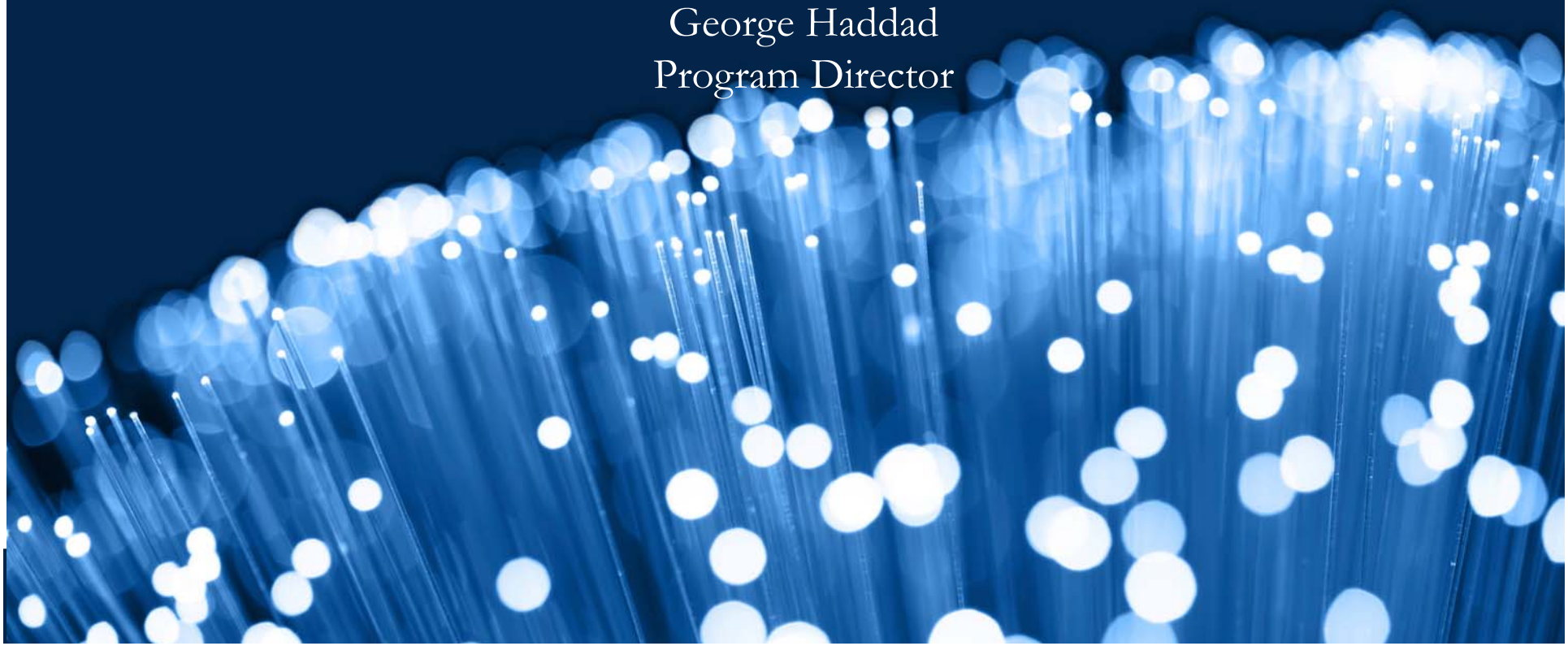
Overview of the Circuits,Communicatons and Sensing Systems (CCSS) Program ECCS Division

US-Ireland Workshop
September, 2014

George Haddad
Program Director



Future Technology Drivers

- Global Communications Services
- Healthcare
- Energy/Smart grid
- Transportation
- Infrastructure
- Environment
- Disaster Mitigation
- Food Supply Tracking

Applications

- Broadband access
- Mobile broadband
- Computing platforms
- Sensor networks
- Imaging
- Cognitive Communication and Sensing Systems

Green Electronics

- Bio-compatible
- Bio-degradable
- Recyclable

Communications And Sensing

- Low energy/information
- Low-power circuits/systems
- Energy scavenging
- Fabrication & disposal

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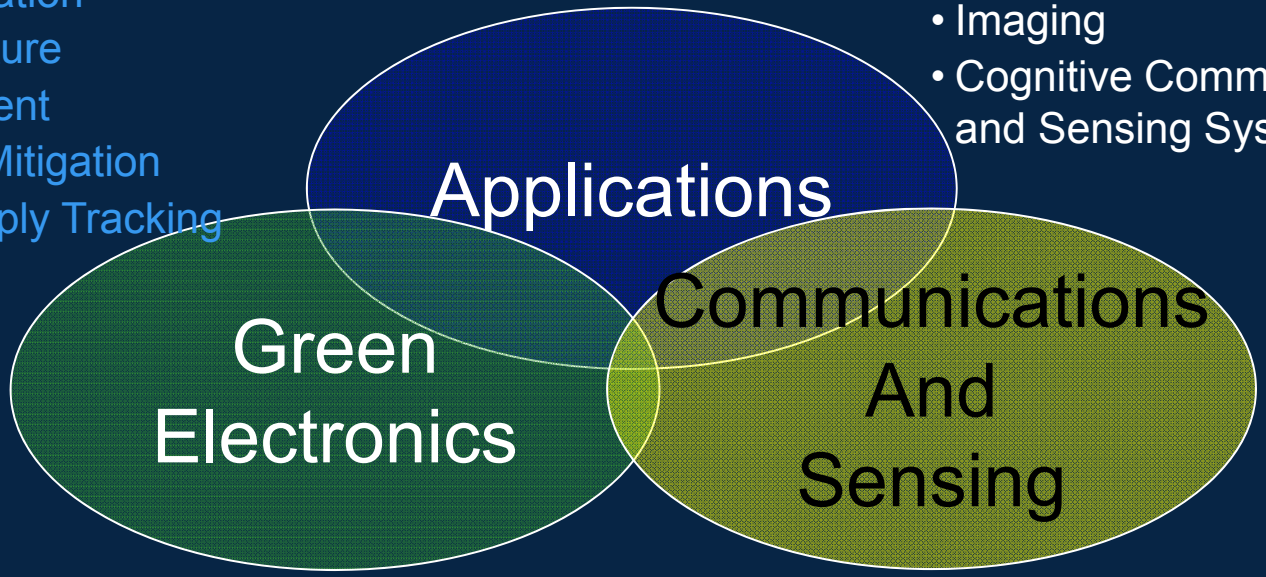

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Integrated Circuits

- **Challenges**
  - 3D integration
  - Interconnects
  - Packaging
  - Power
  - Heat
- **Opportunities**
  - Nanotechnology
  - New architectures
  - Multi-physics design approaches
  - Stochastic design approaches
  - Silicon-Based Photonic Interconnects (Optics and THz wireless and Guided Technologies)

Broadband Access

- **Challenges**
  - Mobile broadband
  - Low power
  - Networking
  - Spectrum access
- **Opportunities**
  - Presidential Directive on broadband access
  - mmWave technologies
  - RF CMOS; RF nanotechnology; mixed-signal design
  - A/D and D/A conversion

Green Electronics

- **Challenges**
  - Material, device, and system technologies
  - Interconnect and packaging technologies
  - Integration and fabrication technologies
  - High frequency performance

- **Opportunities**
  - Transformative impact on industry and society
  - Low cost solutions
  - Systems using flexible electronics

Bio-Medical Applications

- **Challenges**
  - Ultra-low power sensing and wireless communications (implantable, wearable systems)
  - Wireless interface
  - Body area distributed sensing, communications
  - Diagnostic imaging (fast, inexpensive, portable, high resolution)
  - RF radiation treatment/surgery
- **Opportunities**
  - Ultra-low power circuits and communication/sensor systems
  - Body area networks (BAN)
  - High resolution, fast, 3D imaging systems

Bio-Inspired Electronic Systems

- **Challenges**
  - Biocompatible
  - Low Power
  - High Parallelism
  - Cognitive System

- **Opportunities**
  - Resilient systems
  - Re-configurability
  - Adaptability

Design for System Reliability/Resilience

- **Challenges**
  - Reduced feature size and increased integration density
    - Uncertainty in design
    - Reduced reliability
  - Failure-Immune Systems *(critical for applications in healthcare, energy, transportation, security, etc.)*
  - Resilient Systems
- **Opportunities**
  - Self-healing systems
  - Stochastic design
  - Integrated (cross-level) approaches to failure-resistant systems design

Program Directors

George Haddad

- Low Power, Low Noise, High Efficiency Communications, Sensing and Imaging Systems at frequencies ranging from RF to optical frequencies.
- Inter- and Intra-Chip Communications and Networking including THz and optical guided and wireless interconnects.
- Wireless Communications and Sensing circuits and systems.
- Integrated Circuit Design (Mixed-Signal, Fault-Tolerant, Self -Test and Repair, Stochastic Design)
- Real-Time Monitoring and Stimulation of the Brain and other Body functions in natural environments

Program Directors *(Contd.)*

Zhi (Gerry)Tian

- RF/Wireless, Optical, and Hybrid Communications and Networking
- Integrated Sensing, Communication, and Computational Systems
- Spectrum Access and Spectrum Sharing, Cognitive Radio
- Signal Processing and Compressive Sampling
- Cyber Physical Systems and Security.

Program Directors *(Contd.)*

Mona Zaghloul

- Micro, Nano, and Bio Systems (MEMS/NEMS)
- Chemical, Biological and Physical Diagnostics
- Sensors, Actuators and Electronic Interfaces (Brain and other Body functions, Health, Infrastructure and Environment)
- Ultra-Low power wearable and implantable sensing and imaging systems.

Involvement in Special Initiatives

- **EARS: Enhancing Access to the Radio Spectrum**
  - Submission deadline: April 18, 2014; 2 ENG panels
  - Budget: $16M (MPS/ENG/CISE); ECCS portion: 4M
- **CPS: Cyber Physical Systems**
  - Submission deadline: June 2, 2014; multiple ENG-related panels
  - Budget: $35M (CISE/ENG/DHS/DOT); ENG portion: 5M
- **SaTC: Secure and Trustworthy Cyberspace**
  - Submission deadlines: 10/15/2013 – 1/14/2014; 3 CCSS-related panels
  - Budget: $74.5M (CISE/ENG/MPS/SBE/HER); ECCS portion: ?
- **RIPS: Resilient Interdependent Infrastructure Processes and Systems**
  - Submission deadlines: March 19, 2014; 4 panels expected
  - Budget: $8-15M (ENG/CISE/SBE); ENG portion: 8M (?); ECCS portion: ?
- **BIGDATA: Critical Techniques & Technologies for Advancing Big Data S&E**
  - Submission deadline: June 9, 2014; under Cyber Infrastructure Framework for 21th Century (CIF-21)
  - Budget: $23M (CISE/ENG/BIO/SBE/EHR); ENG portion: ?; ECCS portion: 0
- **PFI: BIC: Partnerships for Innovation: Building Innovation Capacity**
  - Topic: "Smart" Service Systems; ENG/IIP

Involvement in Special Initiatives *(Contd.)*

- EARS – Enhanced Access to the Radio Spectrum
  (CCSS/ENG,CISE/CCF,MPS,SBET)
- FRS – Fault Resistant Systems
  (CCSS/ECCS,CCF/CISE,SRC)
- Computer Interconnects (Silicon Photonics, Optics,MMWave,THz Electronics) - Presently working with SRC,CISE,MPS, on a potential major initiative
- Brain Initiative
- Workshop: Non-Invasive Imaging of Brain Functionality and Architecture
  (ECCS,IIP, DARPA,NIH,ONR)

Enhancing Access to the Radio Spectrum (EARS)

- EARS was conceived in 2006 by Andy Clegg of NSF's Electromagnetic Spectrum Management Unit; Andy approached ECCS for partnership
- Spectrum becomes a critical component and priority of the Administration
  - National Broadband Plan, a Congressional mandate to FCC in 2009 to ensure every American has access to broadband capability
  - Presidential Memorandum in June 2010, and Wireless Innovation & Infrastructure Initiative announced by the President in Feb 2011
  - OSTP directs establishing interagency Wireless Spectrum R&D senior steering group, with NSF as co-chair, in Nov 2010
- NSF EARS Workshop in Aug 2010 (MPS, ENG/ECCS, CISE, SBE)
  - Goal: Lead to future enhancements in the efficiency by which the radio spectrum is used
  - 40 invited experts across science, engineering, networking, economics, and commercial, government, and military sectors

EARS Research Topic Areas

- Spectral efficiency
  - » dynamic spectrum access, frequency re-use, and innovative millimeter wave and THz frequency devices and systems
- Reconfigurable wireless platforms
  - » cognitive radio, software-defined radio, novel hardware/software co-design, adaptive antennas,
- Security of wireless signals and systems
- Coexistence with legacy systems
- Special-purpose wireless systems, accommodated within new spectrum-use models
  - » medical devices, surveillance, remote sensing, and passive systems such as radio telescopes
- Wireless system test, measurement, and validation
- Economic models for spectrum resource sharing

Failure-Resistant Systems (FRS): A Joint Initiative between NSF and SRC

- Addresses compelling research challenges for designing and developing electronic circuits and systems resilient to failure
- FRS 2012 Solicitation Under Review, NSF 12-556, deadline July 26, 2012
  - CISE/CCF, ENG/ECCS, Semiconductor Research Corporation (SRC)
  - $6M over 3 years
- Proposals sought in three broad categories:
  - Resilient System Architectures
  - Modeling of Cross-layer Reliable Systems
  - Tools and Automation for Failure-resistant System Design
- Based on NSF-SRC 2010 Workshop: Failure and Uncertainty in Mixed-Signal Circuits and Systems

2

BRAIN Initiative

BRAIN Thematic Areas:

- **Multi-scale Integration of the Dynamic Activity and Structure of the Brain**
  - To elucidate and link dynamics of the brain and neural circuits with brain function, including its real-time physiological, behavioral and cognitive outputs
- **Neurotechnology and Research Infrastructure**
  - To create tools to image, sense, record and affect real-time brain function and complex behavior, and develop theories and systems to collect, visualize, analyze, model , store, and distribute BRAIN data
- **Quantitative Theory and Modeling of Brain Function**
  - To reveal emergent properties of the brain and provide predictive theoretical frameworks to guide future research
- **Brain-Inspired Concepts and Designs**
  - To strategically capitalize on insights gained from BRAIN to inspire novel conceptual paradigms and innovative technologies and designs that will benefit society
- **BRAIN Workforce Development**
  - To educate a BRAIN workforce and create new career opportunities for BRAIN discovery and innovation

2 This is clearly NSF.
Pramod Khargonekar, 22/07/2014

Noninvasive Brain Imaging

Challenge:

"Real-Time Monitoring of Non-Invasive or Minimally Invasive Brain Functions in Natural Environments"

Opportunity:

Integrated Basic Research Efforts in "Materials, Devices, Integrated Circuits, Wireless Communications, Signal and Image Processing, Computing, and Wearable Electronics"

- NSF is very well positioned to carry out such an extensive basic research program to address the challenge by initiating cross-directorate programs.
- This and other initiatives are presently being considered by the BRAIN Working Group.
- ECCS will participate in some of these initiatives and will, in addition, support basic research programs in these areas through collaborative EAGER and unsolicited proposals.

Program Highlights

CAREER: A Scalable, Ultra-Low Power Active Fabric for ECoG
PI: Prof. Brian Otis
Proposal 0845120

- Electrocorticograhy (ECoG_ is a promising candidate for next-generation brain computer interfaces (BCI)
- Our objective is to apply low power circuit techniques to enable an active and scalable ECoG array
- We will utilize our experience with miniaturized low power wireless electronics and system-building techniques

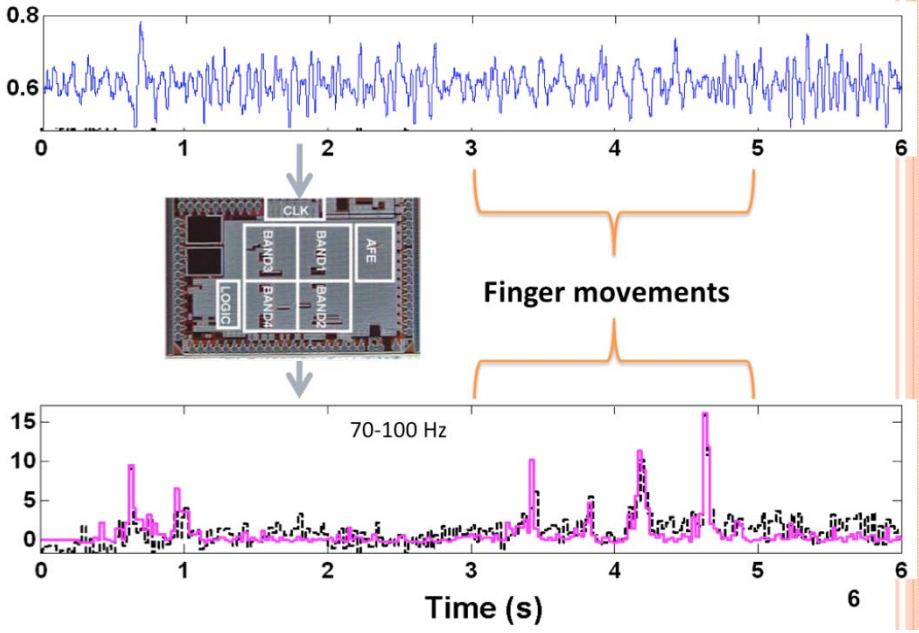
Potential payoffs

- Wired ECoG grids are currently used on humans for localizing epileptic activity for subsequent brain surgery to eliminate seizures
- Patients undergoing this procedure have undergone observation of brain activity correlated to intentional movement (of fingers, etc)
- It has been shown that individual finger-level control through ECoG BCIs is possible, thus promising to re-animate paralyzed limbs, for example
- Our research has a potential payoff of enabling high resolution ECoG implants *without wires*, thus making this vision feasible

Major Results

- Demonstration of a low power spectral decomposition chip architecture for ECoG allowing detection of single-finger intention to move on recordings from humans (see figure to right).
- Demonstration of chip functionality on awake behaving non-human primate.
- Investigation of pre-emphasis filtering of ECoG signals allowing reduction in ADC resolution and power consumption.
- Demonstration of wireless integration of the above developments (in progress).

Actual human ECoG brain activity processed by our IC showing intent to move fingers.

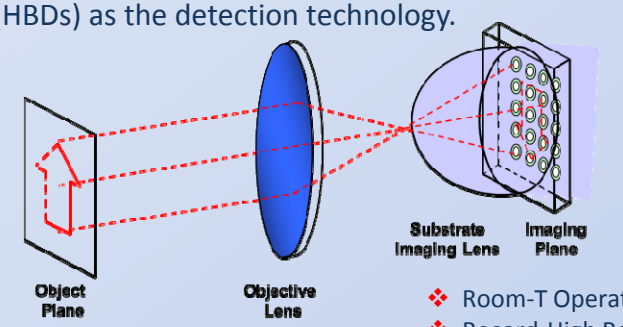


Room Temperature Portable THz Camera Using Heterostructure Backward Diodes

L. Liu, P. Fay, H. Xing University of Notre Dame (NSF ECCS-1002088)

Project Objective and Goal

The objective of this research is to explore the performance and realization of compact, potentially low-cost, integrated THz-frequency imaging systems based on heterostructure backward diodes (HBDs) as the detection technology.

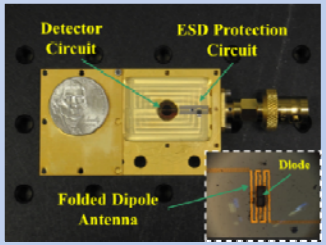


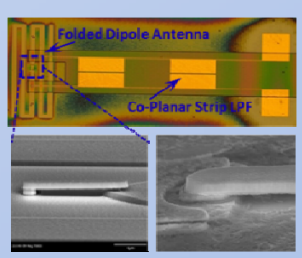
THz Camera (Focal-Plane Array) Based on Reversed Microscope Configuration (higher resolution)

- Room-T Operation
- Record-High Responsivity
- Zero Bias and Low Noise
- Portable and Low Cost
- Video-Rate Imaging

Major Project Results

- Designed, fabricated and characterized lens-coupled folded dipole antennas (FDA) suitable for THz detection/imaging.
- Optimized FDA design for direct matching to HBDs without any additional matching network to maximize responsivity.
- Successfully developed fabrication process for integrating HBDs into FDAs. Initial testing for single detectors shows good agreement between theory and measurement.
- Designed 5×5 focal plane arrays for THz cameras. Critical parameters such as spatial resolution and mutual coupling have been studied.



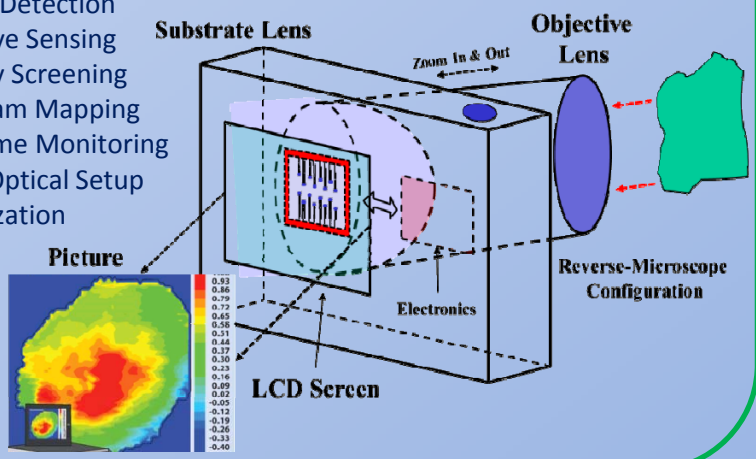


Project Achievements

- For the first time, systematically studied lens-coupled planar FDAs at THz frequencies. Important parameters such as driving point impedance and radiation patterns have been simulated.
- Single detector (or camera pixel) responsivity of > 20000 V/W at 200 GHz demonstrated with simulation leading to compact and low cost camera systems.
- Successfully introduced air-bridge structure to HBD devices for reducing parasitics.
- HBD device characterizations have shown record low noise < 10^{-13} W/(Hz)$^{1/2}$ at room-temperature, and improved cutoff frequency of ~ 6 THz.
- Single detector prototype has been demonstrated for realizing room temperature, portable, low cost and video-rate imaging systems suitable for many important applications.

Important Applications

- THz Imaging
- Cancer Diagnostics
- Hazard Detection
- Explosive Sensing
- Security Screening
- THz Beam Mapping
- Real-Time Monitoring
- Quasi-Optical Setup Optimization



A 240GHz QPSK Chip-to-Chip Wireless Link in 65nm CMOS

NSF ECCS-1201755 – Prof. Ali M Niknejad and Prof. Elad Alon – University of California, Berkeley

I. Research Goals:

- *Demonstrate that high speed (>10 Gbps) chip-to-chip links can be made wireless by using a terahertz carrier frequency and on-chip antennas, taking advantage of the smaller wavelength and advances in CMOS technology.*
- *Increase the data rate of these links by using coherent modulation schemes and higher clock rates.*
- *Improve the energy efficiency of these links to ~ 10pJ/bit, on par with wired links that go from one chip to another chip on a PCB.*

II. Scientific Payoffs:

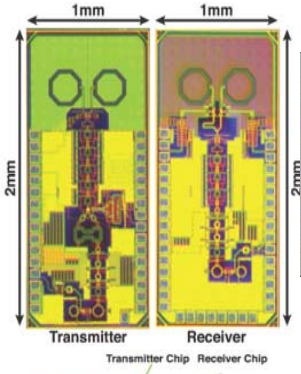
- *Allow multi-core computers to be realized more easily by relaxing the demands on I/O pins by using wireless communication.*
- *Large server farms require high speed links for interconnection of hundreds of switches. Many of these connections can be eliminated using a wireless link, saving significant area and power, and increasing reliability due to the contactless nature of the link.*
- *Terahertz circuit techniques find wide application in fields of medical imaging, scientific exploration of the early universe, and molecular spectroscopy.*

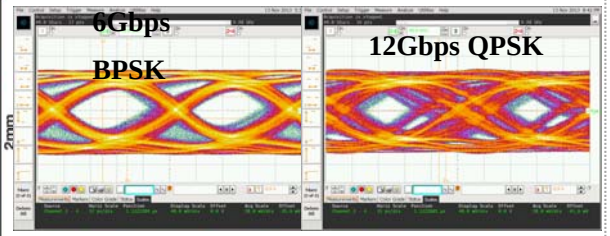
III. Major Results and Broader Impacts:

(a) Intellectual and Industrial: *The key results from the project advances the knowledge in the field of circuit design and terahertz electronics and demonstrates the limits in today's technology. It also serves as a platform for next generation high-speed computing which is necessary for various industrial, economic and military applications.*

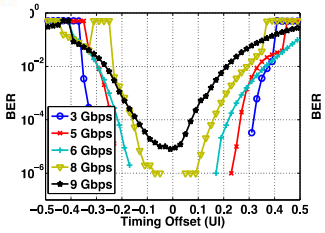
(a) Societal: *Printed Circuit Boards (PCBs) use copper interconnect to transmit signals from one chip to another. These boards have several layers due to the large number of signals routed. By eliminating many of these wires and sending data wirelessly, we can design smaller and lighter components, and more importantly, reduce the amount of e-waste. Devices can also be more easily upgraded and reconfigured, allowing more widespread recycling of components.*

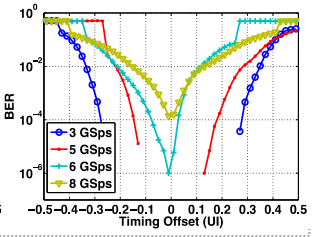
IV. Our second prototype link demonstration:





BPSK Bath-tub **QPSK Bath-tub**



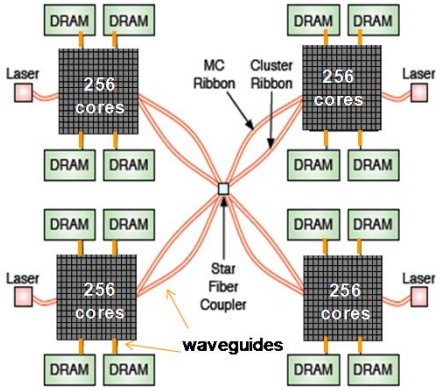


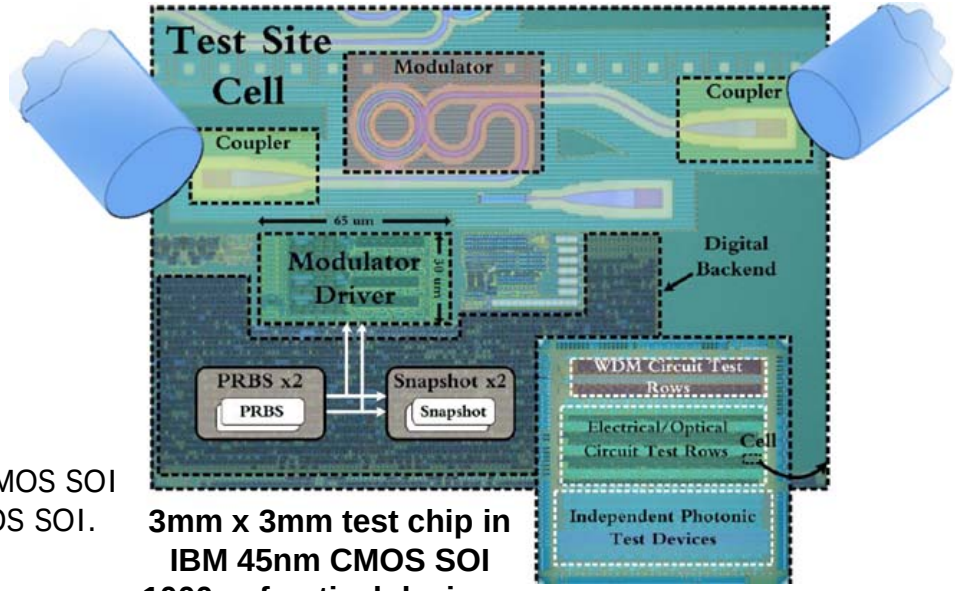
Circuit and System Techniques for High-Throughput, Energy-efficient Silicon-Photonic Interconnects in Advanced VLSI Systems

ECCS-0844994 CAREER Award, PI Vladimir Stojanovic, MIT

Objective:

Enable unprecedented chip I/O bandwidth with monolithic integration of silicon-photonic components and photonics-optimized link circuits in advanced CMOS processes.



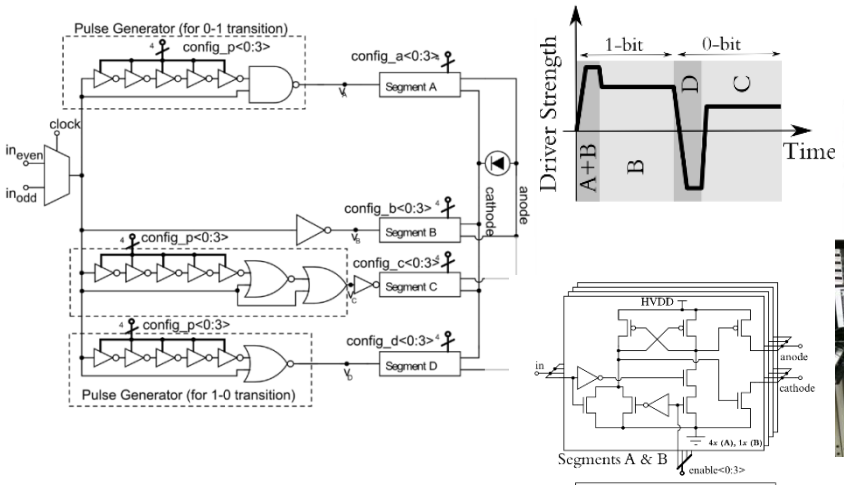


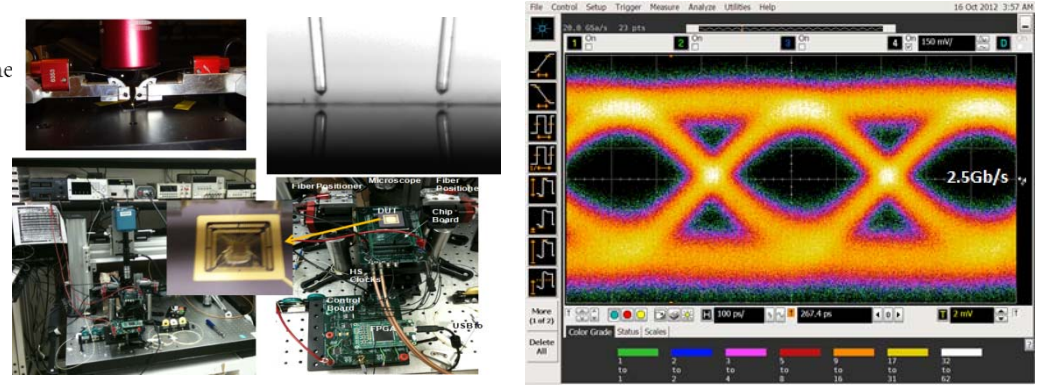
3mm x 3mm test chip in IBM 45nm CMOS SOI
1000s of optical devices, 1M transistors

Presented at ISSCC 2013

Major Accomplishments to date:

Silicon-photonic platform integrated into state-of-the-art 45nm CMOS SOI process. First silicon-photonic circuit and modulator in 45nm CMOS SOI.





Electro-optical test setup and modulated optical eye diagram

Nonlinear pre-emphasis driver circuit:
Overcomes the bandwidth limits of carrier-injection modulators

NSF EECS Award 0903406, Keren Bergman (Columbia U.) & Michal Lipson (Cornell U.)

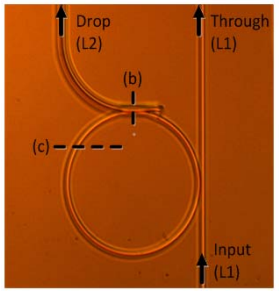
Objectives:

- Design + characterize silicon photonic devices for high-bandwidth-density interconnects.
- Develop CAD Tools for photonic Network-on-Chip (NoC) design and evaluation.

Microring-based resonant devices

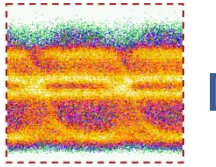
Compact
Power efficient
dense WDM

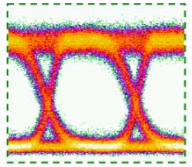
Chip-scale for system-wide high-bandwidth communications

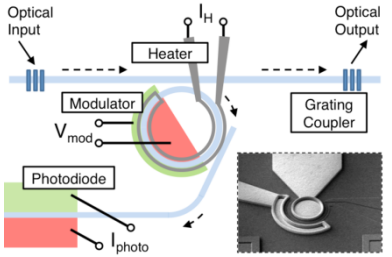


Thermal stabilization

- Silicon resonant structures sensitive to temperature.
- Successfully implemented robust stabilization mechanisms based on optical feedback.



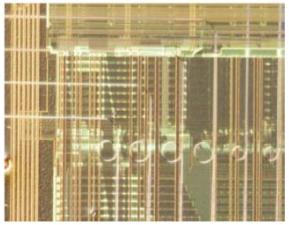




No stabilization. **Stabilized error-free operation.**

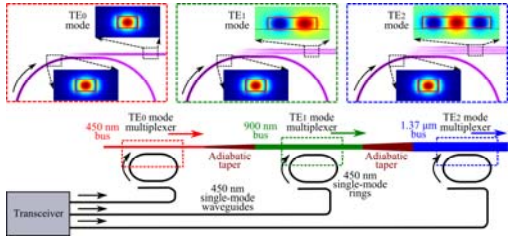
Novel Devices and Platforms

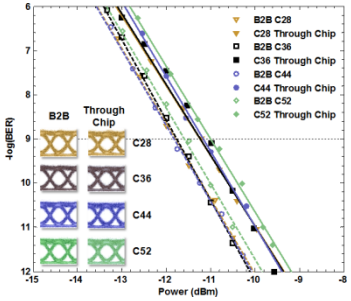
- Demonstrated & characterized high-speed data operation.
- Extract key performance features for network design.



CMOS-Compatible deposited poly-Si and SiN devices

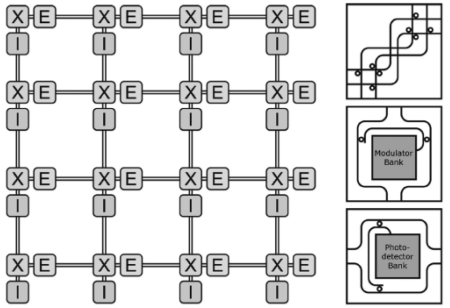
On-Chip microring-based WDM & mode-division multiplexing





CAD Tools for Photonic Interconnects

- PhoenixSim suite of design, simulation, and analysis tools for silicon photonic interconnects.
- Physically-accurate models of devices incorporated into network simulations.



Project # ECCS-1247583

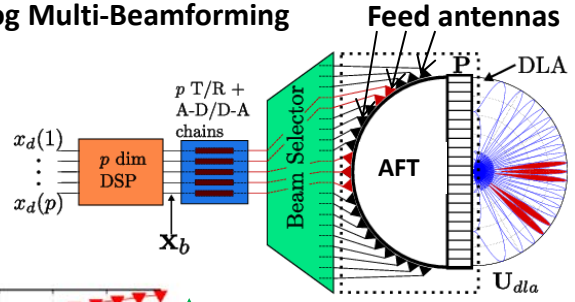
EARS: Beamspace Communication Techniques and Architectures for Enabling Gigabit Mobile Wireless at Millimeter-Wave Frequencies

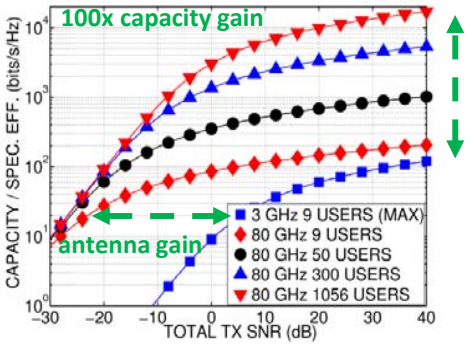
PI: Akbar M. Sayeed, co-PI: Nader Behdad

- **Research Goals**: Development and evaluation of new transceiver architectures that exploit *beamspace communication* – multiplexing data into spatial beams – for electronic multi-beam steering and data multiplexing at mm-wave frequencies. Research plan includes:
  - Design and analysis of optimized antenna array architectures for efficient access to beamspace
  - Development of key system components, including channel models, channel estimation algorithms, and beamspace communication techniques.
  - Computational modeling and prototype-based measurements for system performance assessment
- **Major Results**:
  - Design and analysis of beamspace transceiver architectures for multipath and multiuser environments
  - Optimized discrete lens array (DLA) design for analog multi-beam forming
  - Multipath channel modeling and application to user localization based on channel signatures (patent filed)
  - Prototype-based proof-of-concept demonstration
- **Broader Impacts:**
  - Involvement of undergraduates in research (REU)
  - Interdisciplinary research opportunities for students spanning communication theory, signal processing, antenna design, and prototype development and experimentation

- **Potential Payoff:** Transformative enhancements in the access to, and usage of, the electromagnetic spectrum at millimeter-wave frequencies (30-300GHz), including:
  - Conception and development of millimeter-wave broadband wireless technologies for delivering 10-1000 Gigabits/s speeds
  - Near-optimal performance with dramatically lower transceiver complexity compared to competing designs
  - Standardization and commercialization through prototype development and industrial engagement

Proposed Beamspace MIMO Transceiver with Lens-Based Analog Multi-Beamforming





Potential power and spectral efficiency gains due to beamspace multiplexing at 80GHz vs. 3GHz

EARS: Compact Adaptive MIMO Receivers (#1343309)

Co-PIs: Brian Floyd, Jacob Adams, and Brian Hughes, NC State Univ.

Research Goals:

- Multi-port matching can be used to decouple co-located antennas to enhance capacity through MIMO.
- We are co-developing (a) multi-mode antennas, (b) reconfigurable receivers, and (c) communication algorithms to provide capacity enhancement for extremely compact broadband multi-antenna receivers.

Scientific Impact:

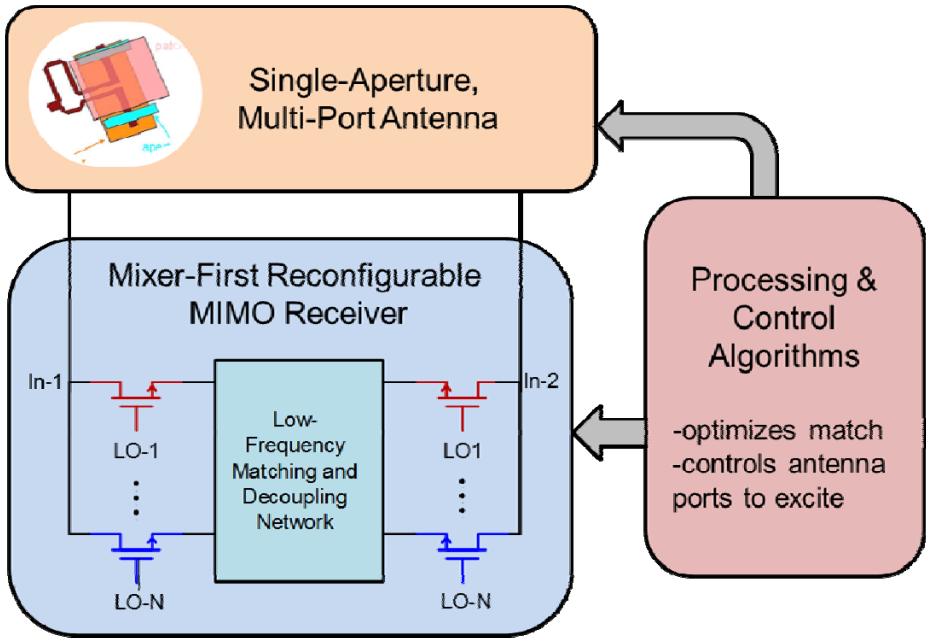
- New *information-theoretic antenna modeling* defines physics-based capacity bounds and guides design of multiport antennas.
- New *mixer-first MIMO receivers* with coupled reconfigurable baseband networks enables adaptive wideband multi-port matching and antenna decoupling.
- New *communication algorithms* for optimization of antenna excitation and control of receiver matching can maximize system capacity.

Major Results:

- Developed optimization approach for symmetric 2- and 4-port MIMO antennas that can determine upper bound on bandwidth and efficiency.
- Designed narrowband tunable baseband decoupling network and taped out 90nm CMOS polyphase mixer prototype.
- Published paper on impact of frequency-selective multiport matching on MIMO capacity.

Broader Impact:

- Enables MIMO techniques to be employed in physically small receivers with strong antenna coupling, allowing increased data rates, greater range, and/or longer battery lives.



Backscattering Tags for the Internet of Things

ECCS 1346854 – Petar M. Djurić – Stony Brook University, New York

I. Recent Outcomes & Accomplishments

Tag-to-tag communication of up to 3 – 4 m and based purely on the backscattering paradigm was successfully established. An external continuous wave exciter was used to enable two backscattering tags to talk to each other.

New concepts of boosted- and phase-diversity-based backscattering were investigated. They will allow for long inter-tag communication ranges that will facilitate many real-world applications.

Publication: L. Geng, M. F. Bugallo, A. Athalye, and P. M. Djurić, "Indoor tracking with RFID systems," IEEE Journal of Selected Topics in Signal Processing, vol. 8(1), pp. 96-105, 2014.

II. Basic Principles

The Internet of Things is a vision where things (objects) form a network and interact with each other in a cooperative manner. A challenging hurdle towards this vision is the inability of todays' radio-less backscattering devices to independently communicate with each other over long distances (greater than a few centimeters).

- ***Technical description:*** *Passive demodulation and backscattering techniques employed by conventional tags render them unable to communicate with each other. This research investigates novel techniques to enhance the backscatter signal and passive demodulation schemes to empower radio-less tags to listen and decode backscatter from other tags in their vicinity.*

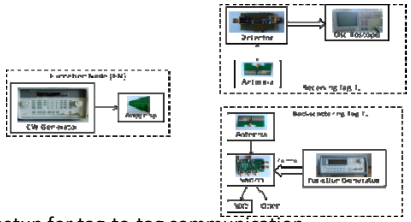
- ***Non-technical description:*** *The objective of the proposed work is to enable direct communication between objects without any intermediaries and by using a very inexpensive technology. Tag-to-tag communication has a range of important applications including localization, tracking, monitoring of objects and people, and the Internet of Things.*

III. Broader Impact

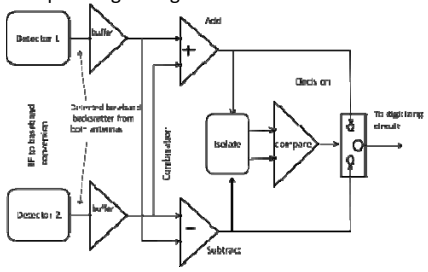
(a) Intellectual, Industrial and Societal: *The aim of the proposed research is to demonstrate the feasibility of an RFID system without RFID readers. The main novelty in the project is a tag that can directly communicate with other tags using backscattering. The new device will permit low cost and high scalability deployments within the Internet of Things. The latter will have an outstanding impact on both industry and society.*

(b) Educational: *The funded project is used for support of a graduate student who is trained to conduct research in hardware and software (the design of protocols for the new device).*

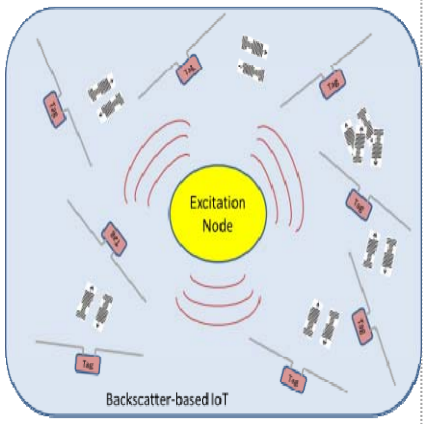
IV. Tag-to-Tag Communication



A setup for tag-to-tag communication.



A novel multi-detector circuit with an enhanced ability to passively decode backscatter from other tags.



An excitation node with communicating radio-less tags.

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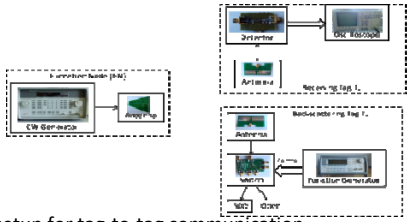

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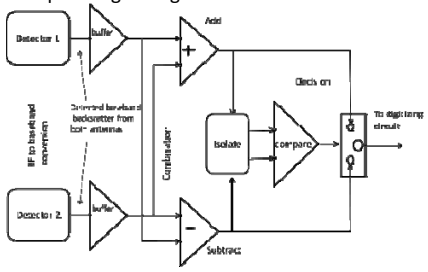

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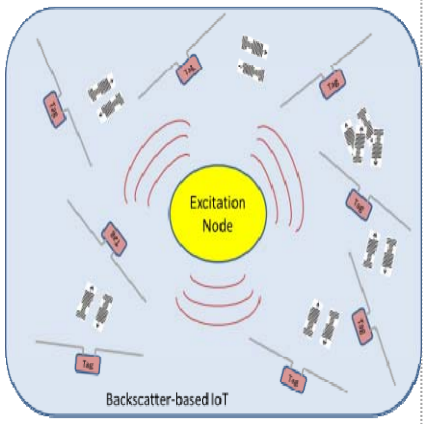


An excitation node with communicating radio-less tags.

Stiffness Mapping for Early Detection of Breast Cancer

ECCS-1306808 -- Olson -- Rose-Hulman Institute of Technology

In our first seven months, we have

- Identified and tested procedures for creating breast tissue phantoms from gelatin
- Developed methodologies for compression stiffness testing of gelatin samples
- Verified displacement/location accuracy for robot with appropriate end-effectors
- Created procedures for extracting surface displacement data for post-processing
- Explored improved fitness measures in computer simulations

Conference presentation accepted: "Early Detection of Breast Cancer through an Inverse Problem Approach to Stiffness Mapping: Fitness Optimization", L. G. Olson and R. D. Throne, U.S. National Congress on Theoretical and Applied Mechanics, June 2014.

This system has the potential to significantly increase the early detection of breast cancer with no unnecessary radiation, essentially no risk, and with little additional cost.

In our first seven months, four STEM undergraduates already making contributions to this interdisciplinary research

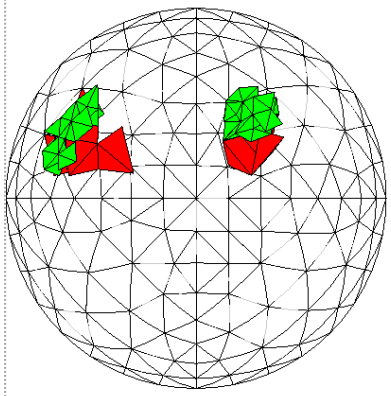
- 1 mechanical/biomedical, 1 mechanical, 2 chemical engineering
- 3 female, 1 male
- Robotics, measurements, computing, hydrogel chemistry

Award-winning middle school teacher engaging 20 middle school students in related science activities

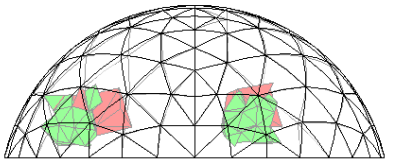
- Testing stiffness and density
- Creating tissue phantoms
- Understanding how engineering and science impacts lives

Manual breast exams (breast palpation) and mammograms are currently the most effective and widely used techniques for early detection of breast cancer. Breast palpation relies heuristically on the significant stiffness (elastic modulus) difference between cancerous tissue and healthy tissue. Unfortunately, manual breast exams are limited in their ability to detect tumors since they only produce local information about the site where the force is applied and do not provide quantitative measurements. Mammograms, while effective, expose the patient to radiation and hence routine mammograms are limited to those in specific age or risk groups. In addition, mammograms do not quantify tissue *stiffness*, an identifying characteristic of breast tumors.

This project's long-term goal is to develop a system that automates, quantifies, and enhances the resolution of the manual breast exam. An electro-mechanical device will gently indent the tissue surface in various locations, recording the tissue surface deflections and the force required. This force and deflection data will be used with inverse techniques involving finite element methods and genetic algorithms to provide detailed 3D maps of the elastic modulus of the interior of the breast tissue.



(a) Bottom View



(b) Side View

Excellent results in simulations: Green is true tumor location, Red is predicted tumor location. (Olson, Rose-Hulman Institute of Technology)

EARS: Collaborative Research: Enhancing Spectral Access via Directional Spectrum Sensing Employing 3-D Cone Filter Banks: Interdisciplinary Algorithms and Prototypes

Grant #: 1247940, PI: Dr Arjuna Madanayake

Research Goals

- Employ low-complexity antenna array based receivers to enhance opportunistic spectral access in cognitive radio networks while taking into account direction, location, modulation, and frequency of radio sources.
- Create 3-D infinite impulse response (IIR) cone filter based low-complexity array processing to perform directional spectrum sensing towards EARS.
- Design low-complexity digital circuits to implement 3-D IIR cone filter based directional sensing and feature detection algorithms using reconfigurable digital hardware platforms such as FPGAs.

Potential Scientific Payoffs

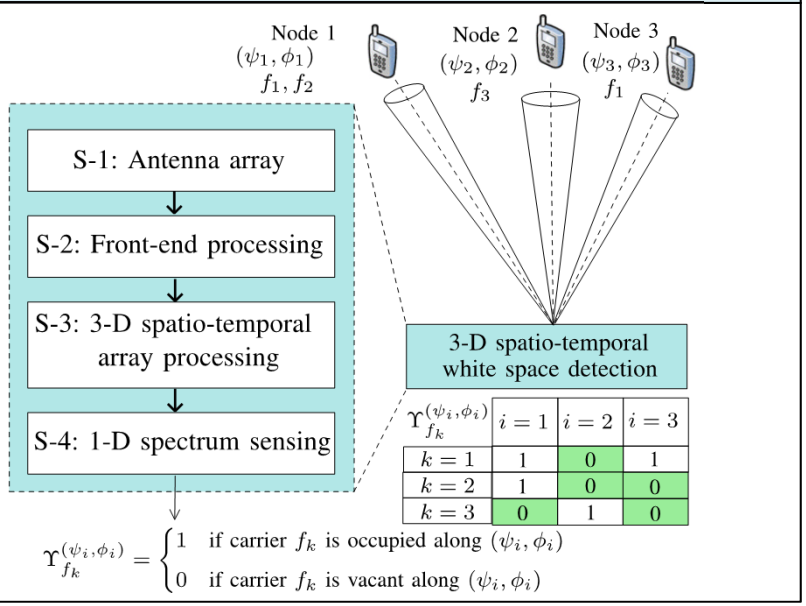
- Increased opportunistic spectral access via directional spectrum sensing and space-time white space detection, for a given frequency channel.
- An order of magnitude lower algorithmic complexity leading to lower power budgets due to 3-D IIR cone filters that are 90% lower in terms of multiplier circuit complexity (compared to phased array receivers).
- Combine low-complexity 3-D IIR array processing together with existing cyclostationary feature detection algorithms that enable radio source localization and directional feature detection towards EARS.

Technical Findings (5 journal and 5 conference papers)

- 2-D/3-D IIR filter based RF source localization algorithms.
- Spectral white spaces in 3-D space-time frequency domain: concept formulation, detection algorithms, prototype circuits, simulation-level verification.
- 2-D/3-D IIR filter based directional cyclostationay feature detection methods: algorithms and circuits.

Broader Impacts

- WIE summer camps at Uakron 2013 & 14
- High-school summer camps at NSU, VA 2013 & 14
- Undergraduate research and 2 NSF-REU students
- Special conference sessions, IEEE MWSCAS 2013 & 14



Spectrally Aware Interference Tolerant RF Nanosystems

ECCS-1247893: D Peroulis, J Rhoads, S Mohammadi/Purdue U

Research Goals:

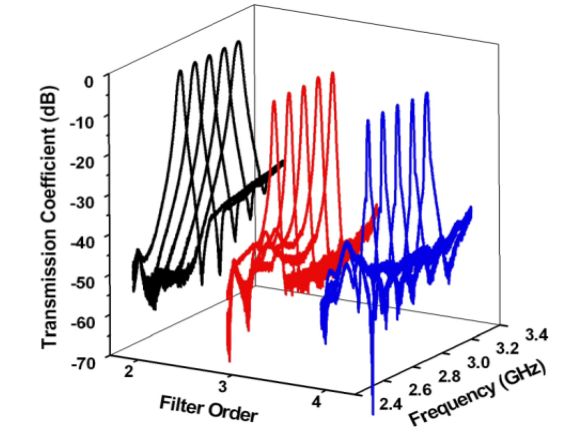
Existing conventional filtering architectures are unable to effectively mitigate spectrally-adaptive and close-to-carrier strong interferers

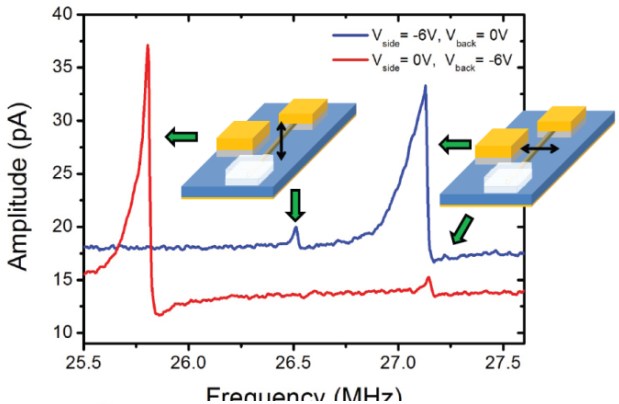
- Develop adaptive filtering architectures for dynamically rejecting strong interferer
- Bandstop filters with integrated nanoresonators with rejection levels equivalent to filters built by resonators with Q > 10× higher
- Reproducible and tunable integrated nanoresonators based on a simple post-CMOS processing technology for ~ 1 GHz filtering

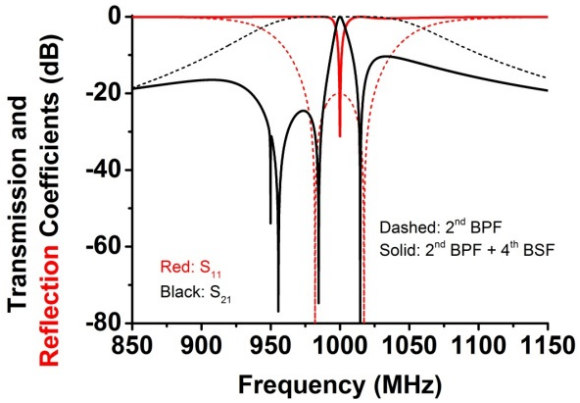
Potential payoff:

Enable adaptive receivers that can:

- Arbitrarily define their useful band
- Reject interferers at an arbitrary location, strength and bandwidth
- Be fabricated with low-cost CMOS technology within the project timeline







Title: Achieving sub-mm Accuracy with a Novel Indoor UWB Positioning System in Dense Multipath Environments for Medical Applications

NSF Grant: ECCS-1002318

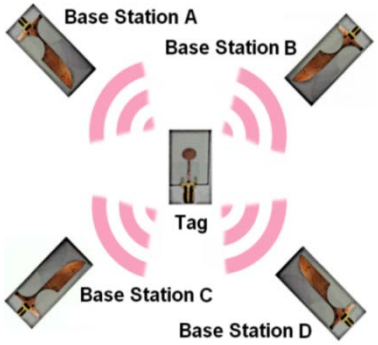
PI: Mohamed R. Mahfouz

Institution: The University of Tennessee, Knoxville

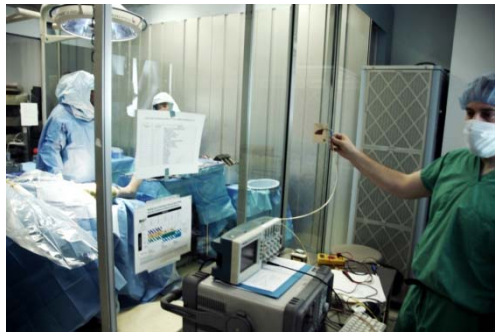
Objectives

- Current commercial ultra-wideband indoor tracking systems are limited to around 10-20 cm of accuracy
- This project aims to develop a wireless indoor tracking system accurate to within 1-2 mm, which is the required accuracy for surgical navigation and guidance

UWB Indoor Positioning System



UWB Measurements During Surgery in the OR

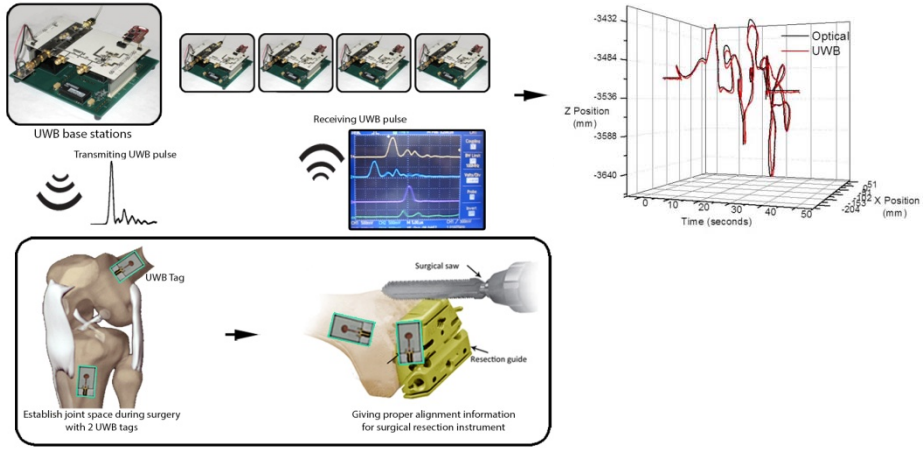


Major Accomplishments

- We developed a precise wireless indoor location system that supports improved surgical outcomes and brings sensor and tracking technology to the next generation of wireless medical devices by improving positioning accuracy to a few millimeters and optimizing the wireless link for operation in hospital environments.

Results

- 3-D accuracy of 3-4 mm for real-time freeform dynamic experiments



Spatial Multiplexing in Multi-Mode Optical Fibers

ECCS-1101905 – Joseph M. Kahn – Stanford University

Technical Goals and Accomplishments:

- Exploiting spatial dimensions in multi-mode or multi-core optical fibers is a key to further increasing transmission capacity of optical networks at all scales.
- We have significantly advanced fundamental understanding of how spatially multiplexed signals propagate and interact in optical fibers and have devised communication and signal processing methods that best exploit the characteristics of spatially multiplexed media.
- This work has been disseminated in twelve papers (three invited) in IEEE or OSA journals, and eight invited talks at major conferences. Many findings are described in: K.-P. Ho and J. M. Kahn, "Mode Coupling and its Impact on Spatially Multiplexed Systems", in *Optical Fiber Telecommunications VI B: Systems and Networks*, I. P. Kaminow, T. Li and A. E. Willner, Eds., Elsevier, Amsterdam, 2013.

Broader Impacts:

Intellectual, Industrial and Societal: Spatial multiplexing is a form of multi-input multi-output (MIMO) transmission, and our work is the first comprehensive study of coupled MIMO channels in optical fibers. Advances in spatial multiplexing help scale optical networks to higher capacity and lower cost and energy per bit, which is crucial for the continued growth of information technologies, which have become so essential to most aspects of modern society.

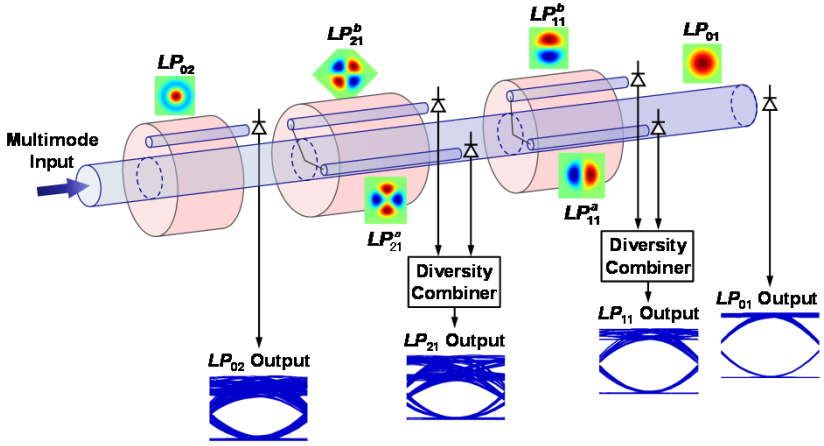
Educational: Students have received unique training that combines the disciplines of guided-wave propagation, communication channel modeling, information theory and digital signal processing. The principal investigator and participating students have reached out to elementary and high school students to stimulate their interest in optics and in careers in science and engineering.

Basic Principles:

Technical: The research is unique and challenging in its integration of principles from guided-wave optics, communication channel modeling, information theory and digital signal processing. To fully understand the outcomes, a scientist or engineer should be knowledgeable in all these disciplines. As signals multiplexed in different modes propagate, they are subject to different delays that distort them, different gains or losses that cause signal fading, and they become cross-coupled, which complicates efforts to separate multiplexed signals at a receiver, whether using digital or optical methods.

Non-technical: Digital information can be encoded into pulses of light and transmitted over very long distances through fibers made of extremely pure glass. At present, different signals are multiplexed in different colors of light, but as all available colors are now used, engineers search for new methods for carrying more digital information through each fiber. A promising method is to transmit different signals on different modes, which are spatial patterns of light that can propagate through a fiber without changing.

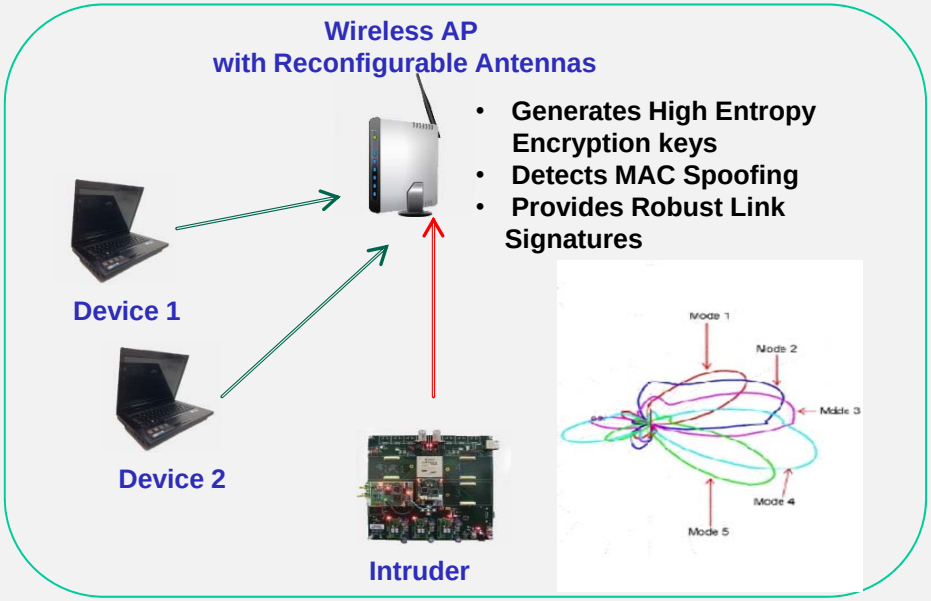
Short-Range Direct-Detection Links for Data Centers



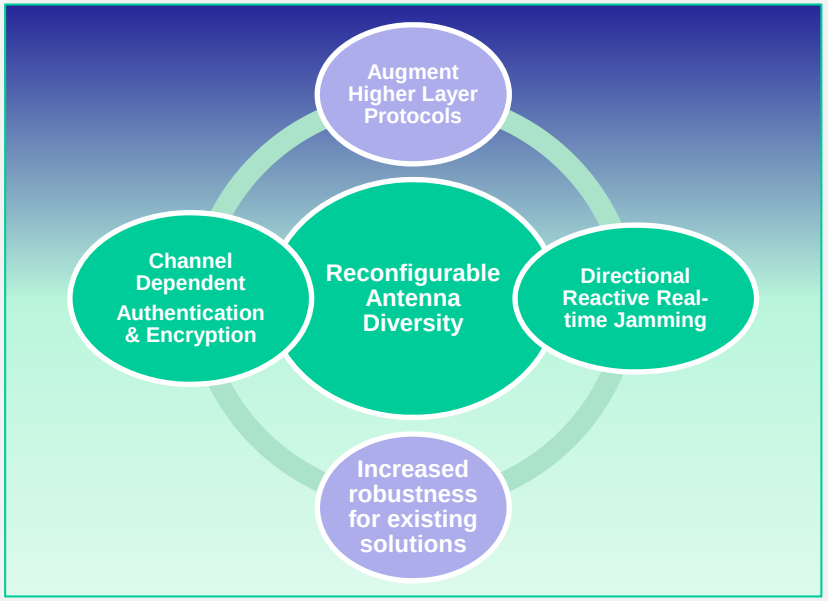
Four data signals, each carrying a bit rate of 40 Gbit/s, are transmitted in different modes within a multi-mode fiber. After propagating 1 km, the span of a large data center, here they are demultiplexed using couplers in which two or three strands of glass are fused together.

A Framework for Wireless Network Security Based on Reconfigurable Antennas

Award #: ECCS-1028608, PI: Kapil R. Dandekar, Drexel University



- Generates High Entropy Encryption keys
- Detects MAC Spoofing
- Provides Robust Link Signatures



Broader Impacts

- Center of Academic Excellence for Information Assurance Education
  - Drexel is a CAEIAE and has used this connection to disseminate project results to the NSA
- Cyber security education materials
  - Drexel is developing a MS degree program in cyber security Project materials will augment two quarter class on SDR security lab
- Undergraduate design projects and under-represented minority recruitment
  - Senior design team performed year long project on high entropy key generation on SDR platform
  - Female student recruited to work on the team

Key Research Results

- Robust link signature and detection metric
  - Developed new link signatures using channel information from multiple modes (patterns) of a reconfigurable antenna
- Intrusion Detection Algorithms for WiFi
  - Developed statistical and machine learning algorithms to detect spoofing attacks in the network with high accuracy
- High entropy encryption key generation
  - Developing encryption key generation algorithms for slow-fading wireless environment to provide longer and more secure keys
- Directional Reactive Jamming
  - Hardware implemented real-time directional reactive jamming for ISM band with reconfigurable antennas

A Wearable Microwave Radiometer for Internal Body Temperature Measurement

ECCS-1202193, PI: Zoya Popović

Research Goals:

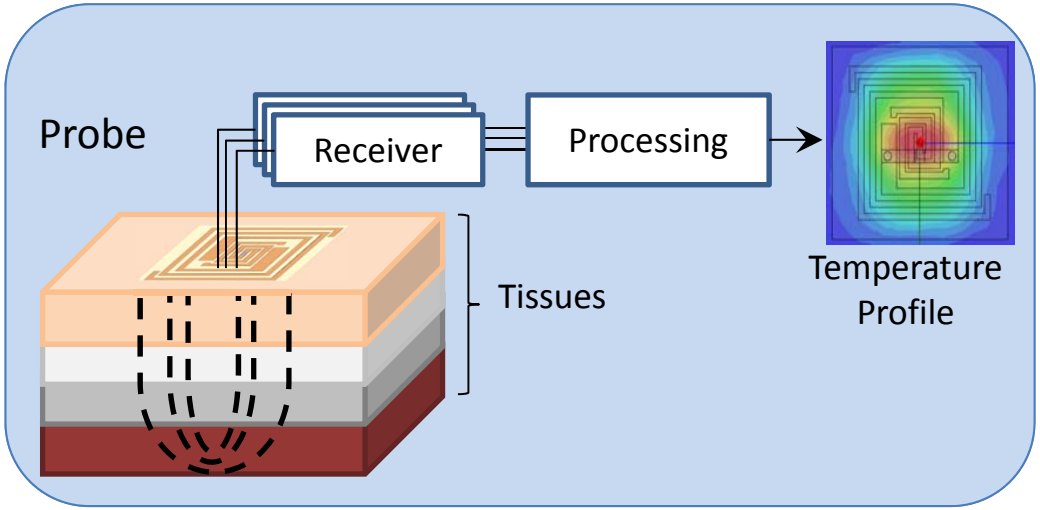
- Design multi-band radiometers to receive thermal emission from a human body phantom
- Design probes capable of receiving thermal emissions at a depth of a few centimeters within a lossy layered phantom
- Develop a measurement setup capable of demonstrating sub-surface temperature measurement in a lossy phantom

Potential Scientific Payoffs:

- Enables new medical research:
  - Circadian rhythm monitoring
  - Non-invasive core body temperature monitoring of personnel under heavy training (e.g. athletes)
  - Monitor temperature of organs during transplant and hyperthermia treatment
- Extend to monitoring temperature internally in industrial manufacturing (e.g. food industry)
- Develop compact sensitive radiometer

Results and Broader impacts:

- Demonstrated ability to measure and predict sub-surface temperature with <0.5K resolution; two-layer water phantom used for demonstration
- Developed electromagnetic model and validated against full-wave simulations
- Enable new medical research, e.g. sleep-disorder studies
- Training of graduate, undergraduate and high-school students; K-12 outreach



Design of Reliable High Speed Links with Unreliable Circuits

PI: Zhengya Zhang, Michael Flynn, University of Michigan, Ann Arbor

Funded by NSF CCF-1255702 and SRC 2013-HJ-2412

Project Description:

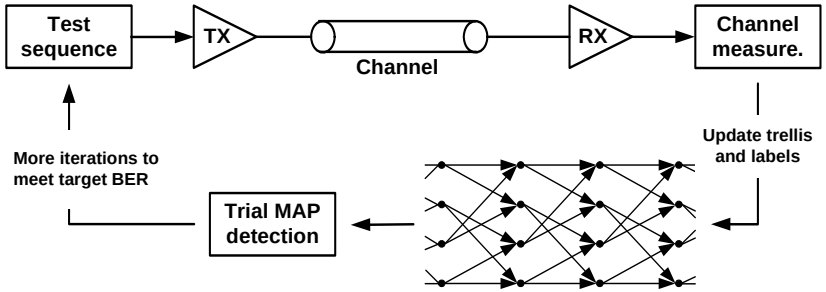
Create a failure-resistant high-speed digital link architecture based on maximum likelihood sequence detection (MLSD) to overcome both channel impairments and circuit nonidealities.

Objectives:

1. Improve the power efficiency of ADC and timing recovery using the extra margin by MLSD.
2. Design highly parallel (up to 10 Gb/s) MLSD for high-speed link equalization.

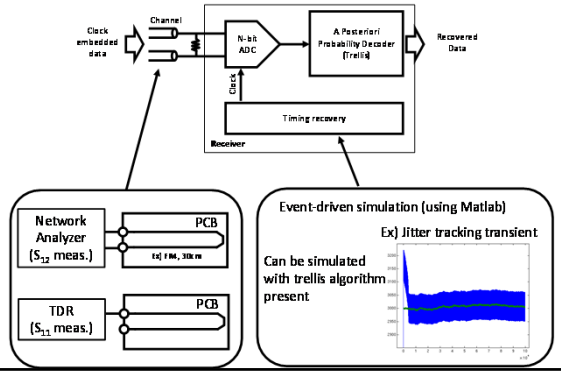
System Block Diagram:

- System model (trellis) is trained dynamically to adapt to the channel and interface circuitry.
- MLSD performs equalization based on trellis.



Year 1 Progress:

Channel characterization and modeling, system simulation, 6Gb/s 65nm test chip design



Future Milestones:

- Year 2: Design of parallel high-speed MLSD and low-power ADC based on sea of comparators
- Year 3: Trellis-based timing recovery, second test chip (10-20 Gb/s link front end + MLSD)

Expected Outcomes:

1. New digital link architecture that uses MLSD to lower the front end power and relax its design requirements.
2. High-speed MLSD for link equalization, soft detection and turbo decoder.

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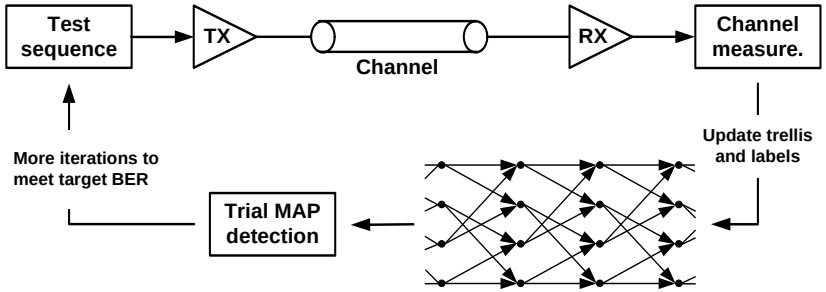

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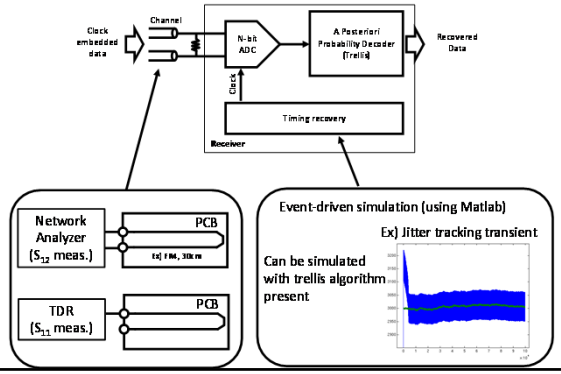


Future Milestones:

- Year 2: Design of parallel high-speed MLSD and low-power ADC based on sea of comparators
- Year 3: Trellis-based timing recovery, second test chip (10-20 Gb/s link front end + MLSD)

Expected Outcomes:

1. New digital link architecture that uses MLSD to lower the front end power and relax its design requirements.
2. High-speed MLSD for link equalization, soft detection and turbo decoder.

2014 ECCS Highlight Title

ECCS #1002294 - Payam Heydari – University of California, Irvine

I. Recent Outcomes & Accomplishments:

In this project, the PI and his research group designed and implemented FOUR complete imaging receiver integrated circuits operating at W-band (75-110GHz).

Accomplishments:

1. In a news wire published in Feb. 17, 2014 issue of Wall Street Journal, Prof. Heydari and his students, in collaboration with TowerJazz Semiconductor, designed the most complex W-band imaging receiver integrated circuits in the owrld. http://online.wsj.com/article/PR-CO-20140217-901236.html
2. The PI published SIX IEEE Journal of Solid-State Circuits, two IEEE Trans. on Microwave Theory and Techniques, and more than 15 peer reviewed conferences, including a highly publicized prestigious IEEE International Solid-State Circuits Conference.
3. The funding of this research led to creation of a large project won passive imaging in silicon technologies with more than 6 Ph.D. students involved.
4. The PI gave several invited talks and TWO Keynote Speeches to two conferences; (1) GlobalSIP 2013 Symposium on: Millimeter Wave Imaging and Communications (see http://www.ieeeglobalsip.org/2013/mmwis.html) and (2) 10th SoC conference (see http://www.socconference.com/SoC10-2012/main10.htm)

Please describe recent outcomes and successes or breakthroughs of the NSF-awarded research. List any recent patents, awards, work products, or publications related to these outcomes.

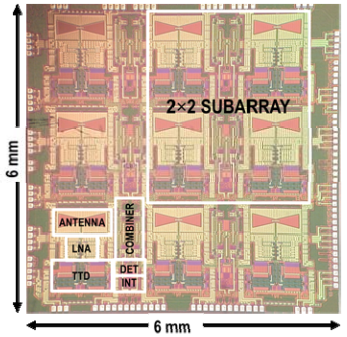
II. Basic Principles:

Millimeter-wave frequency range from 30-300GHz has been an active area of research in the field of active and passive imaging and sensing for several decades. At millimeter-wave frequencies, black body radiation is emitted at a nearly constant power spectral density (i.e., white spectrum), which is directly proportional to the temperature and emissivity of the radiating object. Low-attenuation atmospheric windows centered at frequencies of 35, 94, 140, and 220GHz exist, which provide transmission through obstacles such as clothing, smoke, dust, fog, and clouds. Applications such as concealed weapon detection, airplane navigation in low visibility conditions, and satellite surveillance have been targeted for imaging systems at these frequencies. In recent years, silicon technologies have achieved the required imaging system performance that had previously only been obtained using III-V technologies in a multi-chip module based system. While silicon based imaging receivers require a lens or other focusing system just as their III-V counterparts, due to high integration levels and low cost at mass production, silicon based imaging receiver systems can be especially advantageous when a large number of array elements is required. Combined with the high yield of silicon processes, concepts such as wafer-level arrays become a very exciting and real possibility.

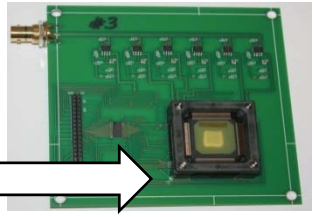
III. Broader Impact:

SILICON technologies have been adopted as the primary platform for development of millimeter-wave (mm-wave) systems for the target applications of short-range high data-rate wireless communication, automotive radar, sensing and imaging.
Recently, benefiting from the aggressive feature size scaling, silicon technology has shown the capability for implementation of W-band passive imaging receivers with fine image and temperature resolution. However, these efforts are limited to a single receiver/pixel. To reduce the scanning time and enable video rate real-time imaging, a focal-plane array (FPA) could be used with an array of detectors located at the focal-plane of a focusing system. As part of the project, we presented the world's first W-band 2x2 FPA in 180nm SiGe BiCMOS process. This work demonstrates the highest integration level of any silicon-based systems in the 94 GHz imaging band.
This highly integrated imaging system will be an ideal candidate for various applications such as remote sensing, security surveillance (e.g., concealed weapon detection at the airport), non-destructive inspection for biological tissues as well as industrial process control.
To further increase resolution, enhance imaging field of view (FOV), reduce the scanning time, and enable video rate real-time imaging, a we have invented a new imaging array architecture based on new concept of spatially overlapping super-pixels. As part of the project, we presented the world's first W-band 9-element imaging array receiver with on-chip antennas. This work demonstrates the highest integration level of any silicon-based systems W-band.
This highly integrated imaging system will be an ideal candidate for various applications such as remote sensing, security surveillance (e.g., concealed weapon detection at the airport), non-destructive inspection for biological tissues as well as industrial process control.

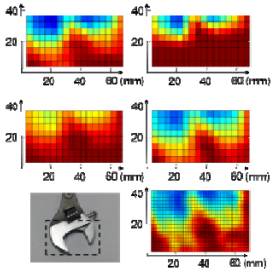
III. Compelling Image:



Die microphotograph of the 9-element fully integrated W-band imaging receiver



Custom PCB and a packaged chip



Advanced Modeling and Design of High-Performance ADC-Based Serial Links

ECCS-1202508, Prof. Samuel Palermo, Texas A&M University

Research Goals:

- Develop a novel statistical-modeling framework for designing advanced ADC-based high-speed serial links
- Develop an energy-efficient transmitter architecture capable of scaling data rate and modulation format based on system performance demands
- Develop a new hybrid ADC-based receiver architecture which combines in a power optimum manner equalization embedded in the ADC and dynamically power-gated digital equalization.

Potential Scientific Payouts:

- Ultra-fast statistical-modeling optimization framework allows for rapid investigation of trade-offs in ADC resolution and analog/digital equalization complexity
- Novel circuit topologies that enable efficient modulation agile transmitters and the embedding of partial analog equalization in the ADC
- The ability to efficiently support data rates in excess of 25Gb/s over very high loss electrical channels, allowing interconnect systems to scale into the next decade

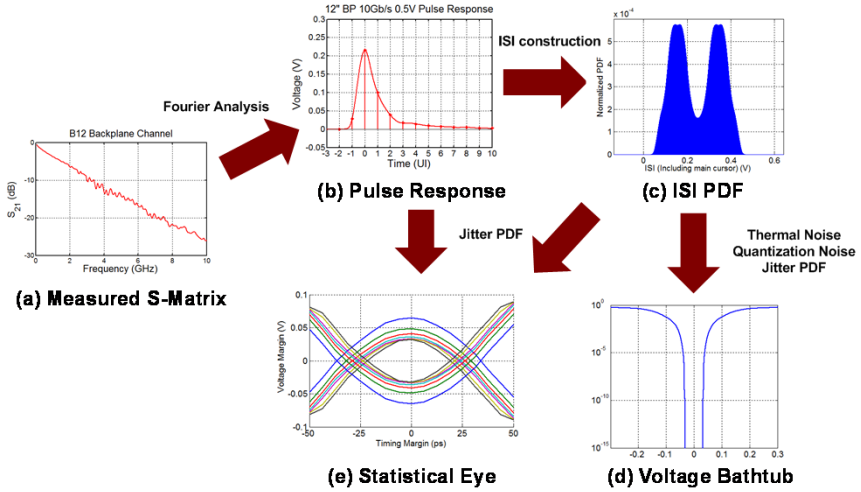
Major Results:

- Implemented the first 1.6GS/s ADC with embedded one-tap DFE in a 90nm CMOS process
- Implemented the first 6b 10GS/s SAR ADC with embedded 2-tap FFE and 1-tap DFE in a GP 65nm CMOS process
- Developed a statistical modeling framework which takes into account the effect of channel ISI, thermal noise, jitter, quantization noise, and ADC metastability

Broader Impact:

Increased bandwidth provided by the ADC-based serial link architectures will allow applications, such as future smart mobile devices capable of Tflop/s performance, multi-channel high-resolution MRI, and exascale supercomputers

ADC-Based Serial Link Statistical Modeling Framework



NSF-ECS 0801798: Development of Environmentally-Friendly Paper-Based Technology Platforms for RFID's and Sensors with "Enhanced Wireless Intelligence"

PI's: Manos M. Tentzeris, J.Laskar (Georgia Tech)

Participating Students: R.Vyas, S.Kim, T.Le, B.Cook, A.Traille, S.Palacios and S.Elia

Objectives

- Development of inkjet-printed platforms for wireless communication and sensing applications on paper and other low-cost environmentally-friendly flexible substrates
- Development of sufficiently conductive inks and inkjet-printed components that could function up to the millimeter-wave frequency range

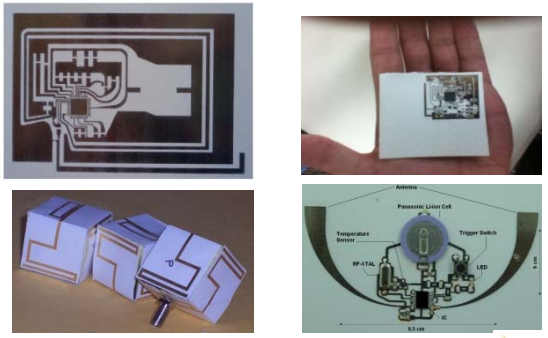
Major Results

• The first inks with conductivity above 10^7 operating up to 60 GHz pushing previous results by 2 orders of magnitude.
• The first ever deposition of Cu on any substrate for the first completely "green" inkjet-printable recyclable RF modules.
•The first inkjet-printed UWB antenna, microfluidic channel and via-holes, as well as the first integrated inkjet printed module (SWIM) on paper, kapton and PMMA (plastic).
•The first "zero-power" ambient TV energy harvesting wireless sensor module
•The first CNT-based and graphene-based gas sensing solutions on virtually any substrate.
•The first "smart cube" 3D antenna solution to achieve an orientation-independent wireless sensing nodes

Accomplishments

- Set the foundation for the first low-cost inkjet-printed RF platforms on virtually any substrate for the first practical Internet of Things / Enhanced Cognitive Intelligence systems
- Demonstrated the first truly autonomous wireless sensor that utilizes only ambient RF power from long-range (up to 5-6 miles) sources
- Demonstrated the ultra-low-cost "green" integration of nanostructures and biostructures with RF structures just through the use of inkjet printing /o the need of clean rooms and masks

Prototypes



Georgia Institute of Technology

CAREER: Cognitive Power Management for Memory Dominated Mobile Devices

AWARD # ECCS-0955157 (4/2010-3/2015)

PI: Ahmed M. Eltawil, University of California, Irvine

UCIrvine | University of California

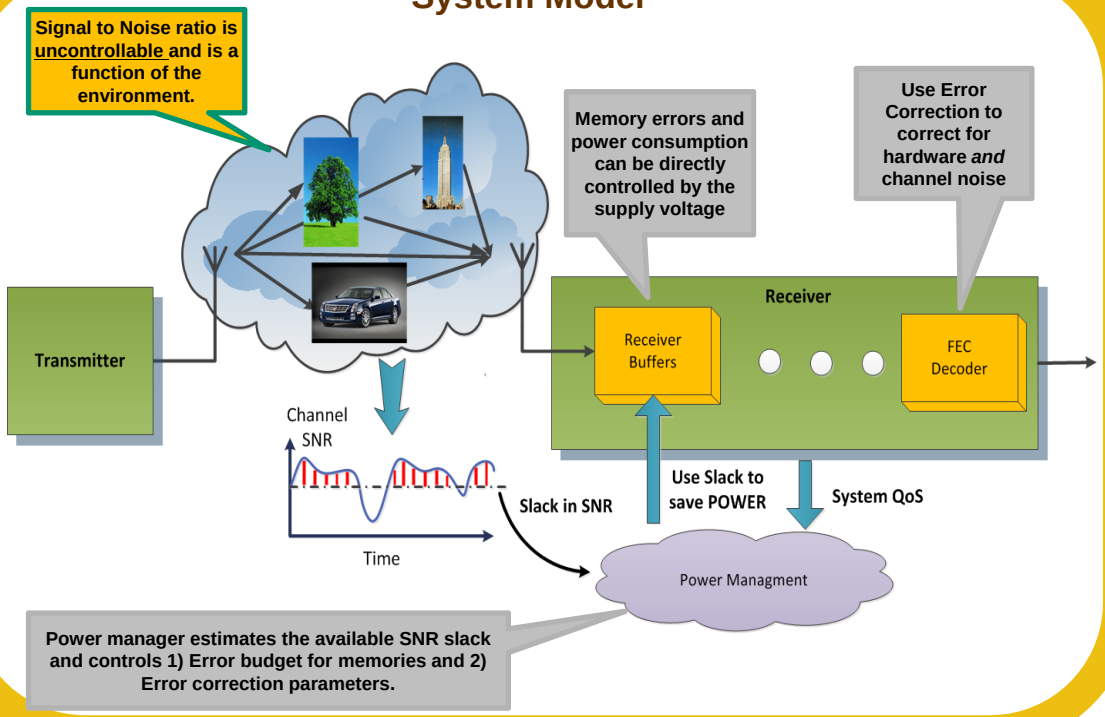
Motivation

- Embedded memories are a major portion of any wireless communication system, consuming a substantial portion of the power and area budget
- While advanced power management techniques are available for general logic, memories are rarely subjected to power management due to their inherent sensitivity to supply and process variations.

Objective

- Utilize variability of wireless channel to allow for aggressive dynamic voltage scaling within the hardware.
- When the Signal to Noise ration (SNR) of the wireless channel is high, allow the hardware (specifically embedded memories) to fail in a controllable manner as long as an overall quality metric is met.

System Model

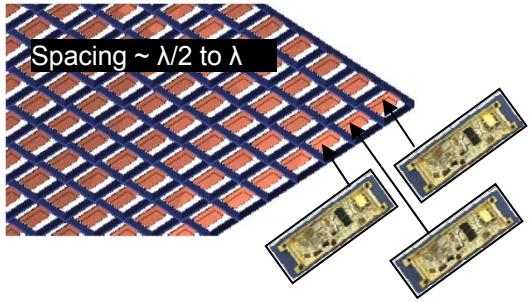


Results

- Developed abstract statistical error models for various memory configurations including SRAMS and DRAMS.
- Developed a unified channel and hardware noise model for OFDM based systems.
- Developed a new class of FEC decoder structures that can handle both channel and hardware noise including LDPC, VITERBI and TURBO architectures.
  - Less than 2% area overhead and power reduction of up to 30%.
- Developed Error Tolerant CACHE architectures.
- Developed power manager algorithms that operate both locally within the receiver and across layers demonstrating up to **40% power savings**.
- Extended concept to other domains including multimedia, and multimedia over wireless.
- Created a fast error aware model for arithmetic and logic circuits.
- Research resulted in **18 publications, one patent application and two records of invention** to date.

CAREER Next-Generation Ultra-Low-Cost Phased Arrays

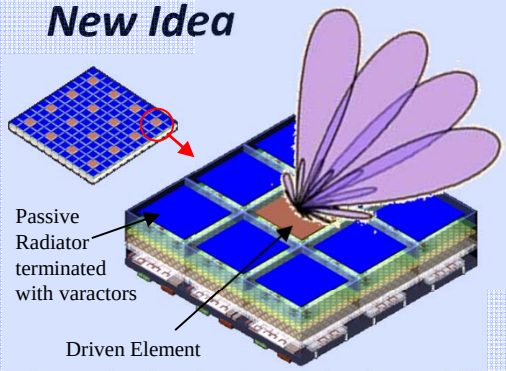
Status Quo



Current Phased Array Architecture

- *A T/R module or phase shifter behind each Antenna*
- *Expensive, high loss, limited beam scan angles, heat management problem*

New Idea



Use mutual coupling and varactor loading to create phase shifts

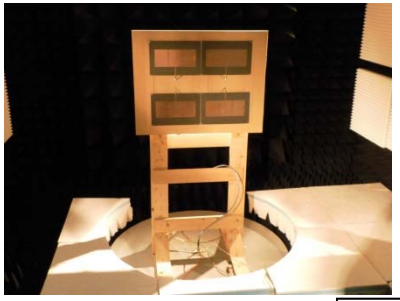
Reduce the # of T/R modules by one order of magnitude

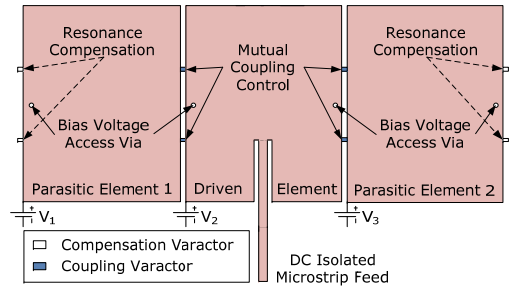
Analog beam steering, increased scan angles, better heat dissipation

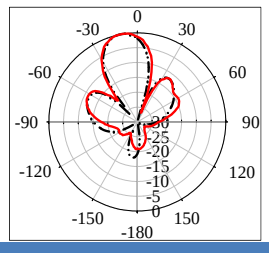
Impacts

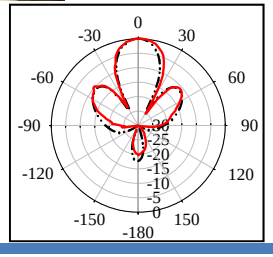
- Demonstrated the concept of spatial aperture combining technique
- Significantly reduced cost
- Continuous beam scanning
- High antenna efficiency
- Maintained impedance matching
- Scalable into larger arrays
- Unique BST technique for conformal ESPAR phased arrays
- Filter/antenna integration for low co-site interference

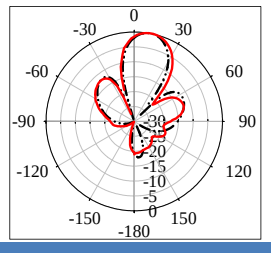
Accomplishments











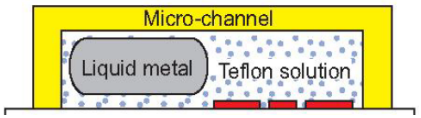
NSF CAREER: Liquid RF Electronics

EECS Award No: 0747766
PI: Prof. Dimitrios Peroulis, Purdue University

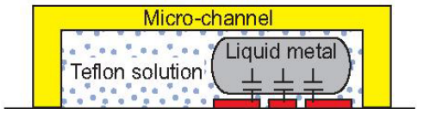
Mission: Strategically merge RF electronics and microfluidics to simultaneously address reconfigurability and thermal management

Goals:
- Liquid metal switches
- Liquid high-power absorptive switches
- Liquid high-quality reconfigurable filters
- Curriculum innovation by integrating education/research goals and results

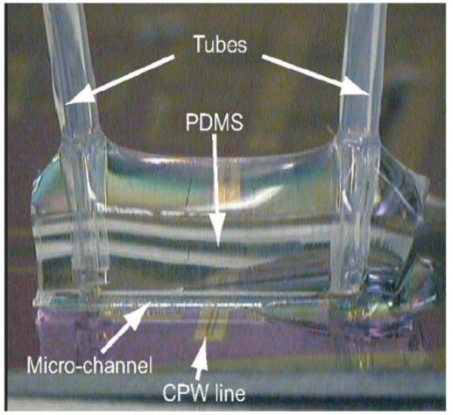
Major Accomplishments (1):
First non-toxic liquid-metal ultra wideband (2 – 100 GHz) RF switch (2007)



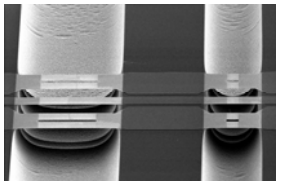
off state
loss < 0.2 dB @ 20 GHz



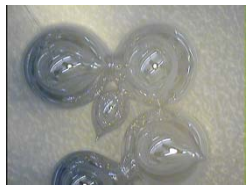
on state
isolation > 20 dB @ 20 GHz



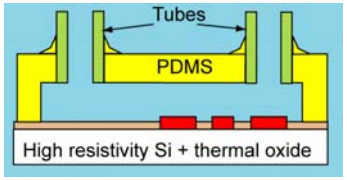
Technology:
- Gallium-indium-tin (Galinstan) alloy
- Water-based microfluidics (high-power)
- Micromachining for RF applications



RF/microfluidic microchannels

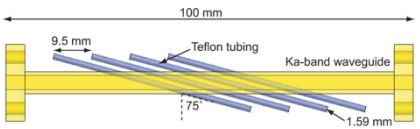


Galinstan microdroplets



Liquid-metal microswitch

Major Accomplishments (2):
First high-power RF liquid switch (2009)



- Freq: 25-40 GHz
- Power: 32 W (hot)
- Loss < 0.5 dB
- Isolation > 22 dB