systems and Vitesse Semiconductor. Conducted in the Micro and Nanotechnology Laboratory.
The goal is to develop InP DHBT with Ft and Fmax > 500 GHz with sub-micron scaling of emitter size down to 0.1 micron. The technology is also required to demonstrate Flip-Flop speed over 200 GHz. A VLSI InP technology of over 10,000 transistor level of mixed signal Direct Digital Synthesizer (DDS) will be developed.

VCSEL and Smart Pixels for VLSI Photonics
M. Feng,* N. Holonyak, Jr., K.-Y. Cheng, K. C. Hsia
Defense Advanced Research Projects Agency, DAAG55-98-1-0303

Conducted in the Micro and Nanotechnology Laboratory.
This project is to develop oxide confined VCSELs at 85 nm and 1330 nm, as well as smart pixels for VLSI photonics.

Wavefunction Engineering of Individual Donors for Si-Based Quantum Computers
M. Feng,* R. Chan, C. Chuang
Defense Advanced Research Projects Agency, Quantum Computer Program, DAAD19-01-1-0324

In collaboration with John Tucker. Conducted in the Micro and Nanotechnology Laboratory.
The goal is to place individual phosphorus donors into silicon with atomic precision, demonstrate electronic control over wavefunction overlap, and characterize the spin singlet and triplet states of the two-electron system on couple donor pairs.

YBCO Superconducting Transmission Line Characterization
M. Feng,* J. Fendrich
Superconductor Technology Inc.

Conducted in the Micro and Nanotechnology Laboratory
This project studies the design rule of MCM using a superconductor as an interconnect line. Loss and phase delay are compared between gold and the superconductor line. Bit-error-rate and crosstalk will also be examined.

Magnetic Resonance

Studies of Relational (Declarative) Memory Processing
N. J. Cohen, A. G. Webb*
National Science Foundation, DBI 0092400

Conducted in the Beckman Institute for Advanced Science and Technology
This study uses functional magnetic resonance imaging in humans for identifying areas of the brain involved in memory processing.

Studying Neurovascular Coupling in Aging with Optical Methods
M. Fabiani, M. D’Esposito, E. Gratton, G. Gratton, A. Kramer, E. McAuley, A. G. Webb*
National Institutes of Health

Conducted in the Beckman Institute for Advanced Science and Technology
This area of research is concerned with using functional magnetic resonance imaging and near-infrared spectroscopy to study the effects of aging on brain structure and function.

Analysis and Design of RF Resonators for MRI Applications
J. Jin,* R. L. Magin, A. G. Webb
National Science Foundation, ECS 94-57735

RF resonators, also known as RF coils, RF antennas, and electromagnetic probes, are crucial devices for obtaining high-quality magnetic resonance images for clinical diagnosis. In this project, researchers develop numerical methods for analysis and design of such resonators for MRI applications. Specific mathematical models will be developed for low- and high-field MRI systems, which may include high-frequency phase variation and bioeffect dosimetry for RF fields.

* Denotes principal investigator.
Constrained Spectroscopic Imaging
Z. P. Liang,* P. C. Lauterbur*
National Institutes of Health, 1R01CA51430-01A4
Conducted in the Beckman Institute for Advanced Science and Technology

Magnetic resonance spectroscopic imaging promises to provide an entirely new way to examine the dynamics of human biochemical processes in vivo noninvasively. However, its practical applications have been limited because of low sensitivity and long imaging time. The primary objective of this research is to develop mathematical methods to effectively utilize the readily available anatomical information to constrain the spectral distribution to reduce imaging time without compromising spatial resolution.

Functional Brain Imaging
Z. P. Liang,* J. Ji
National Science Foundation, BES 95-02121; Beckman Institute for Advanced Science and Technology
Conducted in the Beckman Institute for Advanced Science and Technology

The primary objective of this project is to develop new signal-processing algorithms for detecting brain activities from functional MRI data. Researchers are investigating a wavelet-transform-based filtering and t-test method for signal detection and a multiscale method for image registration and motion correction.

MR Imaging of Time-Varying Objects
Z. P. Liang,* Y. Bresler,* J. Ji, A. Sen Gupta, A. Guo
National Science Foundation, BES 95-02121; National Institutes of Health, NIH-R21-HL062336
Conducted in the Coordinated Science Laboratory

Conventional MR imaging techniques have been widely used to obtain high-resolution images from stationary objects. For time-varying objects such as the beating heart, however, significant image artifacts often arise that render the image useless. This project aims to develop a new class of data acquisition and image reconstruction methods for real-time imaging of cardiac structures and functions.

An Integrated NMR
R. L. Magin,* A. G. Webb
National Science Foundation, DBI 96-05829
Conducted in the Beckman Institute for Advanced Science and Technology

Microlithographic and MEMS technology are being used to integrate the individual components of the receiver for nuclear magnetic resonance. This leads to advantages in packaging for planar microcoils and increases in the signal-to-noise ratio.

Neurocognitive Mechanisms: Appetitive and Aversive Emotion
G. Miller, W. Heller, M. Banich, A. G. Webb*
National Institutes of Drug Addiction
Conducted in the Beckman Institute for Advanced Science and Technology

The goal is to use functional magnetic resonance imaging to study the effects of aversive emotion tasks in humans.

Optimized Hyperthermia Treatment of Prostate Cancer Using a Novel Intracavitary Ultrasound Array
N. Smith, R. Keolian, V. Sparrow, L. Harpster, A. G. Webb*
Department of Defense, DAMD17-02-1-0124
Conducted in the Beckman Institute for Advanced Science and Technology

This collaboration designs ultrasound transducer arrays for destroying prostate cancer via thermal ablation.

Nanoliter Volume Nuclear Magnetic Resonance
J. V. Sweedler, A. G. Webb*
National Institutes of Health, PHS 2 RO1 GM53030-04
Conducted in the Beckman Institute for Advanced Science and Technology

This project designs NMR microcoils for studying chemical separation processes, and involves the construction of multicoil probeheads.

Investigation of Pore-scale Processes that Affect Soil Vapor Extraction
A. Valocchi, C. Werth, A. G. Webb*
Department of Energy, DOE DEFG07-99ER 15007
Conducted in the Beckman Institute for Advanced Science and Technology

This project uses magnetic resonance imaging to study the dissolution of pollutants in various sands and soils.

Applications of NMR Microspectroscopy to Combinatorial Chemistry
A. G. Webb,* R. Subramaniam, J. V. Sweedler
Smith Kline Beecham
Conducted in the Beckman Institute for Advanced Science and Technology

Combinatorial chemistry is the most recently developed synthetic pathway whereby up to a million new therapeutic
drugs can be produced simultaneously. The very small quantities of material (less than 100 pmoles) preclude structural identification by traditional high-resolution NMR. Our efforts are concentrated on designing RF microcoils for operation at high magnetic fields (>11 T) for efficient detection of these chemical products.

In Vivo MRI Thermometry Using New Functional Imaging Agents
A. G. Webb*
Whitaker Biomedical Engineering Foundation
Conducted in the Beckman Institute for Advanced Science and Technology

Fluorine- and proton-based phase-transition agents are being synthesized for in vivo temperature mapping using magnetic resonance imaging. Applications to hyperthermia treatment of cancer are being investigated.

Nanoliter Volume Nuclear Magnetic Resonance
A. G. Webb,* J. V. Sweedler
National Institutes of Health, PHS 1R01GM53030-01
Conducted in the Beckman Institute for Advanced Science and Technology

The aim is to develop microscopic hardware so that single-cell imaging and spectroscopy experiments can be run using the model system Aplysia californica. Using techniques such as diffusion-ordered spectroscopy, the physical environment of neuropeptides within vesicles can be determined, giving valuable information on the mode of action of these metabolites.

Nuclear Magnetic Resonance Microimaging
A. G. Webb*
National Science Foundation, DBI-9722320
Conducted in the Beckman Institute for Advanced Science and Technology

Using microscopic NMR coils and small magnetic field gradients, the resolution of NMR microimaging can theoretically be improved to 1 to 2 cubic microns. Researchers are investigating the mechanisms that limit resolution and devising new methods to overcome these limitations. Biological experiments on spinal cord tissue are also planned.

Subcellular Nuclear Magnetic Resonance Imaging
A. G. Webb*
National Science Foundation, DBI-9722320
Conducted in the Beckman Institute for Advanced Science and Technology

The goals involve the design of radio frequency NMR microcoils for single cell spectroscopy and imaging.

Ultrahigh Field Probes for Magnetic Resonance Imaging and Spectroscopy
A. G. Webb,* S. J. Blackband, T. H. Mareci
National Science Foundation
Conducted in the Beckman Institute for Advanced Science and Technology

Nuclear magnetic resonance microprobes are being constructed for operation at the highest frequency magnets in the world at the National High Magnetic Field Laboratory at Tallahassee, Fla. Coil characterization includes measurements of self-resonant frequencies and magnetic susceptibility for different geometries. High-resolution spectroscopy and microimaging experiments are being performed.

Optical and Discharge Physics

Startup Processes in Metal Halide Lamps
J. G. Eden,* M. J. Kushner, R. Moss, A. Bhoj, T. Sommerer (GE)
General Electric R&D Center

High pressure, metal halide lamps are typically the lighting sources used for street lamps, stadiums, warehouses, and other large indoor arenas. Metal halide lamps start as room temperature, glow discharges. Upon heating, metal-halide compounds in the lamps vaporize to generate multiatmosphere pressure plasmas, which then produce nearly continuum radiation. The starting process usually involves applying high-voltage pulses to tens to one hundred Torr of Ar gas with a small admixture of mercury or another low ionization potential rare gas. Optimizing this process will ultimately produce longer lived, more reliable lamps. In this research project, advanced computer modeling and laser diagnostics are being used to investigate the fundamental plasma processes that occur during startup of metal-halide lamps. Of particular interest are the plasma-surface interactions on the cathode that result in sputtering of cathode materials. Methods to minimize sputtering without using costly exotic materials are being formulated.
Optical Imaging

BIOPHOTONICS: Optical Coherence Elastography and Biomechanical Modeling of Developing Tissues
S. A. Boppart,* N. Aluru
boppart@uiuc.edu
National Science Foundation, BES 05-19920

Conducted in the Beckman Institute for Advanced Science and Technology

As the field of tissue engineering advances, new methods are needed to develop a more physiological and functional tissue. This project involves the development of new optical diagnostic techniques to quantify changing biomechanical properties in developing embryos and engineered tissues. Experimental data will be incorporated into predictive computational models to better understand how “form follows function” and how the biomechanical properties of developing tissue contribute to the resulting organization. Ultimately, this will lead to a better understanding of how external mechanical forces may be used to affect both form and function in developing and engineered tissues.

CAREER: Functional Optical Coherence Tomography for Neural Imaging
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National Science Foundation, BES 03-47747

Conducted in the Beckman Institute for Advanced Science and Technology

Functional optical coherence tomography (fOCT) is being developed to noninvasively track optical changes in neural tissue that occur during electrical activity. In analogy to functional MRI, this new technique will permit the analysis of not only neural structure at high resolutions, but also physiological function at the cellular and molecular level. The use of noninvasive optical techniques can overcome many of the current technical limitations in neuropathology encountered in the use of single-point micropipette recordings, the use of complex parallel banks of sensitive electronics, or the use of voltage-sensitive dyes that are toxic to cells over extended periods of time.

Optical Biopsy of Cancer using Optical Coherence Tomography
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University of Illinois at Urbana-Champaign and University of Illinois at Chicago Intercampus Research Initiative on Biotechnology

Conducted in the Beckman Institute for Advanced Science and Technology

The high-resolution, real-time imaging capabilities of optical coherence tomography (OCT) allow for the acquisition of "optical biopsies" of tissue. Images approaching the level of histology can be acquired without the physical resection and processing of tissue that is common practice today. A compact and portable OCT system is being constructed for clinical use in local hospitals and at the University of Illinois at Chicago. This system will be used to identify various stages of cancer growth as well as metastases and be compared directly to results obtained with histology, the gold-standard for diagnosis. In certain clinical scenarios, the use of real-time OCT may replace the need for tissue excision and analysis.

Optical Coherence Tomography of Cardiovascular Development
S. A. Boppart*
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American Heart Association, #0355396Z

Conducted in the Beckman Institute for Advanced Science and Technology

The development and function of the cardiovascular system is a complex process that too frequently results in structural or functional congenital abnormalities. With recent advances in functional genomics, it is not possible to site-specifically modify the genome to elucidate the genetic causes of these heart defects. Optical coherence tomography (OCT) and Doppler OCT are being used to image and characterize both structural and functional changes that occur in the cardiovascular system. Data from these studies are likely to improve our ability to visualize the effects of not only structural changes, but also functional changes in cardiac performance.

* Denotes principal investigator.
Optical Imaging of Dynamic Three-Dimensional Engineered Tissues
S. A. Boppart,* D. E. Leckband, T. Desai
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National Institutes of Health, #1 R01 EB00108-1
Conducted in the Beckman Institute for Advanced Science and Technology

Engineered tissues are advancing from thin layers of patterned cells to complex three-dimensional tissues grown on micropatterned three-dimensional biocompatible scaffolds. To emulate the physiologic environment, mechanical forces during tissue growth will play a crucial role. This project is developing advanced three-dimensional optical imaging techniques for visualizing the cell-cell and cell-matrix interactions during the growth of engineered tissues under static and dynamic mechanical forces. Primary engineered tissues of interest include blocks of cardiac myocytes and endothelial cell-lined vascular constructs.

Plasmon-Resonant Nanorods as Multifunctional Contrast Agents for Optical Coherence Tomography
S. A. Boppart,* A. Wei
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National Institutes of Health (National Cancer Institute), 1 R01 EB001777
Conducted in the Beckman Institute for Advanced Science and Technology

Recent advances in molecular imaging involve the use of contrast agents to site-specifically label cells and tissues of interest. This project involves the development of novel nanoparticle contrast agents that have specific absorption properties detectable with optical coherence tomography. Gold particle nanospheres and nanorods will have strong absorption properties for not only detection, but also for inducing local hyperthermia for the selective destruction of cancer cells.

A Nonlinear Optical Coherence Tomography System for Biomolecular Detection and Intervention
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National Aeronautics and Space Administration; National Cancer Institute, National Institutes of Health, #NAS2-02057
Conducted in the Beckman Institute for Advanced Science and Technology

Nonlinear optical techniques, such as coherent anti-Stokes Raman scattering (CARS) microscopy, offer the advantage for detecting specific molecular bonds within cells. This project is developing a nonlinear interferometric vibrational imaging technique that will enable the three-dimensional spatial mapping of molecular composition within living cells and tissues. This novel technique will be used to detect biomolecular signatures that are specific to precancerous and malignant cells. High-intensity ultrashort optical pulses will be used subsequently to ablate abnormal cells.

Near-Field Optical Power-Extinction Tomography
P. S. Carney,* V. Markel, J. C. Schotland, E. Wolf,
G. S. Agarwal
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U.S. Air Force Multidisciplinary Research Program of the University Research Initiative Grant, F49620-03-1-0379; National Science Foundation Career Award, 0239265
Conducted in the Beckman Institute for Advanced Science and Technology

Near-field optical power-extinction tomography (NOPET) represents the intersection of total internal reflection tomography (TIRT) and optical power-extinction tomography (OPET) where the probe beams of OPET are replaced with evanescent waves as in TIRT for sample illumination. With this technique it is possible to produce sub-wavelength resolved tomographs of scattering objects from the power lost from the probe fields.

Near-Field Scanning Optical Tomography
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National Science Foundation Career Award, 0239265
Conducted in the Beckman Institute for Advanced Science and Technology

Near-field scanning optical tomography (NSOT) explores the extension of imaging modalities such as photon scanning tunneling microscopy (PSTM) and near-field

* Denotes principal investigator.
scanning optical microscopy (NSOM) to samples that contain three-dimensional structure or when the probe tip is not scanned in grazing proximity to the sample. We solve the linearized inverse scattering problem to produce sub-wavelength resolved tomographs of the object under these conditions.

**Optical Power-Extinction Tomography**
P. S. Carney,* E. Wolf, G. S. Agarwal
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Beckman Research Award; U.S. Air Force Multidisciplinary Research Program of the University Research Initiative Grant, F49620-03-J-0379

*Conducted in the Beckman Institute for Advanced Science and Technology*

Optical power-extinction tomography (OPET) makes use of the power lost from two coherent beams, which simultaneously interrogate a scattering object, to generate a tomograph (three-dimensional image) of that object in a similar manner as computed axial tomography (CAT) makes use of the attenuation of individual beams of x-rays through an absorbing object to generate a tomograph. We are currently developing a prototype instrument. Initial results are promising.

**Photon Scanning Tunneling Microscope**
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*Conducted in the Beckman Institute for Advanced Science and Technology*

A photon scanning tunneling microscope (PSTM) is a device where the object is illuminated by an evanescent wave generated at the face of a prism or slide and the field is detected via a fiber probe in the near-zone of the sample (as in near-field scanning optical tomography). The data obtained with a PSTM are not amenable to direct interpretation, but we show sufficient information exists in the raw data to numerically compute the two-dimensional structure of a thin sample, thus achieving a computational lens for the near-field. Demonstration of this work has just been accepted for publication in *Physical Review Letters.*

**Total Internal Reflection Tomography**
P. S. Carney,* J. C. Schotland, R. A. Frazin; D. G. Fischer (NASA)
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Total internal reflection tomography (TIRT) is an imaging modality that makes use of the evanescent waves to illuminate and probe a sample. The probe depth is controlled through the exponential decay of the evanescent wave. In principle, this form of illumination can also enable super-resolved imaging where features smaller than a wavelength can be resolved. To take practical advantage of this capability, it is necessary to solve the inverse scattering problem that is the focus of this project. We are currently constructing an instrument to take the appropriate measurements.

**Optical Physics and Engineering**

**Investigation of Carbon Nanotube Nano-Optics**
P. S. Carney*
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National Science Foundation NER Grant, 0210495

*Conducted in the Beckman Institute for Advanced Science and Technology*

Carbon nanotubes and semiconductor nanowires are tiny objects (1000 times thinner than a human hair) that have recently drawn considerable attention in the scientific and engineering communities because of their novel structural and electrical properties. We will theoretically investigate the optical and optoelectronic properties of these structures.

**Nanofibrous Scaffolds for Cartilage Engineering**
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bcunning@uiuc.edu, dgriffon@uiuc.edu

*Beckman Institute for Advanced Science and Technology*

Conducted in the Micro and Nanotechnology Laboratory, the Beckman Institute for Advanced Science and Technology, and the College of Veterinary Medicine

The project aims to optimize production of chitosan nanofibers with nanometer-scale diameter for chondrocyte attachment and proliferation. Utilizing nanometer-scale lithography, a silicon template wafer is used to produce large area rubber molds. By filling the molds with chitosan solution, curing the chitosan solution to a solid, and

* Denotes principal investigator.
harvesting the cured fibers from the mold, large populations of fibers with any desired diameter can be produced in large quantities. The fibers produced by this method will be used to determine the extent to which the diameter of chitosan fibers affects \textit{in vitro} chondrogenesis. Our working hypothesis is that decreasing the diameter of chitosan fibers will improve chondrocytes’ attachment, proliferation, and matrix production.

**Optical Biosensors**
B. T. Cunningham  
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SRU Biosystems

\textit{Conducted in the Micro and Nanotechnology Laboratory}

An optical biosensor is used to rapidly screen protein-small molecule interactions that are not easily screened by other methods. The assay is based upon a sensor technology called a "photonic crystal" structure that is inexpensively manufactured from sheets of plastic film and incorporated into disposable microplates. By eliminating the need for a label, the assay is less susceptible to errors and artifacts caused by conformational change or blocking of active binding epitopes. It is envisioned that the technology will be used in the context of a primary screen of a chemical library and as a secondary screen for measuring dose-response characteristics of a protein-small molecule combination.

**Photonic Crystal Biosensor Nanostructures and Materials for Advanced Performance**
B. T. Cunningham*  
bcunning@uiuc.edu  
National Science Foundation

\textit{Conducted in the Micro and Nanotechnology Laboratory}

The specific aims of the research project investigate means for advancing the state-of-the-art for photonic crystal biosensor performance and applications. Sensor designs will be approached first by computer simulation using rigorous coupled wave analysis (RCWA) and finite difference time domain (FDTD) methods, followed by fabrication and testing of the structure. The design goals will be to produce more narrow resonant spectra, higher surface/volume ratio, and higher electromagnetic field interaction with adsorbed material than first-generation designs. The incorporation of different materials to increase surface electromagnetic field intensity, and structures to maximize the interaction of the field with adsorbed biomolecules, will be demonstrated.

* Denotes principal investigator.
Experimental Studies of Microdischarge Devices and Arrays

This research program is focused on fabricating and examining the properties of arrays of microdischarge devices. A variety of processes (wet and dry chemical processing, laser ablation, and ultrasonic milling) are employed to fabricate cylindrical and pyramidal cathodes in silicon as part of a multilayer structure suitable for large-scale production. The properties of arrays and single devices operating in the rare gases are of particular interest, and emphasis is being placed on the characteristics of devices smaller than 50 μm.

Fabrication of Large Area, High Density Microdischarge Arrays on Flexible Substrates
J. G. Eden*
jgeden@uiuc.edu
National Science Foundation; Anvik Corporation

In collaboration with the Anvik Corporation, the fabrication of large arrays of microcavity discharge devices on flexible substrates is being pursued. Excimer laser micromachining techniques, combined with roll-to-roll processing, are attractive for inexpensively manufacturing microdischarge devices in large area arrays.

Femtosecond Nonlinear Optical Phenomena
J. G. Eden*
jgeden@uiuc.edu
Northrop Grumman Corp.

Experiments are being conducted in which ultrafast laser pulses (~100-150 fs) produce ionized filaments in air or other gases. Peak optical field intensities exceeding $10^{13}$ W-cm$^{-2}$ are sufficient to produce stable channels having extraordinary optical and electrical characteristics. In particular, emphasis is being placed on the coherent nonlinear processes occurring in these filaments.

Large Microdischarge Arrays: Diagnostic and Fabrication Equipment
U.S. Army Research Office, DAAD19-01-1-0417

Funds have been provided to purchase equipment for experiments exploring nonlinear optical processes in intense optical fields and the behavior and fabrication of microdischarge devices having dimensions below 100 μm. These equipment items have significantly improved the characterization and functionality of microdischarge devices and arrays fabricated in Si and glass. Improvements in the regenerative amplifier of a Ti:Al$_2$O$_3$ femtosecond system, including its pulse energy and bandwidth, have also been made.

Microdischarge Arrays: Phase 2
jgeden@uiuc.edu
U.S. Air Force Office of Scientific Research, AF EWING TECHNOLOGY 03-1

The focus of this research program is scaling of microdischarge arrays to $10^4$-$10^5$ devices and emitted power densities of 0.1-1 W-cm$^{-2}$ in the ultraviolet. Arrays are being fabricated in silicon with devices having inverted square pyramidal cathodes and polymer or multicomponent dielectrics. Large arrays have also been successfully constructed and operated in glass in which the pixels are excited with an interdigitated electrode configuration. Several diatomic molecular emitters and excitation processes are under investigation, with initial emphasis on mid- and near-UV emitters.

Microdischarge Devices and Arrays: Quantum and Coherence Effects
U.S. Air Force Office of Scientific Research, F49620-00-1-0372

A family of photonic devices, known as microdischarges, is being developed under this multiyear program. Based on microplasmas confined to volumes of nanoliters or less, these devices have remarkable properties, including the ability to operate as stable glows at atmospheric pressure and with specific power loadings of several tens of kW-cm$^{-3}$. Single devices and arrays as large as 30 x 30 pixels have been fabricated in silicon, ceramic, and metal/polymer structures. Many applications, including broad-area UV sources, pump sources for microchip lasers, arc lamp ignition, and gas chromatography, are being pursued. Other research thrusts in this program are femtosecond spectroscopy of small molecules by coherent nonlinear optical processes and the study of the optical properties of nanoparticles for lasers and biosensing applications.

* Denotes principal investigator.
Microdischarge Long Wave Infrared Source Technology Development
J. G. Eden*
jgeden@uiuc.edu
Northrop Grumman Corp.

The characteristics of microcavity plasma devices as emitters in the infrared (5-12 μm) are being studied in experiments with a variety of device designs. Spectroscopic and power measurements of single devices and arrays are being carried out in conjunction with theoretical studies.

Microdischarge Micro-Thruster Technology Development
J. G. Eden*
jgeden@uiuc.edu
Ewing Technology Associates

The potential of microcavity discharges as sources of thrust for small ("pico") satellites is under investigation. Experiments measuring the electrical characteristics of robust device structures, including Ni/BN/Ni designs, are being conducted to assess the magnitude of thrust attainable as well as the device lifetime.

Microdischarges and Rare Earth-Doped Waveguide Devices: Visible and Ultraviolet Sources for Lasers and Sensors

The demonstration of new sources of ultraviolet and visible radiation is the thrust of this research program. Current efforts are two-pronged. Microdischarge devices developed in this laboratory are under study as emission sources for displays or as chemical sensors. Cylindrical and typically 20 to 400 μm in diameter, these microdischarges have properties (VI characteristics, specific power loading) that are unique and quite attractive for a variety of applications. The second facet of this research effort is the study of nonlinear optical phenomena on the sub-100 fs time scale and at intensities exceeding 10^{10} W-cm^{-2}. Using colliding pulse mode-locked and Ti:Al_{2}O_{3} laser systems, wave packet formation, four-wave mixing, and high-order harmonic generation are being studied, both experimentally and theoretically.

Microdischarges for Phased Arrays of Low Coherence Emitters, and Microchip and Microsphere Lasers
J. G. Eden*
jgeden@uiuc.edu
U.S. Air Force Office of Scientific Research, F49620-03-1-0391

A new family of photonic devices, known as microcavity discharges, is being developed under this multiyear program. Based on microplasmas confined to volumes of nanoliters (or less) and spatial dimensions of nominally 10-100 μm, these devices exhibit remarkable optical and electrical properties. The fabrication of single devices and arrays as visible or ultraviolet emitters for applications in biomedical diagnostics, displays, and environmental sensing is being pursued. Microcavity discharge devices with semiconductor cathodes have also been observed to be sensitive detectors of visible and near-infrared radiation, and the properties of these new photodetectors are under investigation. An emphasis of this program is the realization of two-dimensional arrays of microemitters in which adjacent pixels are optically coupled.

Novel Miniature Diagnostic Using Microdischarge Technology
J. G. Eden,* C. Wagner
National Science Foundation; SBIR; SBC ETA UI-99-09-P1

This SBIR program is developing chemical sensors based on microdischarges fabricated in a "flow through" geometry. Because of the high specific power loadings accessible with microdischarges (> 100 kW-cm^{-3}), arrays of these devices are well suited for the remediation of toxic gases. The emission spectra of gases flowing through a single 100–400 μm diameter microdischarge are presently being studied as a diagnostic of molecular fragmentation in the discharge and as a means of detecting impurities in the gas flow stream.

Spatially-Resolved Detection of Weak Magnetic Fields by Laser Magneto-Optical Techniques
J. G. Eden,* J. Gao,* J. M. Talmadge, R. Roth, A. Fai
U.S. Air Force Office of Scientific Research, F49620-01-1-0546

Magneto-optical techniques are being developed under this program to detect weak (< 1 nT) magnetic fields for biomedical applications. By employing epitaxial films of novel garnet films in combination with nonlinear optical processes and synchronous detection, magnetic fields as low as 10 nT have been detected reliably.

* Denotes principal investigator.
Visible and Infrared Laser Spectroscopy
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Northrop Grumman Corp.

Atomic and molecular laser spectroscopy in the visible, ultraviolet, and infrared is the focus of this research effort. Currently, emphasis is being placed on the spectroscopy of the Rydberg states of the neon dimer and rubidium dimers. Excitation spectroscopy of the neon dimer has yielded the first rotationally resolved bands as well as observation of triplet splitting. As a result, structural constants of the molecule have been determined. Femtosecond studies of the dissociation of diatomic molecules, observed in real time, are also being carried out.

Metal Halide Lamp Plasma Model
J. Gao,* J. G. Eden,* F. Shen
APL Engineered Materials

Calculations of ground and excited state potentials of excimer molecules of interest for lamp applications are being carried out. Comparison of experimental photoassociation spectra with quantum calculations has resulted in improved molecular spectroscopic constants for the xenon-monoiodide excimer that emits in the deep ultraviolet at 254 nm. The optimization procedure also involves comparison with emission data, and subsequent studies will focus on the mercury dimer.

Optoelectronics

Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems
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National Science Foundation

The objective of the NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (NanoCEMMS) is the development of a manufacturing capability for manipulation and sensing of materials ultimately at the nanometer scale. To this end, the Photonic Device Research Group is developing optical sources for application in the eventual toolkit, which enables a new revolution of manufacturing. We are developing photonic crystal vertical cavity lasers that employ photonic crystal effects in the direction of light propagation. These devices are promising for the high-power, single-mode operation that will be required for optical sensing at the toolkit. The holes inherent to this device are also suitable for material introduction pores of the toolkit assembly. In addition, we are developing integrated vertical cavity surface emitting lasers (VCSELs) and photodetectors. Such a device will find application in fluorescence identification and position sensing. We are thus pursuing close packed 2-dimensional arrays of intermeshed VCSELs and photodetectors for use as optical sensors.

Next-Generation Optical Materials and Devices
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The goal of nanotechnology is to create materials and devices that exhibit novel and significantly improved properties due to their nanoscale size. We are developing nanophotonic light sources with enhanced characteristics for future photonic ultra-high-capacity communication systems. We seek to combine aggressive advances in 3-dimensional electronic confinement obtained from quantum dots with the unprecedented optical confinement achieved from photonic crystals to develop the next generation of highly efficient microcavity optical sources.

Photonic Crystal Emitters for Next Generation Light Sources
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Army Research Laboratories

We are developing vertical cavity laser sources with enhanced characteristics for future photonic and remote

* Denotes principal investigator.
sensing applications. Our devices consist of vertical cavity surface emitting lasers that are transversely defined by a photonic crystal. The pursuit of suitable nanotechnologies required for photonic crystal fabrication in a variety of materials is under way. Specifically, electron beam and focused ion beam lithography are being developed for photonic crystal fabrication. This work will also focus on transversely coupled photonic crystal defects, producing coherently coupled vertical cavity laser arrays.

**Photonic Crystal Nanophotonic Devices**

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*U.S. Air Force Office of Scientific Research*

The objective is to develop nanophotonic devices based upon photonic crystal nanocavities employing a variety of semiconductor material systems. Our goal is to develop the photonic crystal design and processing techniques to maximize cavity quality values, minimize cavity volume, and minimize waveguide loss. We will also explore novel vertical photonic crystal nanocavities incorporating quantum dots, and pursue coupling photonic crystal cavities and waveguides for integrated devices with post-processing cavity tuning techniques.

**Spatial, Temporal, and Spectral Localization for Advanced Photonic Applications**

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*Defense Advanced Research Project Agency*

Future chip-based optoelectronic systems will require an unprecedented decrease of size and operating power, while simultaneously incorporating greater functionality and complexity. This research program builds on advanced materials and device concepts to create a multifunctional photonic crystal based photonic integrated circuit that incorporates quantum dot active regions. We will explore diode injection and extraction to and from engineered quantum dot structures, integrated with spatial selectivity within photonic crystal waveguides and optical nanocavities. This project will encompass three levels of technology research: system integration, novel device structures, and advanced epitaxial growth. In the Photonic Device Research Group, our objective is to demonstrate a photonic microsystem composed of an electrically injected optical source, compact waveguides, detectors, and optical memory elements.

**VCSEL Reliability**

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*Sun Microsystems*

We are investigating the reliability of vertical cavity surface emitting lasers (VCSELs) operating under high temperature and humidity. This research involves the fabrication of several different VCSEL structures, which will be life tested. After testing, the characteristics of the VCSELs will be examined, and in particular the influence of the laser structure on reliability will be ascertained.

**Fiber Optical Force Sensors for Truck Hunting Applications**

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*Association of American Railroads*

The objective is to develop fiber optical force sensors for measurement of time-dependent lateral impact force on the track for truck hunting applications in railroads. We have succeeded in two designs of fiber optical force sensors based on the attenuation of light transmission due to microbending effects. The idea for our applications is to use our fiber sensors for measurements of lateral impact force as a function of time at various locations on a track. We have previously succeeded in measuring the weigh-in-motion sensor for different waveforms of the force. We will apply our experimental techniques to detect the wheel impact of the side of the track for lateral force measurement. This technology will have potential applications for truck hunting.

**Fundamental Research on Infrared Photodetectors**

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*U.S. Army Research Office, Multidisciplinary Research Program of the University Research Initiative Program, DAAD 19-01-1-0591*

This is a Multidisciplinary Research Program of the University Research Initiative (MURI) project on the fundamental issues of infrared detection. We will focus on the following: investigation of HgCdTe defects using first-principles theory together with optical and electrical characterization, which includes nanotechnology characterization of both III-V and II-VI materials using the near-field scanning optical microscope (NSOM) and the transmission electron microscope (TEM); type II antimony-based quantum-cascade photodetectors; and

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* Denotes principal investigator.
quantum-dot infrared photodetectors (QDIPs) for high sensitivity normal incidence detection. We will also collaborate closely with industry and government laboratories.

**High-Speed Wavelength-Agile Optical Network**
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National Science Foundation

We propose to explore the architecture and device development issues necessary to develop optical local area networks (LANs) that are ready to interface with optical metropolitan area networks (MANs). Our goal is to develop a clear plan for integration of multilwavelength LANs and MANs in order to improve the degree to which the benefits of high bandwidth in the MANs are delivered to end users on the LANs. Our tasks include the following: quantitatively evaluate the impact of wavelength conversion on network reliability and study the design of all-optical access architectures that leverage high-speed wavelength conversion and add/drop channel capabilities; design and fabricate tunable laser sources and wavelength converters using composite resonator vertical cavity lasers; design and fabricate a novel semiconductor-based wavelength converter capable of format-transparent and ultrafast wavelength conversion; and design and fabricate add/drop filters and photodetectors.

**Model and Design of THz Quantum Cascade Lasers**
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SPIRE Corporation (DARPA Phase-II Award), ARMY SPIRE 2005-206-00

We will carry out modeling and design of candidate terahertz (THz) quantum cascade (QC) laser structures with the goal of achieving the highest possible laser operating temperatures. We will also provide device fabrication and measurement support, as possible with University of Illinois facilities. The basic QC laser design will involve a chirped superlattice injection layer, based on the A1GaAs/GaAs epitaxial material system.

**Modeling and Experimental Characterization of Semiconductor Optical Buffers**
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Defense Advanced Research Projects Agency (University of California–Berkeley-prime), DARPA SA4472-32446

The goal of this project is to develop the theoretical models based on the electromagnetically induced transparency effect to design slow-wave devices using semiconductor quantum wells and quantum dots. We will develop the band structure models of semiconductor quantum dot and quantum wells for optical buffer applications and calculate the interband, intersubband transition matrix elements and the nonlinear optical susceptibility spectrum. Experimentally, we will characterize semiconductor quantum-dot samples and measure the group index of novel semiconductor optical buffers, which will be provided by Prof. Chang-Hasnain's group at the University of California–Berkeley.

**Nonlinear Quantum Optical Devices Using Quantum Dots**
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We propose the use of quantum dots (QDs) for slow light and optical buffer applications. We will develop the theory of slow light in semiconductor quantum dots (QDs) and its dependence on physical parameters such as dot size, materials, optical pump intensity, and wavelength. The major goal is to achieve variable time delay with a broad bandwidth from 1 GHz to 40 GHz using semiconductor quantum dot devices. We will also explore the applications of coherent quantum effects in low-dimensional semiconductor structures including quantum dots. This task is part of a Defense Advanced Research Projects Agency funded Photonics Center at the University of California–Berkeley with other team members.

**Semiconductor Optical Buffers Using Grating Slow-Wave Devices**
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National Science Foundation

Optical buffering is essential to optical packet switch implementations that have been proposed worldwide to overcome future problems with large electronic packet switches. We propose to design and fabricate semiconductor-based optical buffers by using sampled gratings, Moiré gratings, and chirped Moiré gratings. These gratings will be fabricated using a new method to obtain a photonic bandgap-engineered material that has a large index contrast, which is essential for group velocity reduction. Our proposed optical buffer, unlike fiber loop delay lines, is variable by using integrated electro-optical switches or current injection. Another significant advantage is that other semiconductor optoelectronic and optical devices can be integrated with our proposed

* Denotes principal investigator.
variable optical buffers since they are based on the same semiconductor III-V compounds. The proposed photonic bandgap structure will be fabricated by our collaborator at the University of California at Berkeley using periodic buried AlOx channels with growth on a patterned substrate. Slow Light in Semiconductor Quantum Well Waveguides S. L. Chuang,* P. Kondratko s-chuang@uiuc.edu U.S. Air Force Office of Scientific Research (University of California-Berkeley-prime), AF UCAL SA4455-32432PG We will develop theory for achieving controllable slow-down of the group velocity in a narrow transparency window by applying a pump beam based on the mechanism of electromagnetically induced transparency (EIT) and by applying an electric field to quantum-well structures with an electric field bias (or an external pump). We can control the exciton energy levels and wave functions. Therefore, we can engineer the slow light effects for applications in novel variable optical buffers, which are essential for all-optical networks. Ultraportable Chemical Sensors Based on Chemoresponsive Dye Arrays K. S. Suslick,* (Chem. Sci.), S. L. Chuang,* M. Chuang, P. Kondratko s-chuang@uiuc.edu HSARPA HSHQPA-05-6-0035 This project is on the development, integration, and characterization of a colorimetric sensor array, including further miniaturization of the sensor array through noncontact, nonaqueous inkjet printing and the further exploration of new chemoresponsive dyes for improved array response. We are responsible for the design and development of extremely compact and low-energy optoelectronic readout of the arrays using LEDs and CCD or CMOS photodetector arrays. Power and Energy Systems Optimal Power Flow Application Issues in the Pool Paradigm E. Bompard (Politecnico of Torino), G. Gross* The Italian Fulbright Commission; U.S. State Department; Power Systems Engineering Research Center The research focuses on the application of the Optimal Power Flow (OPF) to competitive markets. Since the OPF is a central decision-making tool, its application to the more decentralized decision making in the competitive electricity markets requires considerable care. There are some intrinsic challenges associated with the effective OPF application in the competitive environment due to inherent characteristics of the OPF formulation. Two such characteristics are the flatness of the optimum surface and the consequent continuum associated with the optimum. In addition to these OPF structural characteristics, the level of authority vested in the central decision-making entity has major ramifications. These factors have wide ranging economic impacts with implications that are pronounced due to the fact that, unlike in the old vertically integrated utility environment, various market players are affected differently. The effects include price volatility, financial health of various players, and the integrity of the market itself. Researchers apply appropriate metrics to evaluate market efficiency and how the various players fare. Researchers also study the impacts of OPF applications in the Pool paradigm, with both supply and demand sides explicitly modeled, and use extensive numerical simulations. The numerical results show the variability of nodal prices and the skew possible in different "optimal" allocations among competing suppliers. Such variability in the results may lead to serious disputes among the players and the central decision-making authority. Reactive Load Modeling Impacts on Nodal Prices in Pool Model Electricity Markets E. Bompard (Politecnico of Torino), G. Gross* The Italian Fulbright Commission; U.S. State Department; Power Systems Engineering Research Center The project is concerned with the interpretation of nodal prices in competitive electricity markets based on the Pool paradigm. Such prices are the byproducts of the optimization performed by the independent grid operator (IGO) to determine the centralized economic dispatch taking into account all the transmission network and the physical and operational constraints. The IGO implicitly takes into account congestion considerations in determining the centralized economic dispatch. Under the Pool paradigm, a system marginal price no longer exists and each bus may have different real and reactive power nodal prices due to line losses and congestion avoidance considerations that can arise when the limit of one or more constraints is reached. The objective is to explore the economic signals provided by these prices and effectively apply them in the design of markets and the rules of the road for these markets. The main focus of the research is on the explicit evaluation of the impacts of the reactive load on the nodal real and reactive prices. Researchers adopt a rather general model for the representation of the reactive load: the reactive load at each node is represented as an

* Denotes principal investigator.
affine function of the real power load at that node; that is, the reactive load is the sum of a constant and a constant power factor component. This model includes as special cases the constant reactive load and the constant power factor load including the case of purely real load corresponding to unity power factor. Researchers investigate the relationship between the real and reactive nodal prices and evaluate how they are impacted by the dual variables due to the various other physical and operational constraints in the system. Additional study focuses on the significance of the nodal price observations and the effective utilization in developing appropriate price signals in the Pool paradigm.

E. Bompard (Politecnico of Torino), G. Gross*
The Italian Fulbright Commission; U.S. State Department; Power Systems Engineering Research Center

The restructuring of the electricity industry has spawned the introduction of new independent grid operators or IGOs, typically called transmission system operators (TSOs), independent system operator (ISOs), or regional transmission organizations (RTOs), in various parts of the world. An important task of an IGO is congestion management (CM) and pricing. This activity has significant economic implications on every market participant in an IGO region. The research considers the congestion management schemes and the associated pricing mechanism used by the IGOs in five representative systems: England and Wales, Norway, Sweden, PJM, and California. Researchers developed a unified framework for the mathematical representation of the market dispatch and redispatch problems that the IGO must solve in CM in these various jurisdictions. This unified framework is used to develop meaningful metrics to compare the various CM approaches so as to assess their efficiency and the effectiveness of the market signals provided to the market participants.

The Role of Load Demand in Elasticity in Congestion Management and Pricing
E. Bompard (Politecnico of Torino), G. Gross*
The Italian Fulbright Commission; U.S. State Department; Power Systems Engineering Research Center

In the open access transmission regime, the common carrier nature of the transmission system may give rise to frequent conditions of congestion. Under such conditions, a violation of one or more physical or operational constraints in the base case or one of the contingency cases is encountered. Congestion may result in certain cases in marked price volatility and leads to price spikes. This is particularly true in competitive electricity markets that lack demand response. In this study, researchers examine the role that demand responsiveness can play in competitive electricity markets.

Typically, the task of congestion management and pricing is vested in the hands of an independent grid operator (IGO). The IGO uses an optimal power flow (OPF) based tool to determine the necessary actions to relieve the system of the congestion and to determine transmission system usage charges. The actions of price responsive loads may be represented in terms of the customers' willingness to pay. From each customer's demand curve, the elasticity of the load at different prices is known and the benefit function is derived. The load at each bus ceases to be a fixed quantity and becomes a decision variable for the optimization problem of the IGO. In this way, the IGO has additional degrees of freedom in determining the necessary actions for congestion relief.

The project investigates the impacts of load elasticity in congestion management and pricing. Researchers analyze the salient characteristics of the optimum determined by the IGO with elastic load demand explicitly represented. The research team is evaluating elasticity effects on consumer, producer, merchandising, and social surplus. In addition, the demand responsiveness impacts on price volatility in terms of average price and standard deviation are determined and compared to the case without load responsiveness. The increase in market efficiency attainable in the presence of load responsiveness is assessed.

Biomechanical Energy Conversion for Future Marine Corps Operations
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U.S. Office of Naval Research

This project involves determining the best human motions for potential use in generating mobile electric power and then making the best electric generators for these motions. Mobile power is increasingly important for soldiers and for consumers of portable electronics. Batteries cannot supply satisfactory power levels for long enough times to meet most objectives, thus alternative methods have been sought. Human power is a viable method for generating mobile power in the few watts range, without the need for fuels.

* Denotes principal investigator.
Extraction of Low-Order Models from Finite Element Representations of Electromechanical Devices
P. L. Chapman*
Grainger Center for Electric Machines and Electromechanics

The finite element method is very effective at accurately modeling magnetic devices such as inductors, transformers, and motors, but is very computationally intense. Several thousand variables are used to describe what should be captured in only a few. In this project, a model reduction method was demonstrated that begins with the finite element technique. The thousands of variables are systematically reduced to only a few, with little loss of model accuracy. This was demonstrated so far for a single inductor. The new model runs several orders of magnitude faster than previous models.

Fully Integrated Switch-Mode Power Supplies
P. L. Chapman,* C. Liu
Grainger Center for Electric Machines and Electromechanics

A typical switch-mode dc power supply involves several integrated circuits and discrete passive components. By moving all the circuitry to a single integrated circuit, the circuit is reduced in size and potentially cost. Power management and distribution within a chip are better enabled. Several versions of a step-up dc-dc converter have been demonstrated. Newer versions will take advantage of MEMS technology to improve the quality of the passive components and reduce the space occupied by the chip.

Optimal Diversification of Multiple Energy Sources
P. L. Chapman*
National Science Foundation

The goal is to develop a general approach to the design of a power converter that can interface multiple, unlike, electrical energy sources. The interface would be capable of maximizing or minimizing the energy flow from given sources. The diversification of the energy sources takes advantage of environmentally responsible energy, improves reliability, and potentially reduces cost.

Analysis and Evaluation of VAr Support as an Ancillary Service
G. Gross,* S. Tao
Power Systems Engineering Research Center through Cornell University

The unbundling of electricity services has brought about the need to evaluate and quantify the various services. VAr support is one such service. Researchers have analyzed the principal attributes of this service and identified the dominant cost component. The research team is developing an analytic basis for the evaluation of the VAr support needs associated with transactions. The objective is to develop an allocation mechanism for VAr support among the transactions on the system.

Analysis of the Bilateral Transaction Paradigm for Electricity Markets
G. Gross*
The Grainger Foundation Inc.; Power Affiliates Program

Researchers are investigating the structure and functioning of bilateral-transaction-based electricity markets such as those created by restructuring in Norway and Sweden. The objective is to analyze the salient characteristics of the Nord Pool market and to perform a side-by-side comparison with the England and Wales Electricity Pool. The focus is on the assessment of congestion management and pricing. A mathematical model representing the market structure and rules governing the operation of the Nord Pool market has been developed. The study will assess the functioning of the Independent Grid Operator and the critical role of transmission services.

Congestion Management Scheme for Multitranaction Systems
G. Gross,* S. Tao
Economic Policy Research Institute, Department of Defense

Researchers are investigating the allocation of charges for congestion management (CM) in multiple transaction networks. The problem is formulated in two stages. In the congestion allocation stage, the operator determines the congestion burden attributable to each individual transaction. In the congestion relief stage, the operator used an adjustment bidding to determine the congestion relief actions. The allocation scheme is being tested on several systems.

Development of an Analytical Framework for Dispersed Generation
G. Gross,* Y. Lin
The Grainger Foundation Inc.; Power Affiliates Program

Increased competition in the electricity supply industry, increasing costs of transmission and distribution upgrades, greater pressures on cleaner environment, higher energy efficiency, and decreasing marginal costs of new and smaller generation technologies are some of the factors that are going to impact alternatives for adding electricity supplies. The principal objective is to formulate a comprehensive analytical framework for dispersed generation within which the economic, technological,
Environmental, reliability aspects can be studied. Simulation of systems with transmission constrained load pockets and dispersed generation expansion alternatives are being performed.

**Development of an Analytical Framework for Strategic Bidding in Competitive Electricity Markets: Modeling and Policy Analysis**

G. Gross,* G. Deltas (Econ.), M. Joung  
*National Science Foundation, ECS-0000577*

The work is focused on the design, functioning, and performance of competitive mechanisms in wholesale electricity markets taking explicit account of the specific characteristics and constraints of electrical generation and consumption. The objective is to develop a general and comprehensive analytic framework that integrates the game theoretic aspects of electricity exchanges with the unique constraints under which electric power systems operate. This framework will lay the foundation for the evaluation of various designs for electricity market structures and "rules of the road" of auction mechanisms that incorporate the constraints imposed by the physical, engineering, and operational constraints inherent in electricity systems, so as to maximize economic efficiency.

The in-depth analysis of the structural characteristics of electricity markets will provide a basis for the formulation of optimal bidding and offering strategies with both supply- and demand-side bidders. Researchers aim to use the framework to address the various aspects of the implementation and performance of auctions for electricity; the explicit incorporation of uncertainty; the interrelationships between the MWh commodity markets and specific markets in ancillary services; and the impacts of longer term forward and future markets.

These issues will be investigated together with topics related to the opportunities for gaming, the existence and exercise of market power, and the impacts on electricity prices. In addition, the framework will serve as an effective testbed for a wide range of policy experiments, including those focused on the nature and scope of regulation in the restructured industry. Throughout the proposed work, researchers will implement simulation tools to illustrate the performance of various market designs, rule specifications, regulatory policies, and strategic behavior of various players.

**Effective Deployment of Financial Instruments in Competitive Electricity Markets**

G. Gross,* S. Tao  
*The Grainger Foundation Inc.; Power Affiliates Program*

With the recent emergence of the well defined electricity spot markets and the establishment of the trading of electricity futures on specific exchanges, the application of financial instruments such as options, futures, and forwards provides significant new tools to players in electricity. Such instruments can be used for risk management as well as speculation. The focus of this research is on the effective incorporation of these instruments into the operation of electricity trading. Researchers will investigate certain design and definitional issues in the deployment of financial derivative concepts to electricity markets. Of particular interest is the evaluation of the risk mitigation capabilities provided by these instruments for the trading of electricity and their impacts on the spot markets. In this project, researchers will investigate the salient uniqueness of electricity derivative contracts due to the physical power system. The research team also will investigate the possibility of developing new financial instruments and strategies to accommodate the different risk preference of various participants in the spot electricity market. Moreover, researchers will study the impact of financial derivatives on various players of the market.

**Loss Allocation Scheme for Multitransaction Systems**

G. Gross,* S. Tao  
*The Grainger Foundation Inc.; Power Affiliates Program*

Researchers are studying the allocation of losses as a function of physical power flows in multitransaction systems. The research team has recast the power flow problem in a transaction-based network and is studying the issue of appropriately allocating losses on the basis of flows that the transactions bring about. Extensive tests of the approach are being carried out on systems of varying sizes. A mechanism for loss compensation has been developed to provide choice to transacting entities.

**Metering Requirements and Metering Data Applications in Open Access Bulk Electricity Systems**

G. Gross,* J. W. Lee  
*Power Engineering Research Center through Cornell University; The Grainger Foundation Inc.*

The FERC Order No. 888 specified six unbundled ancillary services that may be provided to transmission customers. The NERC has developed a classification of 12 separate interconnected operations services. The unbundling of the services and the disintegration of the vertical structure of

* Denotes principal investigator.
the electricity business have set up new requirements for information acquisition, metering, and communications. This project will examine the communication protocols and the data management aspects of the metering activities.

**Real-Time Security Monitoring and Control**

G. Gross*

National Science Foundation

Researchers have prepared a White Paper that outlines the scope of issues, challenges, and opportunities in the area of real-time security monitoring and control (RTSMC) of power systems in the restructured electricity industry. The counterpart of power system reliability in real-time operations is security—the ability of the power system to withstand contingencies. This White Paper is part of a set of six papers on reliability aspects of the electric power system prepared for the U.S. Department of Energy by the Consortium of Electric Reliability Technology Solutions (CERTS).

**Simulation of the Multinode Open Access Same-Time Information System**

G. Gross,* Y. Tian

The Grainger Foundation Inc.; Power Affiliates Programs

A Web-based simulator of the Federal Energy Regulatory Commission (FERC) mandated Open Access Same-Time Information System (OASIS) network was implemented. The purpose of the simulator is to provide a tool to study the various aspects of an OASIS network, to gain a strong intuitive feel for its operations, and to train users. For a specified time period, the OASISNET simulator reproduces an OASIS network of multiple nodes using the same communications medium as the actual system, the Internet, and with multiple players using the simulator simultaneously. Salient features of the simulator are its modular architecture, as well as the ability to simulate multinode OASIS network operations and to accept simultaneous access from remote users through use of client/server technology. The simulation focuses on the dissemination and use of the available transmission capability information. Applications of the new simulator for training and analysis are under study.

**The Load Frequency Control (LFC) Performance Assessment**

G. Gross,* J. W. Lee

The Grainger Foundation Inc.; Power Affiliates Programs

Load frequency control is used to regulate the frequency of the power system to be within acceptable bounds around the synchronous value. Researchers are constructing a framework for the evaluation of LFC performance assessment taking into account the random variations of the actual load over time. Appropriate metrics for the LFC performance assessment are constructed in the random process based framework. These metrics are used to formulate the criteria for LFC performance assessment. The effectiveness of industry criteria is assessed.

**A Hybrid Systems View of Inverse Problems in Power System Dynamics**

I. A. Hiskens,* D. Liberzon,* M. A. Pai*

National Science Foundation, NSF ECS-0114725

Analysis of power system dynamic behavior frequently takes the form of inverse problems, where the aim is to find parameter values that achieve (as closely as possible) a desired response. Examples include parameter estimation, quantifying parameter uncertainty, boundary value problems, and optimal control. The project developed algorithms for solving such inverse problems. Power system behavior inherently involves interactions between continuous dynamics and discrete events. A systematic hybrid systems framework for modeling, analysis, and algorithms was done. The project is completed.

**Analysis and Design of Vector Controllers for Induction Machines Using Singular Perturbations**

P. T. Krein,* Z. Sorchini

Grainger Center for Electric Machinery and Electromechanics

An alternative machine model is proposed for the analysis and design of controllers. Based on this framework and using singular perturbation analysis, a sliding mode torque controller is presented. It is shown that under certain restrictions, direct torque control (DTC) can be derived from this controller. The derivation provides insight on dynamics and stability of DTC. In addition to the analysis of established controllers, new controllers are proposed. In particular, a controller based on stator flux is shown to encompass benefits of field oriented control and DTC, while avoiding their limitations. The viability of this new controller is confirmed experimentally.

**Coupled Magnetic Applications of Ripple Correlation Control**

P. T. Krein,* R. Balog

Grainger Center for Electric Machinery and Electromechanics

Filters based on coupled inductors are promising for use in energy conversion applications because they allow noisy waveforms to be “steered” into filter circuit elements. Previous work enhanced coupled filters through an automatic tuning process that allows peaks or notches in

* Denotes principal investigator.
filter characteristics to follow circuit characteristics such as switching frequency or specific noise frequencies. The result is a powerful stand-alone filter that has been verified both in simulation and in hardware. A number of papers have been published on these techniques. Present work involves applications of auto-tuning coupled inductor filters to distributed dc power systems.

**Design of Small Inverter-Fed Induction Motors**  
P. T. Krein,* M. Amrhein  
*Grainger Center for Electric Machinery and Electromechanics*

Nearly all induction machines built today are based on previous designs, carrying on constraints imposed long ago. Although new materials are employed, the basic concepts have not changed in decades. However, with power electronic inverters, some constraints no longer apply. This project investigates fundamental design choices, such as number of phases, operating frequency, and number of poles, as well as geometric parameters. The goal is to derive design rules to yield machines with improved efficiencies and operating characteristics. Design tools and methods specialized for inverter-dedicated induction machines are being developed, and complete machines will be designed and tested.

**Development of an Automated First-Principles Design Tool for Electromechanical Devices**  
P. T. Krein,* T. O'Connell  
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*Grainger Center for Electric Machinery and Electromechanics*

The objective is to use closed-form solutions of Maxwell’s equations as a tool for first-principles design of electromechanical devices. In this research, a Mathematica program has been developed that automates such a process. A generic layered material is used to represent material in the rotor, stator, or air gap of an electric machine. Current work focuses on better understanding the nature of the fundamental fields and forces at work inside an electric machine. Conformal mapping based on the Schwarz-Christoffel mapping theorem is being explored to solve analytically for magnetic fields and forces in two-dimensional machine structures.

**Distributed Controls in a Distributed DC Power System**  
P. T. Krein,* R. Balog  
*National Science Foundation Grant, ECS-0224829*

Distributed dc bus architectures have become the standard for power distribution in naval ships and telecomm applications. This study focused on distributed control techniques for point of load (POL) converters that act locally but in an orchestrated manner to ensure reliable system operation without a central controller. It is expected that information contained in the bus voltage can provide adequate information about the system state of health. To test these algorithms, a number of POL converters and controls were designed and built to create a distributed dc system.

**Dynamic Simulations of Hybrid Electric Vehicles**  
P. T. Krein, * M. Amrhein  
*Grainger Center for Electric Machinery and Electromechanics; U.S. Department of Energy*

Hybrid electric vehicle (HEV) simulators, used to design and analyze the performance of different components in hybrid cars, utilize steady-state models. However, in order to analyze designs in detail, dynamic simulations are necessary. Accurate information about peak and steady-state values of currents, voltages, and losses in power electronics devices can be obtained only from dynamic models. Other effects, such as rapid discharging of storage elements (batteries and capacitors), can be observed as well. The project goal was to develop a dynamic model of an HEV with various components, and to show that dynamic simulations could be used for the analysis of subsystem components, which would not be considered in a steady-state model. A dynamic HEV simulator based on Matlab-Simulink was developed at the University of Illinois several years ago and was modified to enhance and support new components such as fuel cells and ultracapacitors. The simulation concentrates on a series HEV, consisting of an energy source (fuel cell, combustion engine), an energy storage system (battery, ultracapacitor), and a traction system (transmission, induction machine, and inverter). The model accommodates the requirements of a design analysis, which especially includes losses in certain parts of the system. A journal paper was published in the IEEE Transaction on Vehicular Technology in May 2005, featuring results obtained from the model. The paper showed that it is possible to efficiently simulate a dynamic HEV model and to gain valuable information about the dynamic performance of system and subsystem components.

* Denotes principal investigator.
Flexible Digital PWM Control for Embedded Power Converters
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Switching power conversion for portable communications, personal digital assistants and most other electronic products is controlled through pulse width modulation (PWM). Since PWM produces strong components at the switching frequency and its multiples, one objective of X. Geng and P. Krein is to study spectral characteristics of PWM for purposes of noise and switching loss management. Nonrandom switching schemes are being developed to reduce interference without extra losses. Applications include flexible digital implementations for the full range of dc-dc converters and small motor drive units for automotive loads.

Life Extension of Lithium-Ion Batteries
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Limited battery life is a problem that affects industries such as aerospace, automotive, and portable electronics. Previously, life extension techniques such as equalization have been shown to increase the life of lead-acid batteries. In this work, experiments using battery equalization were run for over a year to observe changes in cell performance. Results showed that equalization improved pack utilization and extended life, even in small lithium-ion packs.

Mitigation of Power System Collapse through Active Dynamic Buffers
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National Science Foundation Grant, NSF ECS-0224829

Power electronics continues to grow as an element of electrical loads. Loads such as motor drives, computer power supplies, and compact fluorescent lighting serve to "isolate" load dynamics from the utility grid and enforce constant power behavior. They tend to destabilize the grid. In this study, power buffering is examined as a way to mitigate effects of constant power loads by controlling the dynamic impedance of the converter during a disturbance. Experiments have shown the advantages of using power buffers. Further work involves studying the interaction of multiple power-buffer converters in a distributed system.

Modeling of Sensorless Current Mode Voltage Regulator Modules
P. T. Krein,* J. Mossoba
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Special power converters are needed to supply the low voltages required by recent micorprocessors. These voltage regulator modules (VRMs), must provide fast regulation of output voltage, despite drastic changes in the current drawn by the CPU. The first step in successfully designing VRMs is to find a suitable mathematical model. The usual architecture involves numerous dc-dc converters acting in parallel. The research conducted shows suitable methods of simplifying models for VRMs. The proposed model achieves an acceptable level of detail without allowing the simplifications to compromise its accuracy. Optimization of these VRM systems is a subject of ongoing research.

Modular Power Electronics Lab
P. T. Krein,* R. Balog, Z. Sorchini
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Power electronics is a subject taught best by laboratory work in conjunction with formal lecture. Flexible modules have been prepared that allow the students to quickly explore various fundamental topologies in dc to dc, dc to ac, ac to ac, and ac to dc converters without having to worry about the control or isolated gate drive support circuitry. An FET box consisting of two isolated devices and flexible controls allows numerous one- and two-switch topologies to be studied. An SCR control unit that supports controlled rectifier experiments has also been designed. Several undergraduate students assisted in the work.

Re-Rating of Induction Machines for Traction Applications
P. T. Krein,* M. Amrhein, B. I. Fierro
Grainger Center for Electric Machinery and Electromechanics

Electrical machines used in traction applications are often chosen such that their rated power matches the need. However, a machine is inherently designed for a certain torque. Higher output power can be achieved by spinning the motor faster at constant flux. By re-rating the stator winding of the machine to a low nominal voltage, the constant torque range can be extended to higher frequencies and speeds, thus increasing the output power. A 2.25 kW machine was re-rated by a factor of 2:1 and tested in three configurations. The efficiency increased.

* Denotes principal investigator.
with increasing frequency, provided the machine operated at constant torque.

Software Development for a Modular Inverter
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Grainger Center for Electric Machinery and Electromechanics

A modular inverter is being created to serve as a test bed for various motor drive control schemes. This project is to develop a software common platform for control algorithms. By integrating Matlab/Simulink, Code Composer Studio, and Spectrum Digital eZdsp, we are able to streamline software development from computer simulation to target implementation. The process is efficient and allows developers to focus on the control scheme. A user graphical interface allows real-time control of multiple parameters and data logging.

Torque-Angle-Oriented Control for Induction Motors
P. T. Krein,* G. Zhang
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Constant voltage-frequency-ratio control, field-oriented control, and direct torque control are the most popular ac motor control methods. There are also numerous techniques to improve the static and dynamic performance by applying more complex algorithms to these controls. The goal of a proposed torque-angle-oriented control is to simplify control algorithms so that reasonably good static and dynamic performance may be achieved without adding complexity to the motor control system. A digital algorithm has been developed and tested to show the advantages of the torque-angle approach.

An Integrated 42-V Drive Design for Automobile Loads with a Low-Distortion Overmodulation Strategy
P. T. Krein,* A. Kwasinski
Grainger Center for Electric Machinery and Electromechanics

The automotive industry is moving to higher voltages to support more electric automobiles. This study develops an integral design methodology that considers motors, inverters, and the electrical design as a complete system. The proposed design consists of an induction motor wound for a suitable voltage range and driven by an inverter. The inverter is used in an overmodulation regime when bus voltage is low. A 3-D representation of the modulation process showed that a signal based on triangle injection will minimize distortion. This approach was tested experimentally. It was demonstrated that dc bus utilization improves without added losses.

A Microgrid-Based Telecom Power System Using Modular Multiple-Input Dc-Dc Converters
P. T. Krein,* A. Kwasinski
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A microgrid is an independently controlled portion of an electrical grid. It comprises its own power sources (such as fuel cells, solar cells, microturbines), energy storage devices (such as flywheels, batteries, ultracapacitors), and loads, usually interconnected with a larger grid. With independent control, a microgrid with a utility tie can deliver high reliability, high efficiency, and uninterruptible power functions, while reducing energy storage needs compared to traditional systems. This work explores a microgrid-based telecommunications power plant with a distributed architecture. Combinations of converters and controls create a flexible, reliable plant that meets performance needs of modern telecommunication systems.

Evaluating the Potential for Transmission Constraints on the Operation of a Competitive Electricity Market in Illinois
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Illinois Commerce Commission

The goal of this project is to determine if the transmission system in Illinois and the surrounding region is able to support a competitive electricity market: that is, one that would allow for effective competition to keep prices in check and allow for new market participants to compete effectively for market share. The project will seek to determine if there are conditions that could reasonably be expected to occur that would enable a company to exercise market power in one or more portions of the state and thereby create undue pressure on the prices charged to customers and/or inhibit new market participants from entering the market. It should be noted that the intent of this project is not to predict whether or not such market power would actually be exercised by any company. Rather, it is designed to determine if a set of reasonably expected conditions could allow any company to do so.

Interactive Visualization of Electrical Power System Transmission System Capacity
T. J. Overbye,* D. Wiegmann, Y. Sun
Power Systems Engineering Research Center

One of the major goals associated with restructuring in the electrical power industry is to allow nondiscriminatory access to the high-voltage transmission grid. However, a key difficulty in achieving this goal has been the fact that the capacity of the transmission grid has a finite but not

* Denotes principal investigator.
easily determined value. That is to say, the ability of the transmission system to support additional power transactions is limited by the need to maintain system security. The goal of this project is to develop and apply innovative visualization methods to aid market participants in determining this availability.

Workshop to Consider the Practicality of a Continental Energy SuperGrid
T. Overbye*
Richard Lounsbery Foundation

The purpose of this project is to convene a workshop to investigate the technical and societal viability of a proposal for the creation of a “Continental SuperGrid” to meet our country’s energy needs in the mid- to late-half of the 21st Century. The proposal calls for the creation of a continental grid, delivering both electricity and fuel. The electric portion of the grid would be superconducting, high voltage dc, with liquid hydrogen used as the core coolant. The electric power and hydrogen would be supplied from nuclear and other source power plants spaced along the grid. Electricity would exit the system at various dc-ac taps, connecting into the existing ac power grid. The hydrogen would also exit the grid, providing a readily available, alternative fuel—for perhaps fuel-cell based automobiles. While the scope of this proposal is certainly ambitious, given its potential for significant society-wide benefits, it is also one that deserves serious consideration and debate.

Impact of Distributed Generation on Power System Performance
M. A. Pai,* A. Zook
The Grainger Foundation Inc.; National Science Foundation, EPENS-0224829

In this research, the impact of adding new generation at the distribution level was examined. The distribution system is radial in nature and hence, adding generation presents a number of technical problems. In this research, system stability was examined with respect to parameter variations. Effect on transient and small signal stability was investigated. Work is continuing to investigate impact of other forms of distributed generation such as fuel cells, wind power, and so forth.

Model Reduction of Power Systems Using Krylov Subspace Method
M. A. Pai,* D. Chaniotis
National Science Foundation, ECS 00-00474; The Grainger Foundation Inc.

In this research, the iterative solver technique based on Krylov Subspace methodology is being applied for model reduction of power systems. The system is divided into a study area and an external area. The external area is then reduced in dimensionality. A criterion for coherency has been developed, and it has been shown to be equivalent or similar to the recently proposed synchrony method in the literature. Thus, a physical basis for model reduction is presented. (A paper has been accepted for IEEE Transactions—Power Systems).

Power Industry Restructuring and Pricing in Siberia
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Bureau of Educational and Cultural Affairs; U.S. Department of State

The restructuring of the power industry in Russia is under way. The existing nationwide market is planned to be divided into three regional sectors, one of which will be set up in the Siberian region of the country. The restructuring will allow the market arrangements to take into account the regional characteristics of electricity generation, transmission, and consumption. The project aims to develop an auction mechanism for the wholesale electricity trade in Siberia. Key aspects include review of the market structures currently in operation, design of the market forward trade and the associated pricing issues, development of procedures for the evaluation of rational bidding strategies for market players, and training of the players in the new environment.

Dynamic Data Driven Applications for Power Systems
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National Science Foundation

This project is investigating the use of time synchronized measured data for analyzing the state of power systems with particular emphasis on dynamic properties. The data are being considered for use in aiding power system operators in determining closeness to security boundaries, both static and dynamic.

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Dynamic Security Assessment for Operations
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Power System Engineering Research Center through Cornell University

This project is investigating the current state of online stability analysis for power systems and formulating needed research directions. It is looking at commercial software performance measures and the theoretical framework for integration into real-time security application environments.

Integrated Security Analysis
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Department of Energy-CERTS

This project is formulating new security analysis tools for operators using existing computational software code with online data. Traditional security application programs are used to create historical security results that will be used to develop learning algorithms. These algorithms will use both new computational results and historical results. This work is being done jointly with Washington State University.

Post-Contingency Equilibrium Analysis
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Grainger Foundation Endowments

This project is investigating the efficient computation of steady-state conditions following an outage. It enforces constant control inputs.

Reliability Tools for Power System Operators
P. W. Sauer,* T. Overbye

Department of Energy, Consortium for Electric Reliability Technology Solutions through Cornell University Power Systems Engineering Research Center

This project is investigating advanced security analysis visualization concepts to enhance the reliability of the interconnected grid. Results from online security analysis will be presented and displayed to operators in a format suitable for rapid decision making and for assessing the acceptability of the system state.

Transmission System Vulnerabilities in Power Systems
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Grainger Foundation Endowments

This project is investigating the critical set of transmission lines in maintaining an acceptable voltage collapse margin in power systems. The critical set is that group of lines that may be lost while maintaining sufficient capability for voltage support and real power transfer.

Trustworthy Communication and Computing Architectures for Power Systems
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National Science Foundation

This project is investigating the needs of power system communication and computing environments for future use in deregulated power systems. This includes the need to share information between regions and independent operators.

Reliable and High-Performance Computing

Composable Processors
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Conducted in the Coordinated Science Laboratory

As silicon fabrication technology improves, processors and system-on-a-chip (SOC) designs are moving toward gridded layouts to minimize the impact of wire delays on performance. The composable processors project is studying techniques to reduce the design time and cost of grid-based custom processors through the use of a set of pre-designed "tiles" that can be composed together to form a variety of custom system architectures. In addition to the design of the tiles and systems that use them, we are developing software techniques to automatically generate high-performance, low-cost architectures for specific applications in this design methodology.

Magnetoelectronic Reconfigurable Logic
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We are developing reconfigurable logic systems based on a novel magnetoelectronic device: the Hybrid Hall Effect device. These circuits can be configured to compute a wide range of logic functions with nonvolatile storage of their outputs and can be easily integrated into CMOS designs. Current challenges include reducing the power consumption of our circuits and developing system architectures that best take advantage of their capabilities.

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Self-Healing Reliable Reconfigurable Systems
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Reconfigurable logic is an attractive fabric for reliable system design because faults in portions of the logic can be corrected by reconfiguring the system to avoid the faulty resources. We are developing design techniques for reliable systems implemented using reconfigurable logic. These techniques combine application-directed synthesis of redundant functionality to tolerate errors, run-time detection of faults, incremental synthesis for fast repair, and global resynthesis to avoid cumulative effects from multiple faults.

The Amalgam Programmable-Reconfigurable Processor
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Amalgam combines several conventional processors and blocks of reconfigurable architecture into a single microprocessor, using a clustered architecture to minimize the impact of wire delay on cycle time. Our results show that this architecture generates an average of greater than 12x speedup over a simple microprocessor on a range of benchmarks. We are currently developing compiler techniques for this architecture, as well as investigating architectural features to improve performance in far-future fabrication processes.

Architectural Models for Highly Concurrent Instruction Execution
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Superscalar processors can concurrently execute several instructions from a single thread, but are limited in the amount of concurrency they can find and exploit because they must fetch and rename instructions in program order. We build on compiler-assisted thread level parallelization mechanisms that concurrently fetch, rename, and execute multiple, widely separated, portions of the program. We are developing new dynamic techniques for using control-dependence information to find and exploit global instruction-level concurrency within a single thread of execution. Using these techniques, we can achieve execution rates four to ten times that achievable by superscalar processors.

Advanced Predicate-Domain Code Optimization
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The predicated representation, in which control is implemented via conditional execution of instructions rather than branches, presents two general categories of new optimization opportunities: the optimization of program decision logic and the optimization of computation code using predication. This project aims to reduce control overhead by extracting control expressions from predicated code, optimizing these expressions using Boolean minimization techniques, and re-expressing control using more efficient sequences of predicate defining instructions. In the second area, this project works toward a paradigm in which stores, branches, and loop boundaries can be reordered freely to achieve performance goals.

Architecture and Compiler Techniques for Optimizing Memory Accesses
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National Science Foundation, CCR 96-29948/98-09478; Intel Corporation
Conducted in the Coordinated Science Laboratory

The goal of this research is to develop an integrated compiler and architecture approach to drastically reduce the frequency and cost of memory accesses in future computer systems. In particular, a compiler strategy that is built upon interprocedural pointer analysis and new heuristics for estimating the probability of colliding pointer contents will be developed to take full advantage of the data speculation features in future microprocessors. The insights provided by fully disambiguated memory accesses may drastically change the future course of run-time data speculation supports.

Automatic Transformation of Traditional Software Components into a Data-Flow Execution Model
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Due to the cost of building ever-larger uniprocessors with standard, single global on-chip storage, future gigascale
computing platforms will increasingly rely on special-purpose hardware accelerators that employ decentralized data-flow computation models. However, the traditional von Neumann programming model will continue to be strongly preferred due to the high cost of changing the fundamental software model. To improve design productivity in the presence of the widening gap between the programming model and the underlying hardware platform, we are developing deep program analysis and transformation techniques that will enable tools to automatically extract data flow computation components from a von Neumann program.

**Compiler and Architecture Support for Program Tunneling**


*Hewlett-Packard*

*Conducted in the Coordinated Science Laboratory*

Modern programming paradigms often impose major performance penalties on application programs. Object oriented programming, structured exception handling, automatic memory management, middleware services, and operating system calls are all examples of such costly features. The goal of this research is to eliminate the cost of these features for the frequently traversed paths of executable programs. Architecture support, in the form of new protection schemes and no-overhead profiling mechanisms, will be developed to enable the run-time optimizer to safely perform aggressive optimizations.

**Configurable On-Chip Memory Microarchitectures**


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Simple technology scaling offers little hope for breaking the difficult scalability and power/performance barriers associated with traditional on-chip memories. This project seeks to design new configurable on-chip SRAM microarchitectures that will enable large SRAM structures to approach the power efficiency of small custom memories for memory-intensive applications such as media and signal processing. The proposed structures support configurability in access ports, access latencies, and sleep-drowsy states. Our deep analysis toolset, a carefully engineered symbiosis of whole-program data flow, control flow, and pointer/data structure analyses, will disaggregate the application's memory data flows and will allow transformation of existing programs to take full advantage of the configurability of the new SRAM structures.

**Deep Program Analysis**


*Intel Corporation; National Science Foundation, 98-09478*

*Conducted in the Coordinated Science Laboratory*

Current code analysis techniques draw dependences based largely on program structure and on register and memory accesses, many of which are not inherent to algorithms but are merely side effects of implementation in a particular architecture or coding paradigm. The conservative nature of these analysis techniques limits the compiler's ability to perform broad, powerful code optimizations. Deep program analysis is intended to discern the fundamental algorithmic dependences of input programs from among those artificially imposed. The application of deep program analysis techniques could revolutionize program optimization, memory access microarchitecture, software development process, software verification, and software debugging.

**IMPACT Post-Link Optimization Framework**

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Commercial software vendors distribute products in binary executable form, compiled for a specific processor. Very limited technology exists for optimizing binary executables, thus preventing end users from optimizing programs for their particular machines and usage patterns. To remedy this problem, this project is creating a binary optimization framework that will serve as a bridge between the binary executable and the IMPACT compiler. Using this framework, the team can experiment with optimizations targeted machine. Such optimization could be performed at the time of program installation or offline, while the user's machine is idle.

* Denotes principal investigator.
IMPACT Run-Time Optimization Framework
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Aggressive code specialization at compile time can achieve significant performance gains, although it is typically limited by risks of profile-dependence and code-explosion. Therefore, we are developing a framework for adaptive, runtime optimization, allowing profiling and specialization of code regions based on the current workload profile. Rather than solely focusing on opportunities in relatively unoptimized applications, this framework focuses on providing an efficient architecture for targeting optimization of opportunities presented by even the most aggressively optimized code. Components of these frameworks include efficient runtime optimization algorithms, techniques for identifying optimization candidates using nonintrusive profiling, and seamless deployment of optimized code.

Java Run-Time Architecture
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This project focuses on enhancements needed to create highly optimized native code for dynamic Java server applications. This includes the construction of a next-generation Java run-time prototype that offers a means of integration between dynamic code production and static code reuse. Also included are a streamlined object model, nonintrusive profiling, dynamic optimizations, reduced intermodule communication overhead, run-time deployment of optimized code, improved memory management subsystem, and hardware enhancements to support Java specific features.

Memory-Efficient EPIC Processors
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Researchers are developing an improved EPIC architecture that will provide the high performance required by upcoming embedded applications while significantly reducing power consumption and memory bandwidth requirements. This architecture divides the processing resources of the chip into four independent clusters, with each cluster having its own program-controllable data memory. A decoded instruction buffer in each cluster reduces instruction fetch bandwidth and power consumption in loops. Compiler techniques are being developed to coordinate intercluster data movement to eliminate many of the memory accesses required during the execution of media programs on conventional architectures.

Multipass EPIC Microarchitecture
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It is well established that the in-order microarchitecture used by EPIC processor such as Itanium can exploit the compiler's proficiency in planning parallelism. However, the inability of this substrate to accommodate unexpected latencies, such as data cache misses, is its most vexing weakness. To address this problem, we propose multipass pipelining, a new class of in-order microarchitectures in which the processor pipeline defers execution of instructions with unready operands for later processing, thereby avoiding stalls. A first-generation design of this technique delivers substantial performance improvements for applications with significant memory stalls. Future generations promise to further enhance the performance while reducing complexity, area, and power.

Next-Generation EPIC Compiler Technology
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We have demonstrated that IMPACT's aggressive use of predication, speculation, and code replication in its structural transformation approach can attain substantial integer code performance increases over contemporary compilers for Itanium2. Challenges and opportunities remain: sophisticated combinations of transformations required to expose desired levels of instruction-level parallelism pose profile-dependence and stability issues. Selective specialization, while not yet controlled with great precision, shows an ability to improve instruction caching as well as ILP. Control and data speculation interact nontrivially with optimizations and operating system models. Finally, more sophisticated region selection and optimization techniques promise increasingly efficient use of wide EPIC resources.

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OpenIMPACT Compiler Release
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This project aims to release the IMPACT research compiler as a general-purpose, open-source compiler for the IA64 Linux platform. The research compiler's features, such as predicated compilation, instruction-level parallelism optimizations, compiler-engineered speculation, and profile-based optimizations, as well as its extensible research framework, will be retained. In addition, an easy-to-use interface will be provided that will allow OpenIMPACT to be used as a high-performance alternative to traditional compilers. This project will be released under the University of Illinois (UIUC/NCSA) Open Source License.

Predicate Analysis and Predicate-Aware Dataflow Analysis
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Efficient and accurate analysis of predicate relationships and predicate-aware dataflow analysis are essential to effective optimization and scheduling of predicated code. A predicate analysis engine must first quickly analyze the code at the function level to determine all relationships among predicates. Then, it must store its findings in a database that can accurately and efficiently answer queries about the relations among predicates. The first objective of this project is to create a function-level, accurate, and efficient predicate analysis engine. The second objective is to create a predicate-aware dataflow analysis engine that is both accurate and fast.

Rapid Customization of Systems Software
MARCO, Defense Advanced Research Projects Agency (part of MARCO Center Soft Systems Thrust)
Conducted in the Coordinated Science Laboratory
The objective of the project is to develop compiler-based, deep program analysis that transcends the boundaries currently separating the application, the dynamically linked libraries, and the operating system. Code-specialization of library functions and operating system services is based on interprocedural analysis of applications, programmatic logic analysis, data value analysis, and interthread escape analysis. Unnecessary code and modules are eliminated. A new fundamental model of the operating system functions, based on microkernel concepts, is developed to systematically verify the correctness of each customized version. Customization technologies are developed at the source and then at the binary level, with the long-term goal of handling commercial software. Potential benefits include rapid generation of software, smaller software footprints, reduced energy consumption, and higher performance.

Scalable Deep Program Analysis
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Future breakthroughs in computer architecture, software engineering, and trustworthy computing will rely on the compiler to perform program analyses that are considered infeasible today. Deep program analysis refers to compile-time techniques that can derive important properties of the program execution accurately. Examples of deep analysis include value ranges that can be assumed by variables, realizable data flow through memory objects, and memory locations that can be accessed by program components. New scalable approaches to deep program analysis are being developed to enable their application to large, complex software systems.

Scalable, Accurate Interprocedural Pointer Analysis
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Pointer analysis is a critical foundation for virtually all advanced program analysis techniques. In a programming language like C that supports an explicit address operator, indirect calls, structures, heap allocation, and pointer casting, memory activity can easily be obscured. We believe that highly accurate results and the ability to scale to large programs do not have to be mutually exclusive goals. To this end, a pointer analysis framework has been developed that provides an efficient representation for achieving accurate results through novel mechanisms to

* Denotes principal investigator.
deal with procedural side effects, global variables, heap locations, and fields.

**Ubiquitous Instruction-Level Parallelism Architectures**
Intel; Motorola, Inc.; Microsoft Corp.; National Science Foundation, 98-09478

*Conducted in the Coordinated Science Laboratory*

As instruction-level parallelism (ILP) architectures such as Intel IA-64 and TI C6x move into the mainstream of computing, it has become critical to solve the technical problems involved in making these architectures appropriate for future embedded applications. The goal of this research is to develop new compiler, architecture, and microarchitecture concepts to drastically reduce the code size, data transfers, energy consumption, and die size of future ILP processors. New techniques will also be developed to further enhance the performance of future ILP microprocessors.

**Ultra-efficient Giga-scale Computing Platform Architecture**
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This project seeks to achieve orders of magnitude of improvement in power efficiency in future computing platforms by systematically synthesizing and utilizing hardware accelerators in the forms of ASIP, ASIC, and FPGA. This approach is motivated by the availability of immense numbers of transistors in future chips and the limitation of activating only a tiny fraction of them at any given time. New system architectures allow seamless integration of accelerators with processors containing extremely high-bandwidth, short-latency communication. Advanced program analysis and transformation techniques convert traditional memory side-effect-based execution activities into explicit data flow, enabling extremely efficient direct hardware execution.

**Value Analysis Compilation Framework**
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Analyzing the flow of values through program computation provides many opportunities for improving the performance of computer systems. This project has two related objectives: the optimization of existing control flow through value analysis and value speculation. Value flow analysis facilitates dead code elimination and control optimization. Value speculation refers to the execution of instructions before all source operand values have been determined. This can be done when instructions generate the same value for each execution, the same value for a high percentage of executions, or predictable values. Compilers can exploit these regularities through code specializations, collectively referred to as value speculation.

**Verification of Run-time Optimized Code**
Hewlett-Packard

*Conducted in the Coordinated Science Laboratory*

Executable programs are increasingly optimized and modified in the field. Just-in-time compilation of Java programs is a well-known example of such run-time code modification. The goal of this research is to overcome the technical challenges involved in automatic verification of run-time optimized code. An interdisciplinary approach that integrates program analysis algorithms and hardware test and verification techniques will be developed to cover a wide variety of software defects.

**An Engineering Prototyping Environment for Compiling C Program Components into Application-Specific Logic**
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DARPA/MARCO FCRP Gigascale Systems Research Center (GSRC); Xilinx; IBM; Mentor Graphics

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This project seeks to establish an engineering prototyping environment to enable research in ultra-efficient gigascale computing platforms. In this environment, we are prototyping processor design, operating system support, compiler technology, synthesis paths, libraries, and device drivers needed in future heterogeneous software and logic systems. The first generation prototype is based on the
Xilinx ML300 board, the Linux kernel, the Mentor Graphics ASAP tool chain, and the IMPACT compiler. The initial applications being prototyped are from the design driver applications of the MARCO Gigascale Systems Research Center with emphasis on future home entertainment applications.

Fault-Injection-Based Benchmarking
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In this research, we propose to explore issues and techniques for intrusion detection and intrusion tolerance in networked environments. Specifically, we will focus on analyzing data on security attacks to determine vulnerabilities exploited by attackers and to classify the attacks according to their causes; generating measurement-based security attack models depicting the attack process; creating stochastic models that reflect behaviors of the system in the presence of variable workloads, errors, and security attacks; investigating measures and experimental procedures for benchmarking system reliability and security; understanding potential inconsistencies in application and system implementation; and proposing software and hardware intrusion detection and prevention techniques.

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DARPA/MARCO FCRP Gigascale Systems Research Center (GSRC)

Conducted in the Coordinated Science Laboratory
Our focus is on designing hierarchical systems of hardware and software detection and recovery mechanisms to handle multiple and/or near coincident errors and to limit (or prevent) error propagation. We will explore a four-tiered approach to develop and integrate detection and recovery support at different levels of the system hierarchy. These levels can be classified as embedded programmable hardware support; operating system support; compiler support; and application support. Additional work will include updates to the ARMOR (adaptive reconfigurable mobile objects of reliability) software, NFTAPE, and the Reliability and Security Engine (RSE) project.

ITR: Methodologies and Tools for Designing and Implementing Large-Scale, Real-Time Systems
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National Science Foundation, Information Technology Research Program, #0121658 (Subcontracted from Vanderbilt University)

Conducted in the Coordinated Science Laboratory
The research proposed is to develop methodologies and tools for designing and implementing very large-scale, real-time embedded computer systems that achieve ultrahigh computational performance through use of parallel hardware architectures; achieve and maintain functional integrity via distributed, hierarchical monitoring and control; are required to be highly available; and are dynamically reconfigurable, maintainable, and evolvable. The specific application that will drive this research and provide a test platform for it is the trigger and data acquisition system for BTeV, an accelerator-based high-energy physics experiment to study matter-antimatter asymmetries in the decays of particles containing the bottom quark.

Processor Level Error Detection and Recovery Techniques
R. K. Iyer*
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Intel Research Council
This research is aimed at providing hardware-level, low-latency error detection and recovery. To achieve this goal we will develop and demonstrate hardware-implemented error detection and security mechanisms embedded as modules in the hardware-level framework, which is implemented as in integral part of a superscalar microprocessor. While the framework closely interacts with the processor pipeline, we do not propose to redesign the pipeline. Rather, the intent is to understand the pipeline to the extent needed for defining a robust interface with which we can demonstrate the operation and efficacy (coverage) of the modules. The framework and its interface with the pipeline are implemented in a reconfigurable portion of the die along with the processor. Example hardware modules we will explore include preemptive control-flow checking, a process health monitor, hardware-based checkpointing, and pointer-taintedness tracking.

* Denotes principal investigator.
Quality of Distributed Control and Surveillance
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rkiyer@uiuc.edu
Defense Advanced Research Projects Agency;
Multidisciplinary Research Program of the University Research Initiative, N000914-01-1-0576
Conducted at the Coordinated Science Laboratory
The objective of this proposal is to create a scientific foundation for the distributed optimization problem of control and surveillance. The goal of our research is to investigate fault-tolerant and secure communication in a wireless or wireline environment, (e.g. an ad-hoc sensor network). In our approach, we explore and prototype a transparent, high-availability framework for supporting client-server applications operating over wireline or wireless networks, investigate issues and solutions (e.g. protocols) in supporting reliable and secure communications in wireless (e.g. sensor networks), and develop a remote vehicle testbed to investigate and test real-time, secure, and fault-tolerant control.

A Compiler-Enabled Model and Measurement-Driven Adaptation Environment for Dependability and Performance
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National Science Foundation, CNS-0406351
Conducted in the Coordinated Science Laboratory
This proposal has the potential for innovation of new measurement-driven and compiler enabled early detection, making the task of detection and diagnosis of performance problems and operational faults more efficient. To build detectors that can predict the likelihood of failures, we will use experimental system analysis to identify correlations between system behaviors and subsequent failure occurrence. Our research will employ measurement data and their analysis, together with compiler analysis of program behavior, to devise a methodology for data-driven discovery of early symptoms of errors, characterization of system/application sensitivity to errors, and identification of locations to place new detectors and guide engineering of application-specific detectors.

Future Communication Technology for Public Safety
L. Liu,* J. P. Monks, W.-M. Hwu
Motorola, Inc.
Conducted in the Coordinated Science Laboratory
In the next decade, the communications technology for public safety officials will be revamped to take advantage of the capability of modern digital communication systems. It is, however, unlikely that current commercial digital communication schemes will be able to satisfy the stringent requirement of constant connection, very low power, congestion control, and ease of use. The goal of this project is to define the architecture of the public safety digital communication systems via careful analysis of field requirements and creation of new communication protocols. An interdisciplinary approach is taken to integrate user behavior studies with core technology development.

Capacity Versus Robustness: A Tradeoff for Restoration in Mesh Networks
S. Lumetta,* S. Kim
Defense Advanced Research Projects Agency, MDA972-99-1-0005
Conducted in the Coordinated Science Laboratory
Researchers are investigating capacity-efficient recovery methods in high-speed networks. The team recently demonstrated an extension of generalized loopback that operates on a subgraph of the full backup graph in an existing network. The backup capacity on remaining links can then be used to carry unprotected traffic, while all primary fibers retain failure protection. The results demonstrate robustness comparable or superior to that available with covers of rings while providing an additional unprotected traffic capacity of roughly 20% of the network's primary capacity.

Reliable, Efficient Communication on a Fast Ethernet Cluster
S. Lumetta,* J. Joh
University of Illinois, Campus Research Board
Conducted in the Coordinated Science Laboratory
Networks of workstations (NOWs) have proven to be an inexpensive yet effective alternative to vendor-packaged parallel architectures. The performance of NOWs running on Fast Ethernet is often limited by TCP/IP communication overhead between the nodes in NOWs. Researchers are developing a new, lightweight, reliable communication protocol incorporating ideas of user-level communication, lightweight flow control, and multiple network interfaces per connection. The protocol supports the large body of existing parallel applications written to the Message Passing Interface standard. Researchers will evaluate the effectiveness of their design in terms of the performance of these applications when using their protocol.

* Denotes principal investigator.
Survivability and Reliability in Direct Access Networks
S. Lumetta,* L. Li  
*Defense Advanced Research Projects Agency, MDA972-99-1-0005
Conducted in the Coordinated Science Laboratory
Researchers are developing routing and recovery protocols to provide reliable connectivity in direct access optical networks (DANs). DANs decouple access from routing, allowing new users to access to the network without incurring the high cost of an optical switch. Through this decoupling, researchers enable more cost-effective and reliable network expansion. Direct access also simplifies the models of ownership by reducing the depth of the ownership hierarchy and the number of potential security hazards and points of failure for a connection. Finally, DANs allow network providers to offer a wider variety of bandwidth and reliability options.

An Adaptive, High-Performance Software Infrastructure for Hierarchical Systems
S. Lumetta*  
*National Science Foundation, CISE/ACIR Career Award
Conducted in the Coordinated Science Laboratory
Machines with deep memories now dominate supercomputing and provide most enterprise-level computing, making the successful development of a general-purpose approach to such platforms imperative. Researchers are developing a high-performance infrastructure for these systems through the construction of four key components: a virtual machine that abstracts resource allocation and management issues into a simple interface; a hierarchy-aware run-time system that offers the illusion of a nonhierarchical system by adapting to the current hierarchical virtual machine; language constructs and dynamic compiler support to tune application behavior; and applications that demonstrate the value of the framework.

Creating an Integrated Modular Environment for the Modeling, Analysis, and Verification of Embedded Hybrid Systems
N. Neogi,* V. V. Lam, W. H. Sanders  
*National Science Foundation, CCR-0311616
Conducted in the Coordinated Science Laboratory
We are creating a tightly integrated design, analysis, verification, and implementation environment for real-time, safety-critical embedded hybrid systems. Results will include a formalism-independent framework for embedded hybrid system architectural specification; efficient analysis and verification techniques that mitigate the state explosion problem by using escape paths and reward structures to create a directed search of the state space; and an integrated suite of stochastic modeling and analysis tools that augment the Möbius modeling tool with advanced techniques that solve scalable and complex hybrid models with respect to performance and dependability measures and capture the interactions typically found in embedded hybrid systems.

Immersive Network Simulation Testbed
D. M. Nicol*  
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U.S. Department of Homeland Security
Conducted in the Coordinated Science Laboratory
We are developing a network simulator for use in exercises by organizations interested in practicing their response to attacks on their IT infrastructure. The simulator uses high performance modeling and execution techniques, runs in real-time, and supports user interaction with simulated devices using emulation to provide a transparent veneer. A key goal is to use the simulator to automatically produce exercise "injects" that prompt players to react to simulated events.

Modeling and Analysis for Network Security Assessment
D. M. Nicol*  
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Defense Advanced Research Projects Agency
Conducted in the Coordinated Science Laboratory
We are developing simulation-based tools and technology to help a network analyst assess the impact of hypothetical attacks in a network, the effectiveness of defenses and countermeasures, and the quantified ability to continue operations in the face of a network attack. The result of our work will better enable network administrators and designers to protect their systems, and to quantify the cost, risk, and functionality tradeoffs inherent in network defense.

Survivable Trust for Critical Infrastructure
D. M. Nicol*  
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National Science Foundation
Conducted in the Coordinated Science Laboratory
We are exploring the design of a distributed trust backbone, based on computational nodes that provide hardened attestation for their hardware and software identities, organized as a peer-to-peer network. We are focusing on
application of this technology to security applications in IT management of critical infrastructure systems, such as SCADA.

**Measurement of Transient Errors in Microprocessors**

J. Patel,* K. Wells, H. Kommaraju

*Jet Propulsion Laboratory*

Conducted in the Coordinated Science Laboratory

This research addresses the measurement of error rates in commercial microprocessors. Microprocessors are core computing engines in the NASA Remote Exploration and Experimentation Project (REE). One serious problem is single-event upsets due to high intensity radiation in outer space. Knowledge of these error rates is essential in the design of the highly fault-tolerant REE computing systems. The measurement of these error rates is the focus of the proposed research. The research will generate software tools that are capable of measuring and characterizing any errors in microprocessors.

**VLSI Test**

J. Patel,* A. Pandey

*Semiconductor Research Corp.*

Conducted in the Coordinated Science Laboratory

The cost of test application of a single chip grows as a function of the number of clock cycles and/or number of storage bits required to test a chip. As a result, test application time and test data volume have become serious problems in testing of system-on-chip designs. In this research, new scan and BIST organizations are being devised that reduce not just data volume but also test time and associated hardware. Hybrid DFT techniques that combine BIST with deterministic scan vectors are also being investigated.

**CT-CS: Trustworth Cyber Infrastructure for the Power Grid**


*National Science Foundation, #CNS-0524695*

The Trustworthy Cyber Infrastructure for the Power Grid (TCIP) NSF Cyber Trust Center was created to address the challenge of how to protect the nation’s power grid. It will significantly improve the way the power grid cyber infrastructure is built, making it more secure, reliable, and safe. TCIP is working to provide the fundamental science and technology needed to create an intelligent, adaptive power grid that can survive malicious adversaries, provide continuous delivery of power, and support dynamically varying trust requirements. We will do so by creating the necessary cyber building blocks and architecture, and by creating validation technology to quantify the amount of trust provided by the proposed approach.

**Designing Protection and Adaption into a Survivability Architecture: Demonstration and Validation (DPASA-DV)**


*Defense Advanced Research Projects Agency project F30602-02-C-0134, subcontracted from BBN Technologies*

The goal of this project is to develop a survivability architecture and implementation for a large, distributed publish and subscribe system and then to verify that the architecture and implementation enable the system to withstand attacks from a knowledgeable and sophisticated adversary for a significant period of time. The architecture, implementation, and survivability validation methodology we are producing will set a new standard for design methodologies and integrated technologies that ensure continuous performance of mission-critical, network-centric systems defended against skilled adversaries.

**ITR: Experimental Validation of Large-Scale Networked Software Systems**


*National Science Foundation, #0086096*

This research is developing the theory, methodology, and tools necessary to experimentally validate the dependability, performance, and survivability of large-scale networked software systems. The intention is to develop a comprehensive framework for validating (via experimental and model-based methods) large-scale networked software systems. Taken as a whole, this work will provide a sound and fundamental approach to validation of networked software and applications.
NGS: A Compiler-Enabled Model- and Measurement-Driven Adaptation Environment for Dependability and Performance
National Science Foundation, CNS-0406351
Conducted in the Coordinated Science Laboratory
Next-generation parallel and distributed computing must be dependable and have predictable performance in order to meet the requirements of increasingly complex scientific and commercial applications. This research will result in the production and distribution of a practical, integrated compiler and middleware system that uses online models and measurement techniques to achieve performance and dependability in a scalable manner under a wide variety of changing conditions. The techniques we develop could ultimately impact many diverse and critical applications, including those in the electric power distribution, aerospace, healthcare, and financial services sectors.

U.S.-Germany Cooperative Research: Analysis of Multi-Paradigm Möbius Models Using Kronecker-Based Techniques
W. H. Sanders,* P. Kemper
National Science Foundation, #INT-0233490
This collaborative proposal between the University of Illinois and Dortmund University is working to make possible the use of Kronecker representations and analysis methods within the Möbius framework.

Efficient Algorithms for Temporal Planning under Nonlinear Constraints
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National Science Foundation, NSF 03-12084
Conducted in the Coordinated Science Laboratory
This research involves the development of formal mathematical conditions for reducing the search space of planning problems and the demonstration of performance improvements in search engines of planner and other discrete searches. By formulating temporal planning problems as dynamic optimization problems with dynamic variables that evolve over time, this research finds new node-dominance conditions by developing the necessary and sufficient conditions for local optimality. By partitioning the search into stages and by finding only dominating states in each stage using the conditions developed, the search for feasible or optimal plans can be restricted to a much smaller subspace in each stage.

Loss Concealment for Real-Time Multimedia over IP Networks
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Conducted in the Coordinated Science Laboratory
This research entails the design of effective multiple-description coding (MDC) algorithms at senders of IP networks, like the Internet, that take into account the reconstruction method used at receivers for concealing lost packets, in order to deliver audio and video data packets over these networks in real time with high quality (both subjectively as well as objectively). Loss concealment of compressed multimedia data is essential because many coding algorithms remove temporal differences in order to achieve high coding efficiency, thereby introducing a pervasive dependency structure into the bit stream. As a result, losses due to dropped packets or late arrivals will result in the loss of subsequent dependent frames, leading to audio or visual artifacts that can be long lasting and annoying. We have chosen MDC because it is effective for concealing losses in transmissions without explicit redundancy control and for networks without priority transmissions. Empirical tests on the Internet show that packet losses are bursty with small burst lengths. Statistics also shows that two descriptions in MDC are adequate in most situations, whereas four descriptions will allow us to control unrecoverable losses under 8% in the worst site measured. Our research results in efficient MDC algorithms that are input independent, without requiring run-time adaptation of the algorithms to new inputs.

Stochastic Anytime Search with Applications in Autonomous Planning and Scheduling
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National Aeronautics and Space Administration, NASA NCC2-1230
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This research entails the development of a theory and its associated derivative-free search algorithms in order to solve constrained nonlinear programming problems (NSPs) with discrete, continuous, or mixed-integer variables. Our secondary goal is to apply the algorithms developed in autonomous control and planning in NASA applications. The research characterizes constrained local minima in NLPs by necessary and sufficient conditions on points in the unconstrained penalty function, develops stochastic anytime search algorithms that generate solutions of improved quality when given more time and

* Denotes principal investigator.
computational resources, and applies the search algorithms to solve problems in autonomous control and planning.

**Streaming Audio and Video Data with Transformation-Based Error Concealment**

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Conducted in the Coordinated Science Laboratory

This research is on the design of protocols and coding methods for the concealment of errors that occur during real-time transmissions of audio and video data over unreliable IP networks, such as the Internet and wireless networks. Since video and audio transmissions may tolerate some degree of loss, this research analyzes schemes that involve trade-offs in their real-time requirements and tolerance to loss. By studying proper coding of transmitted data, protocols to schedule transmissions and feedbacks, and reconstruction schemes to recover lost data, the results developed can be applied to emerging multimedia-ready 3G and 4G cellular networks.

**Remote Sensing**

**Holographic Velocimetry**


U.S. Office of Naval Research, N00014-90-J-1415; U.S. Department of Energy, DE-FG05-87ER75508; Argonne National Laboratory, ANL 828-62403

Conducted in the Coordinated Science Laboratory

One of the goals of experimental fluid flow is to verify large computational models. This requires the remote measurement of the 3-D velocity vector within a flow. This project uses twin frequency-doubled YAG lasers to record two holograms of the fluid flow at two instants in time. The complete velocity field is then reconstructed by performing 3-D correlations of tracer particles within single volume elements (typically 1 mm³).

**Advanced Solid-State Lidar for the Scott-Admundsen South Pole Station**

G. C. Papen,* C. S. Gardner*

National Science Foundation, OPP 92-19898 DPP

Conducted in the Coordinated Science Laboratory

Current models of ozone depletion over the Antarctic predict that some of the major chemical mechanisms occur on the surface of polar stratospheric clouds (PSCs). In addition, the energy-coupling mechanisms from the lower to the upper atmosphere over the Antarctic are not well understood. Researchers are deploying an advanced lidar system at the South Pole that is capable of measuring characteristics of the morphology of the PSCs. They will also measure upper atmospheric wave activity using Na as a tracer.

**Testing of Parallel Optical Fiber Links**

G. C. Papen
National Science Foundation, ECD 89-43166

Conducted in the Coordinated Science Laboratory

Advanced optical interconnections based on parallel space division multiplexing using a fiber ribbon or wavelength division multiplexing using multiple wavelengths within a single fiber require new techniques to measure and model performance. These techniques are being developed because the aggregate data rates through these parallel spaces exceed 15 Gbits/s. Researchers are developing testing methodologies and equipment to test and model the performance of these high-speed data links.

**High Latitude Mesospheric Dynamic and Chemistry Studies**

G. R. Swenson,* A. Liu
National Science Foundation, ATM 99-0859

Conducted in the Coordinated Science Laboratory

Studies of atmospheric gravity waves in the mesosphere and aurora will be performed with imaging and spectroscopy instrumentation at the NSF backscatter radar facility in Sondrestrom, Greenland. The measurement studies will be complemented by radar measurements as well as an all-sky imagery measurement provided by established instrumentation at the site. University of Illinois instrumentation includes a 4-channel photometer directed along the magnetic meridian, a CCD transmission imaging spectrometer, and a CCD all-sky airglow camera. Scientific objectives include the study of momentum and energy flux carried by propagating waves, chemistry associated with thin sporadic E and metal layers, and particle energy flux and beam characteristic energy of precipitating auroral particle beams. Image processing of 2-D spectrograms and 2-D images of atmospheric observations is a major activity with this program.

* Denotes principal investigator.
Imaging Studies of Mesospheric Gravity Waves
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National Science Foundation, ATM 00-03180
Conducted in the Coordinated Science Laboratory
Small-scale waves propagate from the lower atmospheric convection and mountain driven sources to the upper atmosphere. Existing chemiluminescence produces airglows, which are perturbed by the waves. Airglow imagers observe the perturbations and the horizontal wavelength, and amplitude of the waves are measured. The waves carry momentum and energy, which can interact with the large-scale dynamics to cause major dynamic effects. Observations have been made at Albuquerque, New Mexico, and currently at Maui, Hawaii, where the University of Illinois lidar makes complementary measurements. Signal processing is accomplished to extract the intrinsic wave parameters and power and spectral characteristics of the horizontal wave structure.

Technology Development for the MIDEX WAVES Satellite
G. R. Swenson,* C. S. Gardner
National Aeronautics and Space Administration, NAG5-8569
Conducted in the Coordinated Science Laboratory
This program involves the development of technologies associated with a multiple sensor remote sensing satellite designed to measure small-scale waves in the middle and upper atmosphere. These studies include specifically the demonstration of infrared sensor array technology. Array sensors are planned for 1.26 and 1.45 microns that can be operated at elevated temperatures (160 K) but retain low noise attributes. This technology allows passive radiators rather than active refrigeration, enabling the sensors to operate with low power at a reliable, long lifetime on a small satellite. Other technologies include the development of remote sensing signatures from optical emissions as indicators of atmospheric dynamics for both the stratosphere and mesosphere. Instrumentation includes both nadir and limb imagers and spectrometers as well as a Michelson interferometer to measure Doppler winds.

Semiconductor Lasers

1065 and 1040 nm DBR Laser Diodes
J. J. Coleman*
HRL Laboratories
Conducted in the Micro and Nanotechnology Laboratory
Narrow linewidth, tunable semiconductor lasers are of interest to a variety of applications, including fiber optic communication systems, optical generation of microwave radiation, remote optical sensing, and molecular spectroscopy. Various configurations of tunable lasers have been analyzed, and a two- or three-section distributed feedback (DFB) or distributed Bragg reflector (DBR) laser is often the choice. The goal of these programs is to develop narrow linewidth, single longitudinal mode, strained layer InGaAs DBR laser diodes operating near 1065 and 1040 nm for remote sensing applications.

Development of Advanced Laser Diode Sources for Remote-Sensing Applications
J. J. Coleman,* G. C. Papen*
National Aeronautics and Space Administration, NAG 1-1861
Conducted in the Micro and Nanotechnology Laboratory
Several outstanding technical issues for narrowband systems, such as water vapor DIAL lidars, must be resolved before solid-state, laser-based remote-sensing systems have widespread use. One issue is the development of cw local oscillators (LOs) based on semiconductor laser diode technology for use as injection seeders, which has not been fully realized because of the severe linewidth, tunability, and stability requirements of narrowband systems. This project will develop novel semiconductor devices specifically for use as tunable LO sources for narrowband water vapor DIAL systems operating in the 940 nm region. Researchers will focus on a novel ridge-waveguide, distributed-Bragg-reflector laser, which has significant performance improvements for optical remote-sensing applications relative to conventional Fabry-Perot or distributed-feedback lasers.

EOSS+ Laser Diode Substrate
J. J. Coleman*
Northrop Grumman Corp.
Conducted in the Micro and Nanotechnology Laboratory
The electro-optic test station known as the EOSS+ is designed to support the testing of laser platforms at 1.064 mm through the use of a laser diode source. The characteristics of this diode, such as center wavelength and

* Denotes principal investigator.
peak power, are determined by the capabilities of the test receiver and the design of the EOSS+ unit itself. The purpose of this program is to provide for the fabrication of a custom-built diode grown from a novel substrate designed to meet specification.

**High Brightness Laser Diodes**  
J. J. Coleman*  
*Nuvonyx, Inc.*  
Conducted in the Micro and Nanotechnology Laboratory

The objective of this program is to address several issues related to the MOCVD growth and characterization of InGaAs-GaAs strained layer lasers in the range of 920 nm to 1080 nm for high brightness applications. This approach will be to develop a real index guided laser with integrated beam expanders and other active and passive optics formed by selective area epitaxy. Present narrow stripe semiconductor lasers are generally limited to less than 200 mW of fundamental mode output power, because of the narrow aperture. If the beam can be expanded while retaining fundamental mode operation, then the operating power can be correspondingly increased.

**Narrow Linewidth, Multiple Wavelength, Simultaneous-Emission Laser Diodes for Remote Optical Sensing and Other Applications**  
J. J. Coleman*  
*National Science Foundation, ECS 9900258*  
Conducted in the Micro and Nanotechnology Laboratory

The proposal describes a program to develop multiwavelength, simultaneous-emission lasers based on a ridge-waveguide distributed Bragg reflector semiconductor laser. The specific example of an application that defines the need of such lasers is the differential absorption, remote optical sensing of water vapor. A multiwavelength source with closely spaced narrow laser lines would be useful to obtain the detailed absorption profile without having to turn the laser on and off the absorption peak as is practiced currently. This program is designed to study and develop a simple multiple wavelength source suitable for these kinds of applications.

**Semiconductor Laser Transmitters for Integrated Optical Interconnects**  
J. J. Coleman*  
*National Science Foundation, ECD 89-43166*  
Conducted in the Micro and Nanotechnology Laboratory

This program involves development of semiconductor lasers suitable for use in integrated optoelectronics. There are a number of key technical issues to be addressed in this program, including the development of etched facet structures, distributed feedback and distributed Bragg reflector grating structures, monolithic space division multiplexing arrays designed for fiber coupling, selective epitaxy for wavelength division multiplexing arrays and for multielement integration, master oscillator-power amplifier (MOPA) configurations, frequency stabilization, and distributed Bragg pulse shaper high-speed parallel-to-serial packet encoders.

**Naturally Nanostructured Epitaxial Semiconductors**  
J. M. Gibson,* D. G. Cahill, J. E. Greene, A. M. Zangwill, J. J. Coleman  
*National Science Foundation, DMR 9705440*  
Conducted in the Coordinated Science Laboratory

This FRG/GOALI proposal addresses basic materials science and engineering issues in a collaborative program between the University of Illinois and Hewlett-Packard Laboratories to understand fundamental phenomena and interactions associated with naturally nanostructured epitaxial semiconductors. Goals of the project are to obtain semiconductor epitaxial nanostructures smaller than feasible via lithography and to examine their applications to novel devices. Strain-induced self-organization and kinetically driven pattern formation are two approaches being taken to achieve naturally nanostructured materials.

**Semiconductor Physics**

**Concurrent Electro-Thermal Modeling of Ultra-Scaled MOS Technologies**  
Z. Aksamija, U. Ravaioli*  
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*National Science Foundation, SBC PU 501-1045-01*  

This is an interdisciplinary collaborative project with Mechanical Engineering at Purdue University. The goals are to couple Monte Carlo device simulation of nanoscale devices with detailed phonon transport simulation, to understand thermal effects in ultrascaled integrated devices, and to formulate device design strategies to minimize heat generation.

* Denotes principal investigator.
Network of Computational Nanotechnology
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National Science Foundation, CCR-01-21616
Conducted in the Beckman Institute for Advanced Science and Technology

This work is part of a Multi-University National Science Foundation Center. The main goal of our work is the simulation of tubular nanostructures. We investigate both nanostructures of biology, such as biological ion channels, as well as nanostructures related to solid state electronics, such as carbon nanotubes. The tools of the investigation are based on and developed by methods of computational electronics (e.g. Monte Carlo simulations).

3-D Self-Consistent Simulation of Quantum Dot Spin Transistors of Quantum Information Processing
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Semiconductor Research Corporation, 2003-NJ-1045
Conducted in the Beckman Institute for Advanced Science and Technology

This research concentrates on developing 3-D self-consistent computer tools for realistic simulation of spin operation in silicon quantum dot spin effects transistors in order to assess their feasibility and viability for applications in quantum information processing. We consider Si FET-device configurations similar to Kane's proposal to achieve a C-NOT gate. Our purpose is to obtain a coherent 3-D picture of the interdependence among physical parameters and device considerations for spin-qubit operations, and to provide design rules for optimizing the device.

Scalable Spin-Qubit Circuits with Quantum Dots
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Defense Advanced Research Projects Agency, QuIST program, DAAD19-01-1-0659
Conducted in the Beckman Institute for Advanced Science and Technology

This research is aimed at achieving a scalable elementary spin-qubit circuit for quantum computing that is based on the manipulation of electron spins in coupled III-V semiconductor quantum dots (QDs). We take advantage of the advanced technology for planar and lateral QDs AlGAs/GaAs heterostructures and the fact that the electron effective mass is small, which eases the conditions for quantum confinement. Moreover, III-V materials enjoy

* Denotes principal investigator.
long spin coherence times, which is of utmost importance for preserving quantum information over many qubit operations. For this purpose, we have assembled an international research team involving the University of Basel, the University of Delft, Harvard University, Princeton University, and Tokyo University. Team members have complementary expertise in the physics of quantum computation and spintronics in nanostructures. These areas of expertise are fully integrated into a coherent and interactive effort, leading to the realization of an elementary qubit circuit.

**Interactive Tools for Nanotechnology Education**

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NSF National Science Center for Learning and Teaching Nanoscale Science and Engineering

This project involves a multidisciplinary, multi-university team involving Northwestern University (lead institution), University of Illinois at Chicago, University of Illinois at Urbana-Champaign, Purdue University, and University of Michigan. One of the goals is to pursue research in education addressing the introduction of nanotechnology concepts at various school levels, from middle school to undergraduate programs. Our group is developing interactive simulation and visualization tools to explore new ways to introduce advanced concepts in the curricula.

**Simulation of Nanoscale Biological and Biomimetic Systems**

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NIH Nanomedicine Center for the Design of Biomimetic Nanoconductors

Simulation of ion charge transport in membranes is studied using various engineering simulation approaches, including continuum and particle models, to develop design methodologies for nanoscale systems. Physical approaches like classical and quantum molecular dynamics are relied on to provide first-principle calibration of transport parameter for the engineering reduced order models. The goal of this multidisciplinary project is to create a software infrastructure to support the future design of biomimetic components for a variety of applications in nanomedicine, including implantable self-sustaining power sources and artificial organs.

**The Science and Technology of Nano/Molecular Electronics: Theory, Simulation, and Experimental Characterization**

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Defense University Research Initiative on Nanotechnology, U.S. Army Research Office, SIT 527826-08

Conducted in the Beckman Institute for Advanced Science and Technology

This project is part of a DURINT multi-university effort, with Stevens Institute of Technology as lead institution. The specific goals of this subcontract are to develop nanoelectronics simulation tools to understand the ultimate limits of silicon technology and explore new device concepts based on quantum effects. The emphasis of the work is on 3-D simulation and high performance parallel computing, using nonequilibrium Green's function and Monte Carlo simulation approaches.
Semiconductors

Ge-Sb-Te Phase Change Materials: Optical and Electronic Properties, Structural Transformations, and Fabrication of Nanostructures
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National Science Foundation, DMR-0412939
Conducted in the Coordinated Science Laboratory
The properties of Ge-Sb-Te alloys and the rapid amorphous-crystalline phase change that they exhibit are being investigated using ellipsometry, optical absorption and reflection spectroscopy, photoconductivity, photoluminescence, electrical conductivity, Hall effect, high resolution TEM, and fluctuation electron microscopy. Specific problems include: optical, electronic, and structural characterization of sputtered thin films of the materials; the effects of composition, conditions of synthesis, thermal annealing, and optical or e-beam irradiation on their properties; detection and characterization of nano-crystallites in the amorphous phase and their role in the phase change mechanism; the spatial limits/resolution of the phase change, aimed at fabricating quantum structures.

Photoluminescence Studies of Semiconductor Nanostructures and Rare Earth-doped Semiconductor Materials
S. G. Bishop,* I. Adesida, J. J. Coleman, J. O. White
University of Illinois
Conducted in the Micro and Nanotechnology Laboratory
This research program applies photoluminescence (PL), photoluminescence excitation spectroscopy, time resolved PL, and PL imaging to the characterization of defects and impurities in bulk and epitaxial semiconductor materials, and the composition, doping, thickness, interfaces, uniformity, and quantum confinement effects in semiconductor nanostructures. Rare earth-doped semiconducting glasses and rare earth implanted GaN are being developed as sources of near- and mid-IR radiation. Excitation of the intra-4f shell emission from rare earth dopants (e.g. Er$^{3+}$, Pr$^{3+}$, Dy$^{3+}$) in chalcogenide glasses by broad band optical absorption in the Urbach edge of the host glass is under investigation as a novel optical pumping mechanism.

High Quantum Efficiency Infrared Photodetector Arrays Based on Nanowire Heterostructures
Y. C. Chang* (Physics), K.-Y. Cheng,* K. C. Hsieh*
kycheng@uiuc.edu
National Reconnaissance Office, NRC000-05-C-0023
Conducted in the Micro and Nanotechnology Laboratory
The goal of this project is to developed high quantum-efficiency, high color-contrast multi-wavelength quantum wire infrared photodetector (QWRIP) arrays. The QWRIP uses a self-assembly approach to create high-density nanoscale quantum wire structures that provide the basis for high quantum efficiency infrared detection. The QWRIP combines the best features of the quantum well infrared photodetector (QWIP) and quantum dot infrared photodetector (QDIP) to offer normal incidence absorption, high quantum efficiency, and adjustable infrared absorption from 8 to 40 μm. Unique polarization sensitive absorption properties of quantum wires enable two distinct quantum wire infrared detection layers (or a quantum wire layer and a quantum well layer) with different spectral responses to be monolithically integrated without interference, yielding excellent color contrast.

Center of Hyper-Uniform Nanophotonic Technologies for Ultra-Fast Optoelectronic Systems (HUNT Center)
kycheng@uiuc.edu
Defense Advanced Research Projects Agency, University Photonics Research Centers Program, HR0011-04-1-0034
Conducted in the Micro and Nanotechnology Laboratory
The mission of the HUNT Center (Center of Hyper-Uniform Nanophotonic Technologies for Ultra-Fast Optoelectronic Systems) is the development of critical technologies, including hyper-uniform nano-photonic fabrication, high performance quantum dot vertical-cavity surface-emitting lasers, and ultra-fast light-emitting transistor-based lasers for the realization of ultra-fast (≥100Gb/s) optoelectronic interconnect systems. Center programs encompass semiconductor nanoscale materials growth, nano-patterning, nanoscale material analysis, nanostructure laser device design and fabrication, optical receiver design and fabrication, as well as high-speed optoelectronics integrated heterogeneously on a common semiconductor platform to perform ultra-fast optical interface functions.

* Denotes principal investigator.
GaAs-based Metal-Oxide-Semiconductor Structures
K.-Y. Cheng,* K. C. Hsieh*
kycheng@uiuc.edu
Agere Systems
Conducted in the Micro and Nanotechnology Laboratory
The goal of this research program is to develop oxide deposition techniques for the fabrication of GaAs-based metal-oxide-semiconductor field effect transistors (MOSFETs). Various oxides, including SiO$_2$, Al$_2$O$_3$, Ga$_2$O$_3$, and Gd$_3$Ga$_5$O$_{12}$ are deposited on GaAs in an ultrahigh vacuum system at Bell Laboratories to form MOS structures. Researchers will characterize their structural, optical, and chemical properties through transmission electron microscopy, photoluminescence spectroscopy, and Auger electron spectroscopy, respectively, to improve the oxide deposition process.

Ultra-High-Speed Heterojunction Bipolar Transistors
K.-Y. Cheng*
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Semiconductor Research Corporation, SRC-2001-NJ-946
Conducted in the Micro and Nanotechnology Laboratory
The goal of this research is to develop viable techniques that allow demonstration of Inp-based HBTs with $f_T>400$GHz for insertion into the ultra-high-speed (>100 GHz) circuits.

VCSEL and Smart Pixel Research for VLSI Photonic Systems
K.-Y. Cheng,* N. Holonyak, Jr.,* M. Feng,* K. C. Hsieh*
kycheng@uiuc.edu
Defense Advanced Research Projects Agency, DAAG55-98-1-0303
Conducted in the Micro and Nanotechnology Laboratory
The purpose of this research is to develop technology related to VLSI photonic systems. The scope of the program ranges from basic materials research, to the fabrication of large-scale integrated circuits, to advanced technologies for the integration of systems in heterogeneous materials. Goals of the project include the design, growth, fabrication, and testing of III-V semiconductor vertical cavity surface-emitting lasers; the development of smart pixels, circuits for the detection of optical signals, intelligent routing of the information, and re-emission of optical signals; and the development of techniques for the integration of heterogeneous materials.

Materials Research for High-Performance Optoelectronic Devices Employing III-V Compound Semiconductor Native Oxide Layers
N. Holonyak, Jr.*
National Science Foundation, DMR-9612283
Conducted in the Micro and Nanotechnology Laboratory
The primary thrust of this program is the growth and characterization of heteroepitaxial materials employing quantum wells, quantum dots, layer disordering, and native oxide device definition, e.g. buried apertures. This work is focused on the development of better lasers, LEDs, and transistor lasers.

Surface Engineering for Compliant Epitaxy
K. C. Hsieh,* K.-Y. Cheng,* I. Adesida
Defense Advanced Research Projects Agency, F49620-98-1-0496
Conducted in the Micro and Nanotechnology Laboratory
The goal of this research is to realize dislocation-free and stress-relaxed lattice mismatched epitaxy growth of different compound semiconductors on various substrates across the whole wafer or on selected areas for device integration applications. Our immediate goals include fundamental understanding of the growth conditions related to the formation of strained-modulated and defect-absorbing templates and the development of techniques to fully control the formation of strain-absorbing and deformable growth templates with an emphasis on processing simplicity and system integrability. InP-based optoelectronic and microwave devices will be integrated selectively on surface-engineered GaAs substrates.

Wafer Bonding for Advanced Optoelectronic Devices
K. C. Hsieh,* K.-Y. Cheng
Defense Advanced Research Projects Agency, MDA 972-00-1-0020
Conducted in the Micro and Nanotechnology Laboratory
The goal of this research is to develop wafer-bonding technologies for hybrid integrating mismatched device structures for advanced optoelectronic integrated circuits. The potential applications include fabricating high-performance visible LEDs, vertical-cavity-surface-emitting lasers, resonant-cavity photodetectors, 2-D and 3-D photonic crystals, and high-performance semi-insulating wafer substrates. Our current efforts are focused on developing high-efficient wafer-bonding strategy and fundamental understanding of the hybrid interface properties, including interface microstructures, electrical and optical characteristics, interface strain/stress and

* Denotes principal investigator.
adhesion properties, and so forth. The long-term goals will include developing chip-scale photonic/electronic integration methodologies for high-density 3-D architectures.

**ITR/SY: Foundations of Solid-State Quantum Information Processing**
_National Science Foundation, EIA-01-21568_

The core of this program is an exploration of three distinct but related solid state technologies as candidates for quantum information processing: single spins on individual P-donors in silicon, ferromagnetic particles in close proximity to a superconductor, and superconductor phase electronics based on Josephson tunneling and SQUIDs. Supporting this effort will be a theory component that addresses key issues concerning the evolution and monitoring of quantum-entangled states and an experimental study of qubit dynamics using the highly developed techniques of modern quantum optics.

**Biologically Inspired Artificial Haircell Sensors**
C. Liu,* D. L. Jones, F. Delcomyn
_U.S. Air Force Office of Scientific Research, F49620-01-1-0496_

_Conducted in the Micro and Nanotechnology Laboratory_

This work is aimed at developing artificial haircell sensors that are inspired by biological haircell sensors. This work is focused on studying the fundamental principles of neurological responses of haircells to develop micromachined devices that mimic the performance of biological entities.

**CAD Design Tools for Millimeter-Wave Wireless Communication Microsystems**
C. Liu,* M. Feng, S. M. Kang, E. Michielssen, J. Schutt-Ainé

_Conducted in the Micro and Nanotechnology Laboratory_

A mixed technology computer-aided design system is being developed for the cost effective design of wireless communication modules that will ultimately enable networked distributed MEMS. The module, operating at millimeter-wave frequencies, will allow direct interface between MEMS transducers and the free-space electromagnetic radiation. MEMS components offer unique advantages for RF circuits. As an example, micromechanical switches exhibit lower insertion loss and higher isolation compared with conventional electronics switching components. MEMS fabrication technology for silicon and composed semiconductor materials is being studied in order to realize mechanical RF switches as well as high-gain antennas to validate results of the E-M simulation.

**Efficient Computational Prototyping of Mixed Technology Microfluidic Components and Systems**
C. Liu*
_Defense Advanced Research Projects Agency_

_Conducted in the Micro and Nanotechnology Laboratory_

The objective is to develop microfluid components (including pumps and valves), materials (including polymeric MEMS and biodegradable materials), and applications (including drug delivery systems). Microfluid circuits are on the scale of micrometer to millimeter; they are used to transport biological and chemical materials.

**Integrated Biomimetic Sensors Using Artificial Hair Cells**
C. Liu,* F. Delcomyn
_National Aeronautics and Space Administration, NAG 5-8781_

_Conducted in the Micro and Nanotechnology Laboratory_

The main focus of this work is to develop prototype micromachined artificial haircell (AHC) sensors that can be used as modular building blocks for a variety of sensors for sensing acceleration, flow rate, and tactile information.

**Integrated Capillary Microelectrode Arrays for Studies of Olfactory Response Patterns in the Insect Brain**
C. Liu*
_Defense Advanced Research Projects Agency, Controlled Biological Systems Program_

_Conducted in the Micro and Nanotechnology Laboratory_

This project aims to develop the first arrayed capillary microelectrodes using integrated microfabrication technology and to demonstrate the enhanced capabilities for monitoring neurological behavior of insect olfactory systems.

**Integrated Sensing: Biomimetic Sensors for Autonomous Underwater Vehicles**
C. Liu,* G. Karniadakis, C. Chryssostomidis
_National Science Foundation, ECS 02-25S19_

_Conducted in the Micro and Nanotechnology Laboratory_

A team of researchers from the University of Illinois and the MIT Ocean Engineering Department join efforts in

* Denotes principal investigator.
developing artificial lateral line sensors for autonomous underwater vehicles (AUV) that are useful for underwater exploration, warfare, and security. The lateral line sensor is a basic flow sensor for nearly all species of fish and many amphibian animals. We will develop micromachined underwater flow sensors with artificial haircells, shear stress sensors based on thermal transfer, and pressure sensors. Such sensors will be developed on a flexible substrate suitable for underwater applications.

Integrated Sensitive Skin with Advanced Data Architecture
C. Liu,* N. Shanbhag, D. L. Jones
*Denotes principal investigator.
National Science Foundation, IIS 00-80639
Conducted in the Micro and Nanotechnology Laboratory
An interdisciplinary team of researchers will develop microfabricated, multiple modality sensor skin with advanced data structure and signal processing algorithms. A flexible sensor skin that imitates biological tactile sensors faces important challenges in terms of microfabrication, materials, density of sensors, and accompanying circuits. Prof. Liu and students will develop advanced multimodal sensors with self-configuration capabilities. Prof. Shanbhag is developing energy efficient signal processors, while Prof. Jones is interested in developing signal processing algorithms that are biologically inspired.

Mechanically Conformal and Electronically Reconfigurable Aperture (RECAP) Using Low-Voltage MEMS and Flexible Membrane for Space-based Radar Applications
C. Liu*
Defense Advanced Research Projects Agency
Conducted in the Micro and Nanotechnology Laboratory
The objective is to develop micromachined antennas with reconfigurable wavelength and directionality using micromachined switches. We are currently developing micromachining processes based on polymeric materials to realize three-dimensional RF MEMS.

CAREER: Biologically-Inspired Integrated Sensors for Robotics Applications
C. Liu*
National Science Foundation, IIS 99-84954 CAR
Conducted in the Micro and Nanotechnology Laboratory
This CAREER award is aimed at imitating biological haircell sensors that are widely used in the biological world. The research is focused on developing micromachined artificial haircell sensors for flow sensor applications.

Research Experience for Undergraduates (REU)
C. Liu*
National Science Foundation, IIS 99-84954 REU
Conducted in the Micro and Nanotechnology Laboratory
This grant provides undergraduate students with opportunities to conduct advanced research projects in C. Liu's research group.

Nanoscale Science and Engineering Center (NSEC): Center for Integrated Nanopatterning and Detection Technologies
C. Mirkin (Northwestern Univ.), C. Liu, S. Sliigas, G. Shartz, M. Ratman, M. Hersam, and others
National Science Foundation, SBC NW 0830-520-N602
Conducted in the Micro and Nanotechnology Laboratory
This is an NSEC center project in which more than 20 faculty members located at Northwestern University, the University of Illinois, the University of Chicago, and others are participating. The central objective of this center is to develop integrated nanopatterning technologies. The major thrusts in this project are nanopatterning techniques, optical chemical sensors, and microfluid platforms for biological detection. The C. Liu group works in the first and third areas.

Parallel, Ultrafast Sub-100 Nanometer Dip-Pen Nanolithography
C. Mirkin (Northwestern Univ.) C. Liu*
Defense Advanced Research Projects Agency, Army NW 0650-300F245
Conducted in the Micro and Nanotechnology Laboratory
The Dip Pen Nanolithography (DPN) method is uniquely capable of directly patterning chemicals onto substrates with sub-100 nm spatial resolution. It is a powerful technique for depositing materials for surface chemistry. However, the DPN method typically relies on single probes and is serial in nature. In this work, we develop highly parallel arrayed DPN probes using micromachining techniques. Both passive and active probes are being developed. The active probes can be lifted individually. The actuation is based on thermal bimetallic bending or piezoelectric bending.

* Denotes principal investigator.
Controlled Coupling of Donor Atom Wavefunctions in Silicon
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U.S. Army Research Office, DAAD 19-00-1-0407

The goal of this project is to selectively place PH$_3$ molecules onto the hydrogen-terminated silicon surface via STM lithography and overgrow them into the crystal as phosphorous donors. If successful, this work could provide a means for constructing quantum computers based on control of ground-state wavefunctions on individual P-atom donors. Other potential applications include single-charge electronics, cellular automata, and nanometer-scale field-effect transistors. Reproducible characteristics are made possible by the large ~5nm Bohr diameter for individual donor bound states, so that coupling between nearest neighbors will be defined accurately if redistribution is limited to ~1nm or less during ultra-low-temperature overgrowth.

Wavefunction Engineering of Individual Donors for Si-Based Quantum Computers
J. Tucker,* M. Feng, Y. C. Chang,
T. C. Shen (Utah State Univ.), R. R. Du (Univ. of Utah)
U.S. Army Research Office, 42257-PH-QC

The goal of this multi-investigator program is to develop the basic fabrication and measurement technologies needed to implement a silicon-based quantum computer. To do this, researchers must place individual phosphorous donors into the silicon lattice with atomic precision, establish electrical control over wavefunction overlap between donor-pairs, and successfully detect spin states of the resulting two-electron system by measuring the presence or absence of electronically-induced polarization. The research team does not propose working quantum logic gates within this three-year project. If successful, however, that goal will be undertaken in a follow-up program that incorporates SiGe overgrowth and patterning of individual top-gates for each P-atom donor.

Signal and Image Processing

Directional Multiresolution Image Processing: Theory, Algorithms, and Applications
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National Science Foundation (CAREER Award)
Conducted in the Coordinated Science Laboratory

This project seeks to develop new "true" two-dimensional representations that can deal more effectively with typical images having smooth contours. The focus is on the development of directional and multiresolution image expansions using nonseparable filter banks, in much the same way that wavelets were constructed from filter banks. In essence, the proposed research pursues nonseparable extensions of wavelets and multiresolution techniques so that they can capture the directional information—an important and unique feature of multidimensional signals. In parallel, newly developed image representations will be explored in a variety of applications, where substantial improvements over current methods are expected.

A Modern Autofocus Methodology with Applications to Radar Imaging
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Conducted in the Coordinated Science Laboratory

Synthetic aperture radar (SAR), geophysical and seismic imaging, ultrasound imaging, optical coherence tomography (OCT), and many forms of astronomical imaging are examples of coherent imaging systems. In practice, due to imprecise knowledge of the motion of the sensor or due to signal propagation through a medium having a spatially varying propagation velocity, the produced imagery is improperly focused. This project develops a modern autofocus methodology that provides a systematic approach to the design of autofocus algorithms. Toward this end, a theoretical paradigm is devised for the autofocus problem in which prior assumptions in the problem statement are systematically utilized in producing efficient, high-quality image restorations.

* Denotes principal investigator.
Audiovisual Speech Recognition in Automotive Environment
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Conducted in the Coordinated Science Laboratory

Speech recognition in an automobile is typically performed using a single microphone, often mounted in the sun-visor in front of the driver. With typical road noise, most recognizers generate too many errors for practical use. This research project experiments with speech recognition using multimodal recordings acquired by a visor-mounted array including eight microphones and four cameras. We focus on accurate visual face tracking lip feature extraction and robust audio noise cancellation. Our goal is to demonstrate that error rate of a multichannel audiovisual recognizer is much lower than error rate of a standard recognizer under automotive test conditions.

Landmark-based Speech Recognition in Music and Speech Backgrounds
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National Science Foundation, CISE 0132900

Conducted in the Beckman Institute for Advanced Science and Technology

Human listeners are able to recognize speech based on dynamic portions of the signal, even if all static portions are masked by noise or by background music. This research seeks to develop mathematical models capable of abstracting the perceptual response patterns of human listeners. Probabilistic auditory scene analysis uses cognitive stochastic automaton models, combined with use of dynamic Bayesian network methods, in order to imitate the ability of listeners to understand speech mixed with loud background music. Landmark-based speech recognition imitates the extra sensitivity of humans to dynamic as opposed to static signals.

Prosodic, Intonational, and Voice Quality Correlates of Disfluency
M. Hasegawa-Johnson,* J. Cole, C. Shih
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National Science Foundation

Conducted in the Beckman Institute for Advanced Science and Technology

Prosody is the stress and rhythm pattern of naturally spoken language. Linguists agree that the sound of a phoneme depends on its prosodic context, but experimental data describing the prosodic-phonemic interaction are only now becoming precise enough to support efforts in automatic speech recognition. Our research seeks to precisely describe the prosodic-phonemic interaction using both detailed phonetic analysis and probabilistic speech recognition models. This research has already succeeded in demonstrating, for the first time in the literature, that the use of prosody can lead to improved word recognition accuracy in a large-vocabulary speech recognition experiment.

Face Processing
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Research Conducted at the Beckman Institute for Advanced Science and Technology

Researchers are developing methodologies and algorithms for 2-D and 3-D face analysis with applications in face detection, recognition, tracking, and animation. For analysis, we are particularly interested in outdoor scenarios where the illumination and head pose are highly varying. For animation, a major project is text- and speech-driven realistic synthetic talking faces.

Image and Video Databases
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Conducted in the Coordinated Science Laboratory and the Beckman Institute for Advanced Science and Technology

A number of challenging issues in image and video indexing and retrieval are being studied. Of particular interest are the following: similarity- and example-based retrieval, the use of relevance feedback from users to improve retrieval performance, and the recognition of semantic concepts in video based on multimodal cues.

Multimodal Human–Computer Interaction
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Conducted in the Coordinated Science Laboratory and the Beckman Institute for Advanced Science and Technology

The term "human-computer interaction" is used in a broad sense to include communication between persons and computers as well as communication between persons mediated by computers. Researchers are investigating a
A Comprehensive Retargetable Embedded Systems Software Development Environment
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University of Virginia, National Science Foundation subcontract

Conducted in the Coordinated Science Laboratory

New compiler technology and a high-performance software development environment specialized for digital signal processors are being developed. Challenging signal processing applications in wireless video communication will be used as a testbed for evaluating the performance of the new optimizing compiler technology. The new compilation and software tools will be introduced into an instructional Digital Signal Processing Laboratory course for leading-edge undergraduate education and additional evaluation.

Solid State Devices

Luminescence and Laser Studies in III-V Semiconductors
N. Holonyak, Jr.,* G. Walter
National Science Foundation, ECS 82-00517

Conducted in the Micro and Nanotechnology Laboratory in conjunction with the Department of Physics

Heterojunctions in Al$_x$Ga$_{1-x}$As-GaAs and related materials are being examined. Quantum size effects have been observed and have led to single and multiple active layer quantum-well diode light emitters and lasers. Stimulated emission, absorption, disorder, alloy clustering, carrier scattering, phonon processes, tunneling effects, and impurity diffusion in these structures are being studied. Impurity-induced disordering and Al-bearing native oxides are being studied and used to form stripe-geometry lasers and more complicated array structures. Quantum well lasers have been operated in an external grating cavity in an extended wavelength range. Newer forms of quantum-well lasers have been realized, including native-oxide-defined lasers and waveguides. Quantum dot lasers coupled to quantum well lasers are being studied. Also, heterojunction bipolar light emitting transistors (HBLETs) have been identified and are being studied; these include HBLETs both with and without quantum well and quantum dot modifications.

* Denotes principal investigator.
Quantum-Well Heterostructures
N. Holonyak, Jr.,* G. Walter
National Science Foundation, DMR 89-20538
Conducted in the Micro and Nanotechnology Laboratory in cooperation with the Department of Physics and the Frederick Seitz Materials Research Laboratory
The fundamental properties of III-V heterostructures grown by vapor phase epitaxy are being studied. On quantum-well MOCVD AlGaAs-GaAs heterostructures, laser operation 400 meV above $E_g$(GaAs) has been observed, the first cw 300 K laser operation has been achieved, laser operation on phonon-sidebands below the confined-particle states has been observed, and alloy disorder and clustering in quantum-well heterostructures have been identified. Impurity-induced disordering of quantum-well heterostructures and Al-bearing native oxides, that is, the native oxide of Al$_x$Ga$_{1-x}$As formed at 400° to 500°C with H$_2$O + N$_2$, are being examined via TEM and photoluminescence studies. This project is the first (1977) to realize p-n quantum-well lasers and to coin the name "QW lasers."

Supercomputing Research and Development

An Integrated Framework for Performance Engineering and Resource-Aware Compilation
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National Science Foundation, EIA 99-75019
Conducted in the Coordinated Science Laboratory
This project developed a comprehensive and integrated approach to application composition and development, system and application modeling and evaluation, performance characterization, compiler optimization, and low-overhead runtime support. Achieving these capabilities required fundamental advances in methods for hierarchical, multilanguage modeling, simulation, and evaluation, and techniques for adaptive, resource-aware compilation and runtime support. We took a systematic and synergetic approach to making these advances and incorporated them into an integrated performance engineering framework and resource-aware compilation and runtime system. In addition, we demonstrated the use of the integrated framework/system via application to several important parallel and distributed multimedia, video database, and computer vision applications.

Thin Films and Charged Particles

Synthesis and Study of Tailored Organometallic, Inorganic, and Polymeric Precursors for Sol-Gel Processing, Charged Liquid Cluster Beam Deposition, and Chemical Vapor Deposition
H. Choi,* K. Kim,* S. Lim, M. G. Kang
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APL Engineered Materials
To fabricate highly ordered micro and nano structures, such as nanowires, nanoparticles, and thin films of controlled chemical composition and stoichiometry by charged liquid cluster beam technique, chemical vapor deposition (CVD), and Sol-Gel processing, it is crucial to have precursors with desired properties. Such precursors are designed, synthesized, and their physical properties are evaluated by analyzing the materials prepared from them. Resulting optimal precursors are used to fabricated the desired highly ordered nanoscale structures.

Precision Particle Fabrication: The Targeted Delivery of Microsphere Encapsulated Aminobisphosphonates for Treating Autoimmune and Neoplastic Diseases of The Mononuclear Phagocytic System
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Veterinary Medical Research Funds
The main objective of this multidisciplinary initiative is to successfully encapsulate two aminobisphosphonates, pamidronate and zoledronate, into hydroxyethyl starch microspheres using a patent-pending technology known as precision particle fabrication. The long-term goals of this pilot investigation would be to develop a novel, commercially viable therapeutic modality for treating autoimmune and neoplastic disorders involving the mononuclear phagocytic system.
Tissue Engineered Scaffolds with Imbedded Microspheres to Improve Bone and Soft Tissue Healing Through Controlled Delivery of Growth Factors
R. Jamison,* K. Kim,* H. Choi,* Y. Choy, A. Morgan, A. Sendemir-Urkmez, C. Kearney, C. Kyung
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College of Engineering

This research is to optimize the design of tissue engineering substitutes for bone by understanding the relationship between the size, structure, and distribution of microspheres in porous scaffolds and their drug release characteristics. An array of microspheres from chitosan and hydrogel polymer, biocompatible material currently used for treatment of burns and delivery of drugs, will be produced, loaded with growth factors, and then embedded in porous scaffolds of the same polymers. The rate, concentration, and duration of drug release will be measured in vitro for several growth factors that have shown promise in other studies.

Coating of Liquid Crystal Display Panel Components Using the Charged Liquid Cluster Beam Technique
K. Kim,* H. Choi,* S. H. Rhee
LG. Philips LCD

In collaboration with Beckman Institute for Advanced Science and Technology

This work focuses on extensive utilization of the CLCB technique developed by this research group for deposition of films needed for the manufacture and development of high-performance LDCs. In particular, the work makes use of the unique capabilities of the CLCB technique to produce high-quality films of controlled chemical compositions and stoichiometries that are needed for various key LCD components, including metallic semiconducting and insulating films. These films are characterized and evaluated using the microanalysis facilities at the University of Illinois.

Development of Methods for Fabricating Uniform Micro- and Nanospheres and Capsules of Biodegradable and Biocompatible Materials for Application to Biotechnology
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Dong Wha Pharmaceutical; Alkermes

Advanced methods of fabricating uniform biodegradable and biocompatible micro- and nanospheres and multilayer capsules of precise size, shell thickness, porosity, and charge are investigated for various applications in biotechnology. Applications under investigation include advanced drug delivery, tissue engineering, biosensor/biomarker development, and bioavailability enhancement of functional foods. Mechanical, hydrodynamic, electrical, and sol-gel techniques and their combinations are used to fabricate the particles. The smallest particles fabricated to date are in the 10-nanometer range, and the largest in the mm range.

Electromagnetic Railgun Hydrogen-Pellet Accelerator for Magnetic Fusion Reactor Refueling
K. Kim,* H. Fan
U.S. Department of Energy, DE-FG02-84ER52111

Feasibility of an electromagnetic railgun as a high-velocity (~10 km/s) hydrogen pellet injector for refueling magnetic fusion reactors is investigated both experimentally and theoretically. A variety of advanced railgun configurations are considered, especially those that rely on magnetic propulsion of the pellet by a plasma-arc armature and that do not require a fuse to effect the system operation. The principal diagnostics used are laser interferometry, optical spectroscopy, streak camera, and magnetic probes. A CAMAC system is employed for data acquisition and processing. Using the present acceleration scheme, a solid hydrogen pellet velocity in the range of 3.3 km/s has been demonstrated.

Epitaxial Growth and Characterization of GaN-based Materials and Application to Electronic and Optical Devices by Plasma-assisted Molecular Beam Epitaxy
K. Kim,* S. H. Rhee, C. W. Park
Concorde Diversified, Inc.

The objective of this work is to grow device-quality GaN-based films for fabrication of short-wavelength optical devices and high-speed, high-power electronic devices. The growth technique used is the plasma-assisted molecular beam epitaxy that employs an atomic nitrogen beam from an rf-discharge nitrogen plasma and a Ga source beam. The growth system is one designed and fabricated at the University of Illinois, and the nitrogen plasma source is uniquely capable of producing contamination-free plasmas. The films are characterized using a variety of microanalysis techniques including RHEED, XRD, SEM, and TEM.

* Denotes principal investigator.
Epitaxial Growth and Characterization of GaN-based Nitride Semiconductors Using Plasma-assisted Molecular Beam Epitaxy for Development of High-Speed, High-Power Heterostructure Electronic Devices

K. Kim,* I. Adesida,* S. J. Hong, T. Day, C. W. Park
ETRI Electronics, Inc.

The dual objectives of this work are to grow and characterize device-quality heterostructure GaN-based films and use them to develop high-speed, high-power electronic devices. The materials growth is achieved using a plasma-assisted molecular beam epitaxy system designed and fabricated at the University of Illinois. The plasma source is capable of producing contamination-free nitrogen plasmas. The films are characterized using a variety of microanalysis techniques including RHEED, XRD, SEM, TEM, AFM, PL, CL, SIMS, and Hall measurement.

Investigation of Methods for Controlled Fabrication of Thin Films and Nanoparticles Using Charged Liquid Cluster Beams of Precursor Solutions

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LG. Philips LCD

A novel scheme utilizing flow-limited field-injection electrostatic spraying (FFESS) of precursor solutions is investigated to develop methods of fabricating thin films and nanoparticles of controlled size and morphology. The unique aspects of the FFESS technique is its inherent capability to produce uniform, charged nanodrops of controlled size, chemical composition, and stoichiometry, allowing for fabrication of high-quality films and uniform nanoparticles. Specific applications include fabrication of catalytic nanoparticles to facilitate development of advanced displays and deposition of polymer films for OLED development.

Investigation of Novel Approaches to Fabricating Micro and Nanoscale Structures for Development of New Devices for Lighting, Display, and Power Storage

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Charged liquid cluster beam technique, chemical vapor deposition (CVD), Sol-Gel processing, and other chemical and physical techniques are utilized, either individually or in combinations, to fabricate highly ordered micro and nano structures, such as nanowires, nanoparticles, and thin films, of certain technologically important materials. The target of this investigation is to develop novel device concepts for lighting, display, and power storage.

Investigation of Plasma-Material Interaction Using Transaugmented Electromagnetic Railgun

K. Kim*
U.S. Department of Energy

Feasibility of employing a transaugmented electromagnetic railgun as a testbed with which to study plasma-material interaction is investigated both experimentally and theoretically. A variety of advanced railgun configurations are considered that allow for separate control of the velocity, temperature, and density of the free-traveling plasma-arc armature. The principal diagnostics used are laser interferometry, optical spectroscopy, streak camera, and magnetic probes. A CAMAC system is used for data acquisition and processing.

Nanowire and Nanotube Interconnect Technology for 3-D ICs

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Synchrotron Radiation Center

To improve on-chip interconnect performance beyond the 65 nm node, 3-D interconnects and nanotubes are investigated, with the focus placed on better understanding of their material properties, their compatibility with semiconductor processing techniques, and the development of macroscopic models to facilitate quantification of their impact on performance enhancement. The proposed research will be founded on novel processes for the growth of both vertical nanowires and carbon nanotubes along with a cross-disciplinary expertise in the areas of nanotechnology, novel materials synthesis, nanoscale chemical processing, and signal integrity-driven electromagnetic interconnect modeling and simulation.

A Novel Method for Preparing Thin Films and Nanoparticles by Using Charged Liquid Cluster Beams of Liquid-Mix Precursors

K. Kim,* H. Choi,* Y. Yang
University of Illinois

A novel scheme using field-injection electrohydrodynamic spraying of liquid-mix precursors is investigated for development of a method for fabricating thin films of metals, semiconductors, superconductors, and insulators. The same technique is also suitable for fabricating nanoparticles from a variety of liquid precursors. Unique aspects of this new technique are that it is inherently capable of producing a uniform, charged fine spray of liquid precursors of controlled size, chemical composition,
and stoichiometry, and that the energy of the spray can be controlled, allowing for fabrication of high-quality films and uniform nanoparticles.

**Design of Microparticles for Precision Drug Delivery**
D. Pack,* K. Kim,* H. Choi, C. Berkland, Y. Choy, C. Kyung

*hyungssoo@uiuc.edu
National Institutes of Health

*In Collaboration with Chemical and Biomolecular Engineering*

The primary goal of this project is to investigate the effects of microparticle size and size distribution, and the shell thickness of microcapsules, on small molecule drug encapsulation and release. We have developed a novel method for fabrication of uniform polymer microspheres and microcapsules that allows precise control of the particle diameter and shell thickness. By controlling the particle size, we showed we could achieve zero-order release of model drugs and discovered several competing mechanisms that can affect release rates. Four model drugs that span a range of sizes and water solubility will be investigated: piroxicam, ciprofloxacin, ganciclovir, and cyclosporin.

**Tunneling Microscopy**

**Nanoelectronics: Low-Power, High-Performance Components and Circuits**

*U.S. Navy, ASUSG 98-152SG

*Conducted in the Beckman Institute for Advanced Science and Technology*

This is a Multidisciplinary Research Program of the University Research Initiative (MURI) at the Beckman Institute with the goal of combining STM nanofabrication with atomistic simulations to develop novel nanoelectronic device structures on the atomic and molecular size scale. Techniques are being developed to fabricate and test these structures *in situ* in the UHV STM. This program also involves collaborations with Arizona State University, University of Notre Dame, and University of California at Berkeley, to explore new interconnect schemes for nanoelectronics and to interface nanoelectronic devices with conventional microelectronic circuits.

**Journal Articles**

**Advanced Automation**


* Denotes principal investigator.
Advanced Processing and Circuits


Kim, S., Cueva, G., and Adesida, I. Iridium Schottky contact on In$_{0.52}$Al$_{0.48}$As. Electronics Letters, 41:11, 665-667 (May 26, 2005).

**Aeronomy**


**Applied Computation Theory**


**Bioacoustics**


**Circuits**


### Computer Engineering


### Decision and Control


Alpcan, T., Basar, T., and Tempo, R. **Randomized algorithms for stability and robustness analysis of high-speed communication networks.** *IEEE Transactions on Neural Networks, 16:5*, 1229-1241 (Sep. 2005).

Athanasopoulou, E. and Hadjicostis, C. N. **Probabilistic approaches to fault detection in networked discrete event systems.** *IEEE Transactions on Neural Networks, 16:5*, 1042-1052 (Sep. 2005).


Hadjicostis, C. N. and Verghese, G. C. **Coding approaches to fault tolerance in linear dynamic systems.** *IEEE Transactions on Information Theory, 51:1*, 210-228 (Jan. 2005).


Huang, K., Hong, W., and Ma, Y. Symmetry-based photo-editing. *Pattern Recognition, 38*:6, 825-834 (Jun. 2005).


Digital Signal and Imaging Processing


Electromagnetic Communication and Electronics Packaging


**High Frequency Devices**


Lin, G. R., Kuo, H. C., Lin, C. K., and Feng, M. Ultralow leakage In$_{0.53}$Ga$_{0.47}$As p-i-n photodetector grown on linearly graded metamorphic In$_x$Ga$_{1-x}$P buffered GaAs substrate. *IEEE Journal of Quantum Electronics*, 41:6, 749-752 (Jun. 2005).

**Magnetic Resonance**


Optical Imaging


Optical Physics and Engineering

Becker, K. H., Eden, J. G., and Schoenbach, K. H. 


Wagner, C. J. and Eden, J. G. Xenon microdischarge at 300-800 torr: Laser spectroscopy of Xe$_2$ a$^3\Sigma_u^+$(1_u 0_u$^-$) and Xe$_2$ a$^3\Sigma_u^+$(1_u 0_u$^-$). IEEE Transactions on Plasma Science, 33:2 Part 1, 568-569 (Apr. 2005).
Optoelectronics


Power and Energy Systems


Reliable and High-Performance Computing


Remote Sensing


Dragic, P. D. Suppression of first order stimulated Raman scattering in erbium-doped fiber laser based LIDAR transmitters through induced bending loss. *Optics Communications, 250*:4-6, 403-410 (Jun. 15, 2005).


**Semiconductor Lasers**

Elarde, V. C., Bryce, A. C., and Coleman, J. J. **High performance laser with nanopatterned active layer by selective area epitaxy**. *Electronics Letters, 41*:20, 1122-1124 (Sep. 29, 2005).


**Semiconductor Physics**


Signal and Image Processing


**Solid State Devices**

Chung, T., Walter, G., and Holonyak, N. Growth mechanism of InAs quantum dots on GaAs by metal-organic chemical-vapor deposition [art. no. 053510]. *Journal of Applied Physics, 97*:5, 53510 (Mar. 1, 2005).

**Supercomputing Research and Development**


**Thin Films and Charged Particles**


**Papers Presented at Conferences and Symposia**

**Advanced Automation**


**Advanced Processing and Circuits**


**Bioacoustics**


**Circuits**


**Communications**


**Computer Engineering**


**Decision and Control**


**Digital Signal and Imaging Processing**


Electromagnetic Communication and Electronics Packaging


Electromagnetics


High Frequency Devices


Magnetic Resonance


Optical Imaging


Optical Physics and Engineering


Optoelectronics


Power and Energy Systems


**Reliable and High-Performance Computing**


Remote Sensing


Semiconductor Lasers


**Semiconductor Physics**


**Semiconductors**


**Signal and Image Processing**


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Theses

Advanced Automation


Advanced Processing and Circuits


Applied Computation Theory


Bioacoustics


Circuits


Communications


Computer Engineering


Digital Signal and Imaging Processing


Electromagnetics


Decision and Control


**High Frequency Devices**


**Magnetic Resonance**


**Optical Imaging**


**Optical Physics and Engineering**


**Optoelectronics**


Power and Energy Systems


Reliable and High-Performance Computing


**Remote Sensing**


**Semiconductor Lasers**


**Semiconductor Physics**


**Semiconductors**


Signal and Image Processing


Thin Films and Charged Particles


Awards and Honors

Ilesanmi Adesida
Scientific Member, Bohmische Physical Society Fellow, Institute of Electrical and Electronics Engineers (IEEE) Engineering Council Advisors List for Outstanding Advising, University of Illinois, 1993, 1999 Distinguished Lecturer, IEEE Electronic Device Society, 1977-1999 University Scholar, University of Illinois, 1997, 1999 Associate Member, Center for Advanced Study, 2000-2001

Narendra Ahuja
Fellow, American Association for the Advancement of Science Fellow, American Association for Artificial Intelligence
Fellow, Association for Computing Machinery
Fellow, Institute of Electrical and Electronics Engineers
Fellow, International Association for Pattern Recognition
Fellow, International Society for Optical Engineering
University Scholar, University of Illinois
Beckman Associate, University of Illinois Center for Advanced Study, 1990-1991
Associate, University of Illinois Center for Advanced Study, 1998
Donald Biggar Willet Professorship, University of Illinois College of Engineering, 1999
Incomplete List of Teachers Ranked as Excellent by Their Students, 2002

Jont Allen
IBM Faculty Award, 2004

Tamer Basar
Member, National Academy of Engineering
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, International Federation of Automatic Control (IFAC)
Member, European Academy of Sciences
Associate Member, University of Illinois Center for Advanced Study, 1993-1994
Nearing Distinguished Professor of Electrical and Computer Engineering, University of Illinois, 1998-
Zaborszky Lecturer, Washington University, St. Louis, 1999
IEEE Millennium Medal, 2000
President, IEEE Control Systems Society, 2000
NASA "Revolutionize Aviation Goal" Award, 2001
Honorary Editor, *J. Applied and Computational Mathematics*, 2002-
Penner Distinguished Lecturer, University of California, San Diego, 2003
Editor-in-Chief, *Automatica*, 2004-
Tau Beta Pi Daniel C. Drucker Eminent Faculty Award, University of Illinois College of Engineering, 2004
Hendrik W. Bode Lecture Prize, IEEE Control Systems Society, 2004
Giorgio Quazza Medal, IFAC, 2005
Outstanding Service Award, IFAC, 2005
Professor, Center for Advanced Study, University of Illinois, 2005-

Tangul Basar
Senior Member, Institute of Electrical and Electronics Engineers (IEEE)
Faculty Initiate Eta Kappa Nu, 1990
Tokten Fellow, United Nations, 1991
Engineering Council Advisors List for Excellence in Advising, University of Illinois, 1997

James Beauchamp, Emeritus
Fellow, Audio Engineering Society, 1981
Fellow, Acoustical Society of America, 1999

Jennifer Bernhard
New Faculty Fellow, Sloan, 1997
Faculty Fellow, NASA-ASEE, 1999, 2000
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2000
Anderson Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 2000
Collins Scholar, University of Illinois College of Engineering, 2000
Senior Member, Institute of Electrical and Electronics Engineers (IEEE), 2001
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2002-2005
Accenture Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2004
H. A. Wheeler Applications Prize Paper Award, IEEE Antennas and Propagation Society, 2004

Stephen G. Bishop
Fellow, American Association for the Advancement of Science
Fellow, American Physical Society
Fellow, Optical Society of America
Board of Trustees, Gettysburg College, 1992-

Richard Blahut
Member, National Academy of Engineering, 1990
Fellow, IBM, 1980
Fellow, Institute of Electrical and Electronics Engineers, 1981
Fellowship, Japan Society for the Promotion of Science, 1982
Henry Magnuski Professor, 2000
Daniel C. Drucker Eminent Faculty Award, University of Illinois College of Engineering, 2000
Institute of Electrical and Electronics Engineers (IEEE)
Claude E. Shannon Award, 2005
Stephen Boppart
Fellow, Whitaker Foundation, 2001
Young Faculty Award, American Association of Anatomists, 2001
Xerox Faculty Award for Research, University of Illinois College of Engineering, 2002
Top 100 Young Innovators in the World, Technology Review Magazine's, 2002
Everitt Award for Teaching Excellence, University of Illinois College of Engineering, 2003, 2005
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2004
Young Alumni Achievement Award, University of Illinois Department of Electrical and Computer Engineering, 2005
Tau Beta Pi Outstanding Alumni Award, University of Illinois, 2005
Institute of Electrical and Electronics Engineers (IEEE) Engineering in Medicine and Biology Society Early Career Achievement Award, 2005

Yoram Bresler
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Technion Fellowship, 1995-1996
University Scholar, University of Illinois, 1999
Associate, University of Illinois Center for Advanced Study, 2001-2002

Donna J. Brown
Outstanding Young Woman of America, 1984

Marie-Christine Brunet
Anderson Consulting Outstanding Faculty Adviser, 2000
College of Engineering Advisors Lists, 2003, 2004

Andreas Cangellaris
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Outstanding Technical Paper Award, 3rd Electronics Packaging Technology Conference (EPTC), Singapore, 2000

Nicholas Carter
Distinguished Paper Award, International Symposium, Tokyo, Japan, 2000

Patrick Chapman
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2002
Grainger Associate, 2002-

Keh-Yung Cheng
Fellow, Institute of Electrical and Electronics Engineers (IEEE), 2001
Fellow, American Association for the Advancement of Science (AAAS), 2004
Ministry of Education Distinguished Visiting Chair Professor, National Tsing-Hua University, Hsinchu, Taiwan, 2003-2004

Weng C. Chew
Fellow, Institute of Electrical and Electronics Engineers (IEEE), 1993-
Founder Professorship, University of Illinois College of Engineering, 1999-2005
Graduate Teaching Award, IEEE, 2000
Schelkunoff Best Paper Award, IEEE-TAP, 2001
Campus Award for Excellence in Professional Teaching, University of Illinois, 2001
ISI Most Highly Cited Author (top 0.5%), 2002-
Fellow, Optical Society of America, 2003-
Fellow, Institute of Physics, 2004
Y. T. Lo Endowed Chair Professor, University of Illinois Electrical and Computer Engineering Department, 2005-
Distinguished Lecturer, IEEE AP, 2005-
Cheng Tsang Man Visiting Professor, Nanyang Technological University, Singapore, 2006-
IBM Faculty Award, 2006

Yun Chiu
CalView Teaching Fellow Award, University of California College of Engineering, 2003
Jack Kilby Outstanding Student Paper Award, International Solid-State Circuits Conference, 2004

Kent Choquette
Fellow, IEEE/Laser and Electro-Optical Society
Fellow, Optical Society of America
Distinguished Lecturer, IEEE/Laser and Electro-Optical Society, 2000-2001
Distinguished Lecturer, IEEE/Laser and Electro-Optical Society, 2001-2002
Engineering Council Award for Excellence in Advising, University of Illinois, 2004

Shun L. Chuang
Fellow, American Physical Society
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Japan Society for the Promotion of Science
Fellow, Optical Society of America
EPSRC Fellow, Visiting Professor at Cavendish Laboratory, University of Cambridge, United Kingdom Engineering Excellence Award, Optical Society of America Associate, University of Illinois Center for Advanced Study, 1995 Sabbatical Chair, Sony Research Center, Japan, 1995 Distinguished Lecturer Award, IEEE Lasers and Electro-optics Society (LEOS), 2004-2005

**Paul D. Coleman, Emeritus**
Fellow, American Physical Society Fellow, Institute of Electrical and Electronics Engineers (IEEE) Fellow, Optical Society of America Honorary Doctor of Science, Susquehanna University Fellow, American Association Advancement of Science Centennial Medal, IEEE, 1984

**James J. Coleman**
Fellow, American Association for the Advancement of Science Fellow, American Physical Society Fellow, Institute of Electrical and Electronics Engineers (IEEE) Fellow, Optical Society of America IEEE LEOS William Streifer Scientific Achievement Award Distinguished Lecturer, IEEE, 1997-1998, 1998-1999 Franklin Woeltge Professorship, University of Illinois Electrical and Computer Engineering Department, 2002

**Minh Do**
Best Doctoral Thesis, Swiss Federal Institute of Technology Lausanne, 2001 Faculty Early Career Development (CAREER) Award, National Science Foundation, 2003 Best Paper Award at the Institute of Electrical and Electronics Engineers (IEEE) International Conference on Acoustics, Speech, and Signal Processing, 2005

**Floyd Dunn, Emeritus**
Member, National Academy of Engineering Member, National Academy of Sciences Fellow and Past President, Acoustical Society of America Fellow, American Association for the Advancement of Science Fellow, American Institute of Engineering in Medicine and Biology Fellow, American Institute of Ultrasound in Medicine Fellow (founding), International Academy for Medical and Biological Engineering Fellow, Institute of Acoustics, United Kingdom Fellow, Institute of Electrical and Electronics Engineers (IEEE) Honorary Member, Japan Society for Ultrasound in Medicine Honorary Member, Rochester Center for Biomedical Ultrasound Research Fellow, National Institutes of Health Eleanor Roosevelt International Cancer Fellow, American Cancer Society, 1982-1983 Senior Fellow, Fulbright-Hays, 1982-1983 Fellow, Japan Society for the Promotion of Science, 1982-1996 University Scholar, University of Illinois, 1988 Fogarty International Fellow, 1990 Life Fellow, Institute of Electrical and Electronics Engineers, 2000

**James G. Eden**
Milton Feng  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Fellow, Optical Society of America  
Associate Member, University of Illinois Center for Advanced Study, 1998  
Outstanding Research Award, Dr. Pan Wen Yuan Foundation, Taiwan, 2000  
Nick Holonyak, Jr. Professorship, University of Illinois, 2000-2005  
Best Student Paper Award, International GaAs Manufacturing Conference, 2003

Steven J. Franke  
Senior Member, Institute of Electrical and Electronics Engineers

Leon A. Frizzell  
Fellow, Acoustical Society of America  
Fellow, American Institute for Medical and Biological Engineering  
Fellow, American Institute of Ultrasound in Medicine  
Senior Member, Institute of Electrical and Electronics Engineers  

Chester S. Gardner  
Fellow, American Association for the Advancement of Science  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Fellow, Optical Society of America  
CEDAR Prize Lecture, National Science Foundation, 1996

George Gross  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Grainger Professor in Electrical Engineering, University of Illinois College of Engineering, 1993-1998

Christoforos Hadjicostis  
Fellow, Josephine de Karman  
Fellow, National Semiconductor Corporation  
Fellow, Grass Instrument Company  
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2001

Recognized Reviewer of Institute of Electrical and Electronics Engineers (IEEE) IEEE Transaction on Automatic Control, 2001  
Faculty Outstanding Teaching Award, University of Illinois Electrical and Computer Engineering Department, 2003  
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2004  
Willett Faculty Scholar, University of Illinois College of Engineering, 2005  
Senior Member, IEEE, 2005

Bruce E. Hajek  
Member, National Academy of Engineering  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Beckman Associate, University of Illinois Center for Advanced Study, 1984  
University Scholar, University of Illinois, 1986  
Fellow, J. S. Guggenheim Foundation, 1992  
President, IEEE Information Theory Society, 1995  
IEEE Koji Kobayashi Computers and Communications Award, 2003

Ibrahim Hajj, Emeritus  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Best Paper Award, Southwest Symposium on Mixed-Signal Design, 1999  
Golden Jubilee Award, IEEE Circuits and Systems Society, 1999  
Meritorious Service Award, University of Illinois, 2001  

Mark Hasegawa-Johnson  
Senior Member, Institute of Electrical and Electronics Engineers (IEEE)  
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2002

Karl Hess  
Member, National Academy of Engineering, 2001  
Member, National Academy of Sciences, 2003  
Fellow, American Academy of Arts and Sciences  
Fellow, American Association for the Advancement of Science  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Louis A. Fridrich University Scholar, 1993
Swanlund Chair in Electrical and Computer Engineering, University of Illinois, 1996-
Professor, University of Illinois Center for Advanced Study, 1998-
Heinrich Welker Memorial Award, 2001
Honorary Doctor of Sciences, ETH Zuerich, 2003

Nick Holonyak, Jr.
Member, National Academy of Engineering
Member, National Academy of Sciences
Fellow, American Academy of Arts and Sciences
Life Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Optical Society of America
Fellow, American Physical Society
Member, Center for Advanced Study, University of Illinois
John Scott Medal, City of Philadelphia, 1975
Edison Medal, IEEE, 1989
National Medal of Science, 1990
Honorary Doctor of Science, Northwestern University, 1992
Honorary Member, Ioffe Physical-Technical Institute, St. Petersburg, Russia, 1992
Centennial Medal, American Society for Engineering Education, 1993
John Bardeen Chair Professor of Electrical and Computer Engineering and of Physics, University of Illinois, 1993-
Honorary Doctor of Engineering, Notre Dame University, 1994
Fellow, International Engineering Consortium
Eminent Member of Eta Kappa Nu
Distinguished Alumnus of Tau Beta Pi
Foreign Member of the Russian Academy of Sciences
IEEE Third Millennium Medal, 2000
Frederic Ives Medal of the Optical Society of America, 2001
National Medal of Technology, 2002
Fellow, American Association Advancement Science
IEEE Medal of Honor, 2003
Global Energy International Prize, 2003
Washington Award, Western Society of Engineers, 2004
Lemelson-MIT Prize, 2004
Von Hippel Award, Materials Research Society, 2004

Thomas S. Huang
Member, National Academy of Engineering
Foreign Member, Chinese Academy of Engineering
Foreign Member, Chinese Academy of Sciences
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, International Association of Pattern Recognition
Fellow, Japan Society for the Promotion of Science
Fellow, Optical Society of America (SPIE)
Fellow, The International Optical Society
Fellow, J. S. Guggenheim Foundation, 1971
Associate, University of Illinois Center for Advanced Study, 1990
University Scholar, University of Illinois, 1990
Fujitsu Endowed Chair Visiting Professor, University of Tokyo, 1993
William L. Everitt Distinguished Professor, University of Illinois, 1996-
Peter H. Bartels Visiting Professor, University of Washington, 1997
Center for Advanced Study Professor, University of Illinois at Urbana-Champaign, 2003-
Honored as a Pioneer in Signal Processing at the IEEE ICASSP, 1998
Honda Lifetime Achievement Award, 2000
IEEE Third Millennium Medal, 2000
IEEE Jack Kilby Medal, 2001
King-Sun Fu Prize, International Association Pattern Recognition, 2002
Pan Wen-Yuan Foundation Outstanding Research Award, 2002
IBM Faculty Award, 2002, 2003
Tau Beta Pi Daniel Drucker Eminent Engineering Faculty Award, University of Illinois College of Engineering, 2005
Okawa Award for Information and Telecommunication Technology, 2005
Scientist of the Year Award, IS&T and SPIE Electronic Imaging, 2006

Wen-Mei Hwu
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
IEEE Computer Society Certificate of Appreciation, for Service as Both General and Program Chair for the Silver Anniversary MICRO Conference
Fellow, Association of Computing Machinery
Intel Associate Professor, University of Illinois Electrical and Computer Engineering Department, 1992-1993
University Scholar, University of Illinois, 1994
Franklin W. Woeltge Professorship, University of Illinois Electrical and Computer Engineering Department, 2000
Tau Beta Pi Daniel Drucker Eminent Engineering Faculty Award, University of Illinois College of Engineering, 2001
Computerworld Medal Honors, 2002
Faculty Outstanding Teaching Award, University of Illinois Electrical and Computer Engineering Department, 2002
Sanders III Advanced Micro Devices, Inc. Endowed Chair, University of Illinois Electrical and Computer Engineering Department, 2003

Ravishankar K. Iyer
Fellow, Association for Computing Machinery
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, American Association for the Advancement of Science
Associate Fellow, American Institute of Aeronautics and Astronautics
Distinguished Visitor, IEEE, 1989-
Distinguished Service Certificate, American Institute of Aeronautics and Astronautics, 1997
George and Ann Fisher Distinguished Professor, University of Illinois College of Engineering, 1998-
Emanuel R. Piore Award, IEEE, 2001

Kanti Jain
Member, Board of Directors, International Society for Optical Engineering (SPIE), 1992-1994
Member, Executive Committee, Board of Directors, SPIE, 1992, 1993
Editor, Microlithography World, Pennwell Publishing Company and SPIE, 1992-2004
Publications Chair, International Society for Optical Engineering, 1992, 1993
Fellow, International Society for Optical Engineering, 1993
Founding Member, Department of Physics Advisory Board, University of Illinois, 1998-2002
Fellow, Optical Society of America, 1999
Fellow, Institute of Electrical and Electronic Engineers, 2005

Jianming Jin
Fellow, Institute of Electrical and Electronics Engineers
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1997, 2000
Henry Magnuski Outstanding Young Scholar, 1998-2000

Douglas L. Jones
Fulbright Fellowship, 1987
Fellow, Institute of Electrical and Electronics Engineers

Farzad Kamalabadi
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2002

Sung-Mo Kang, Emeritus
Fellow, American Association for the Advancement of Science
Fellow, Association for Computing Machinery (ACM)
Fellow, Institute of Electrical and Electronics Engineers
Foreign Member, National Academy of Engineering of Korea
President, IEEE Circuits and Systems Society, 1991
SRC Inventor Recognition Award, 1993, 1996, 2002
Series Editor, Elsevier, 1994-1997
Charles Marshall University Scholar, University of Illinois, 1995
Technical Excellence Award, Semiconductor Research Corp., 1999
Golden Jubilee Medal, IEEE CAS Society, 1999
IEEE Millennium Medal, 2000
Distinguished Alumnus Award, University of California-Berkeley, 2001
President, Silicon Valley Engineering Council, 2002

Kyekyoon (Kevin) Kim
Overseas Member, National Academy of Engineering, Korea, 2002

Ralf Koetter
Co-Editor-in-Chief, Special Issue of the IEEE Transactions on Information Theory
Associate Editor, IEEE Transactions on Communications, 1999-2000
Associate Editor, IEEE Transactions on Information Theory, 2000-
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2000
Incomplete List of Teachers Rated Excellent, 2000
Collins Scholar, 2000
IBM Partnership Award, 2001
Willet Faculty Scholar, University of Illinois, 2002

Philip T. Krein
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
William E. Newell Power Electronics Award, IEEE
Grainger Endowed Director's Chair in Electric Machinery and Electromechanics
Grainger Associate, University of Illinois Department of Electrical and Computer Engineering, 1995-2002
Fulbright Scholar, 1997-1998
Past President, IEEE Power Electronics Society
University Scholar, University of Illinois, 1999-2002
Division II Director, IEEE, 2003-2004
Distinguished Lecturer, IEEE Power Electronics Society

**P. R. Kumar**
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Franklin W. Woeltge Professor of Electrical and Computer Engineering, University of Illinois, 2000-
Field Award, Control Systems, IEEE

**Jean-Pierre Leburton**
Member, New York Academy of Science
Fellow, American Association for Advancement of Science
Fellow, American Physical Society
Fellow, Electro Chemical Society
Fellow, Institute of Electrical and Electronics Engineers
Fellow, Optical Society of America
Associate, University of Illinois Center for Advanced Study
Hitachi Ltd. Quantum Materials Chair, Research Center for Advanced Sciences and Technology, University of Tokyo, 1992
Chevalier Dans L'Ordre Des Palmes Academiques, 1994
King Albert II of Belgium, Round Table on the "Mobility of European Research Scientist" European Science and Technology Commission, 2001
Inaugural Montefiore Distinguished Lecture, Penn State University, 2002
Gregory Stillman Professor in Electrical and Computer Engineering, University of Illinois College of Engineering, 2004
Gold Medal for Scientific Achievement, 75th Anniversary of the Alumnus Association of the University of Liege, Belgium, 2004
Quantum Devices Award, Outstanding Achievement in the Area of Compound Semiconductor Research, 2004

**Stephen Levinson**
Fellow, Acoustical Society of America
Fellow, Institute of Electrical and Electronics Engineers

**Zhi-Pei Liang**
University Scholar Award
Beckman Fellow, University of Illinois Center for Advanced Study, 1997
Henry Magnuski Scholar, University of Illinois College of Engineering, 1999

**Daniel Liberzon**
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2002

**Young Author Prize, International Federation of Automatic Control, 2002**

**Chang Liu**
Academician, Academia Sinica, 1998
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, National Science Foundation, 2000

**Michael C. Loui**
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
University Distinguished Teacher/Scholar
Carnegie Scholar, Carnegie Foundation for the Advancement of Teaching

**Steven Lumetta**
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2000

**Joseph W. Lyding**
IBM Postdoctoral Fellow, 1983
Beckman Fellow, University of Illinois Center for Advanced Study, 1987-1988
Associate, University of Illinois Center for Advanced Study, 1996-1997
Fellow, American Physical Society, 1997
University Scholar, University of Illinois, 1997
Fellow, American Vacuum Society, 2000

**Sean Meyn**
Fulbright Research Scholar for Research on Optimization and Network Scheduling, 1997

**Pierre Moulin**
Associate Editor, Institute of Electrical and Electronics Engineers (IEEE) *IEEE Transactions on Information Theory*, 1996-1998
Incomplete List of Teachers Ranked as Excellent by Their Students, 1996, 1999, 2000, 2005
Associate Editor, *IEEE Transactions on Image Processing*, 1999-
Area Editor, *IEEE Transactions on Image Processing*, 2002-
University of Illinois Center for Advanced Study, 2003
IEEE Fellow, 2003
Founding Editor-in-Chief, *IEEE Transactions on Information Forensics and Security*, 2005-
Board of Governors, IEEE Signal Processing Society, 2005-
Sony Faculty Award, 2005
David Nicol
Marion and Jason Whiting Fellowship, Oxford University, 2000
Fellow, Institute of Electrical and Electronics Engineers
Best Paper Award, IPSI Studenica Conference, 2004

Burks Oakley II
Incomplete List of Teachers Ranked as Excellent by Their Students, 15 times, University of Illinois
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Searle Scholar, 1982
Named "one of the most distinguished Ph.D. recipients over the past 50 years," University of Michigan, Horace H. Rackham School of Graduate Studies, 1988
Centennial Certificate, American Society for Engineering Education, 1993
Outstanding Advisor List, University of Illinois College of Engineering, 1994, 1995
Educom Medal, 1996
Third Millennium Medal, 2000, IEEE, 2000
Fellow, American Society of Electrical Engineers (ASEE), 2002
Meritiorious Service Award, ASEE Electrical and Computer Engineering Division, 2002
Achievement Award, Education Society, IEEE, 2002
Alumni Society Merit Award, Biomedical Engineering Department, University of Michigan, 2003
Distinguished Member Award, IEEE Education Society, 2005
Most Outstanding Achievement in Online Teaching and Learning by an Individual, Sloan Consortium, 2003

William D. O'Brien, Jr.
Founding Fellow, American Institute of Medical and Biological Engineering
Fellow, Acoustical Society of America
Fellow and Past President, American Institute of Ultrasound in Medicine
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Past President, American Institute of Ultrasound in Medicine
Past President, IEEE Sonics and Ultrasonics Group
Past Treasurer, World Federation of Ultrasound in Medicine and Biology
Honorary Member, Society of Vascular Technology
Centennial Medal, IEEE, 1984
Editor-in-Chief, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 1985-2001
Distinguished Lecturer, IEEE Ultrasonics, Ferroelectrics and Frequency Control Society, 1997-1998
IEEE Third Millennium Medal, 2000
Donald Biggar Willet Professor of Engineering, College of Engineering, University of Illinois, 2003-
Distinguished Service Award, IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society, 2003

Michael L. Oelze
Fellow, National Institute of Health Post-Doctoral Research, 2002-2004

Thomas Overbye
BP Amoco Award for Innovation in Undergraduate Education, University of Illinois College of Engineering, 2000
Institute of Electrical and Electronics Engineers (IEEE) Third Millennium Medal, 2000
Region 4 Power Engineering Society Outstanding Engineer Award, IEEE, 2001
Grainger Associate, University of Illinois Department of Electrical and Computer Engineering, 2002
Sigma Xi Distinguished Lecturer, University of Illinois, 2001-2003

Janak H. Patel
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Association of Computing Machinery
Donald Biggar Willet Professor, University of Illinois College of Engineering, 1999

William R. Perkins
Life Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Past President, IEEE Control Systems Society
Distinguished Member, IEEE Control Systems Society
Centennial Medal, IEEE, 1984
Distinguished Lecturer, IEEE Control Systems Society, 1986-1987
President, American Automatic Control Council, 1996-1997
IEEE Third Millennium Medal, 2000
NASA "Turning Goals into Reality" Award, 2001

Constantine D. Polychronopoulos
Board of Directors, Association for Computing Machinery SIGARCH
Editor, International Journal of High-Speed Computing, 1989-
Mitsubishi Endowed Professorship, University of Tokyo, 1993
Best Research Paper Award, Institute of Electrical and Electronics Engineers Supercomputing, 2000
N. N. Rao  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Edward C. Jordan Professor of Electrical and Computer Engineering, University of Illinois, 2003

Umberto Ravaioli  
Fellow, Institute of Physics  
Fellow, Institute of Electrical and Electronics Engineers, 2003

Elyse Rosenbaum  
Best Student Paper Award (co-author, faculty advisor), EOS/ESD Symposium, 2003  
Bliss Faculty Scholar Award, University of Illinois, 2005

William Sanders  
Fellow, Institute of Electrical and Electronics Engineers  
Fellow, Association for Computing Machinery  
Elected Member, IFIP Working Group 10.4 on Dependable Computing  
Member, Sigma Xi  
Member, Eta Kappa Nu  
Member, Motorola Research Visionary Board (RVB), 2005  
Member, Advisory Board for the Computational Sciences and Engineering Division (CSED) for Oak Ridge National Laboratory, 2005  
Praefectus, IEEE Educational Activities Board, 2001-2002  
Engineering Council Award for Excellence in Advising, 2002  
Best Paper, Pacific Rim International Symposium on Dependable Computing, Tsukuba, Japan, 2002  
Incomplete List of Teachers Ranked as Excellent by their Students, University of Illinois, 2002, 2003  
Donald Biggar Willett Professor of Engineering, University of Illinois College of Engineering, 2005

Dilip V. Sarwate  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)

Peter W. Sauer  
Member, National Academy of Engineering  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
U.S. Air Force Meritorious Service Medal, 1993  
Honorary Professional Degree in Electrical Engineering, University of Missouri-Rolla, 1995

Academy of Electrical Engineering, University of Missouri-Rolla, 1996  
Outstanding Electrical Engineer Award, Purdue University, 2004  
Grainger Chair Professor of Electrical Engineering, University of Illinois, 1998-2003  
IEEE Third Millennium Medal, 2000

Chalmers F. Sechrist, Jr., Emeritus  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Past President and Vice President, IEEE Education Society  
IEEE Third Millennium Award, 2000

Naresh Shanbhag  
Distinguished Lecturer, Institute of Electrical and Electronics Engineers Circuits and Systems Society, 1997-1999  
Best Paper Award, IEEE Transactions on VLSI Systems, 2001

Andrew Singer  
Hughes Aircraft Graduate Fellow  
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2001  
ONR Special Research Award in Ocean Acoustics 2001  
Outstanding Undergraduate Advisor Award, University of Illinois College of Engineering, 2002  
Willett Faculty Scholar Award, University of Illinois, 2002

Mark W. Spong  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Phi Beta Kappa  
Visiting Professor, Catholic University, Leuven, Belgium, 1997  
Editor, IEEE Transactions on Control Systems Technology, 1997-2000  
Visiting Professor, National University of Singapore, 1999  
Engineering Council Advisors List for Outstanding Advising, University of Illinois, 1999, 2005  
Senior U. S. Scientist Research Prize, Alexander von Humboldt Foundation, Germany, 1999  
Visiting Professor, Technical University of Munich, 2000  
Vice President for Publications, IEEE Control Systems Society, 2000-2002  
IEEE Third Millennium Medal, 2000  
Southwest Mechanics Lecture Series Distinguished Speaker, 2001
Distinguished Member Award, IEEE Control Systems Society, 2002
O. Hugo Schuck Award, American Automatic Control Council, 2002
Donald Biggar Willet Professor of Engineering, 2003
John R. Ragazzini Control Education Award, American Automatic Control Council, 2004
President, IEEE Control Systems Society, 2005

Timothy N. Trick, Emeritus
Fellow, American Association for the Advancement of Science
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, International Engineering Consortium
Past President, IEEE Circuits and Systems Society
Past Vice President, IEEE Publication Board
Centennial Medal, IEEE, 1984
IEEE Board of Directors, 1986-1989
National Engineering Consortium Board of Directors, 1990-
President, National Electrical Engineering Department Heads Association, 1994-1995
Golden Jubilee Medal for Extraordinary Contributions to the IEEE Circuit and Systems Society, 2000
IEEE Third Millennium Medal, 2000
Alumni Award for Excellence, University of Dayton, School of Engineering, 2000
Outstanding Electrical Engineer Award, Purdue University, 2001
University Research Award, Semiconductor Industry Association, 2002
Board of Governors, Eta Kappa Nu, 2002-2005

John Tucker
Senior Member, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, American Physical Society
Microwave Pioneer Award, IEEE, 2002

Nitin Vaidya
Distinguished Visitor Program Speaker, Institute of Electrical and Electronics Engineers (IEEE) Computer Society, 1998-2001
Best Paper Award, The Eighth International Conference on Personal Wireless Communications (PWC), Venice, 2003
Editor-in-Chief, ACM SIGMOBILE Mobile Computing and Communications Review (MC2R), 2003-2004
Editor-in-Chief, IEEE Transactions on Mobile Computing, 2005-

Venu Veeravalli
Senior Member, Institute of Electrical and Electronics Engineers (IEEE), 1998
Chair, IEEE Ithaca Section, 1999-2000
Editor, Communications in Information and Systems (CIS), 2000
Associate Editor, IEEE Journal on Selected Areas in Communications–Wireless Series, 2000-2001
Co-organizer of the National Academy of Engineering, Frontiers of Engineering Conference, 2001
Associate Editor, Detection & Estimation, IEEE Transactions on Information Theory, 2001-2003
Beckman Associate for the Center for Advanced Study, University of Illinois, 2002-2003
Invited Participant in the National Academy of Engineering, Frontiers of Engineering Conference, 2002

Pramod Viswanath
Eliahu Jury Award from Department of EECS, University of California–Berkeley, 2000
Bernard Friedman Award from Mathematics Department, University of California–Berkeley, 2000
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2003

Benjamin W. Wah
Fellow, American Association for the Advancement of Science (AAAS)
Fellow, Association for Computing Machinery
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Society for Design and Process Science
University Scholar, University of Illinois, 1989
IEEE Distinguished Visitor, 1989-1992
Fujitsu Visiting Chair Professor on Intelligence Engineering, University of Tokyo, 1992
Editor in Chief, IEEE Transactions on Knowledge and Data Engineering, 1993-1996
Associate Editor-in-Chief, Information Sciences, 1993-
McKay Visiting Professorship, University of California, Berkeley, 1994
Second Vice President, IEEE Computer Society, 1998
First Vice President Elect, IEEE Computer Society, 1998
Robert T. Chien Professor of Electrical and Computer Engineering, University of Illinois, 1999-2003
IEEE Third Millennium Medal, 2000
President, IEEE Computer Society, 2001
Sun Yun-suan Honorary Chair Professor, National Tsinghua University, 2002
Raymond T. Yeh Life Time Achievement Award, Society for Design and Process Science, 2003
Franklin Woeltge Professor of Electrical and Computer Engineering, University of Illinois, 2004-
1st Prize, Suboptimal Temporal Metric Track, 4th Intel Planning Competition, 2004
Best Paper Award, IEEE International Conference on Tools for Artificial Intelligence, 2005

Andrew Webb
Engineering Council Advisors List for Outstanding Advising, Institute of Electrical and Electronics Engineers, 1995, 1998
Guest Professorship, University of Wurzburg, 2000-2001

Bruce C. Wheeler
Fellow, American Institute for Medical and Biological Engineering
Honorary Knight of St. Pat, University of Illinois College of Engineering, 1999
Award for Excellence in Undergraduate Advising, University of Illinois, 2000
Outstanding Medical Scholar Advisor, 2004

Martin Wong
Institute of Electrical and Electronics Engineers (IEEE)
   CAD Transactions Best Paper Award, 2000
IBM Faculty Award, 2000, 2004
David Bruton Centennial Professor in Computer Sciences, University of Texas at Austin, 2001
Best-of-20-Years ICCAD Paper, 2002
IEEE Distinguished Lecturer, 2005-

Jianhua (David) Zhang
Outstanding Advisor Award, University of Illinois College of Engineering and Engineering Council, 2001