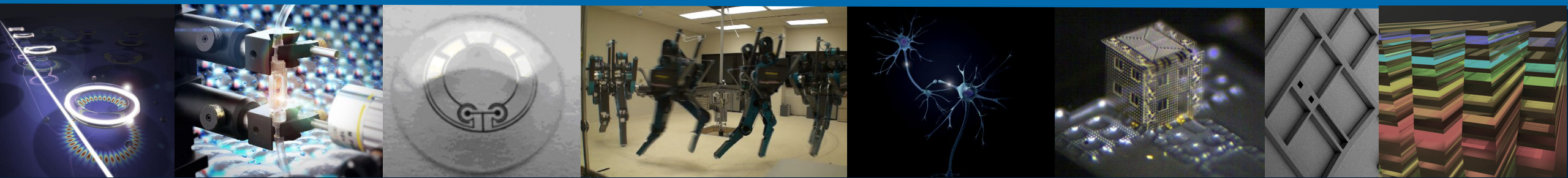
U.S./Morocco Workshop on Sensors and Wireless Networks for Smart Cities

An Overview the Electrical, Communications and Cyber Systems (ECCS) Division

Samir El-Ghazaly
Division Director, ECCS
Engineering Directorate
National Science Foundation
Arlington, VA



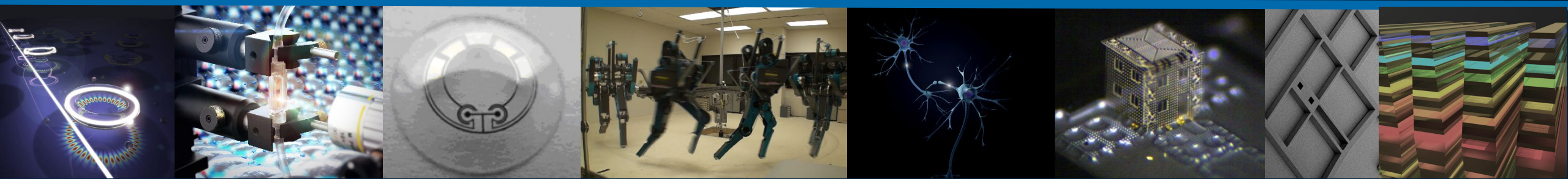
Acknowledgement

Workshop co-Chairs:

Driss Benhaddou **Tarek El-Ghazawi** **Mohamed Essaaidi**

NSF Program Directors:

Usha Varshney **Eyad Abed**



NSF's Origin, Mission, and Structure

- Independent federal agency established by Congress in the NSF Act of 1950
  - *"To Promote Progress of Science," and "Advance National Health, Prosperity, and Welfare," and "Secure the National Defense"*
- Supports fundamental research and education across all fields of science and engineering
- Sponsors research primarily through grant mechanism, but operates no laboratories
- Discipline-based structure with cross-disciplinary mechanisms
- Uses "rotators" or IPAs and permanent program directors
- FY2015 Budget ~ $7.5 billion

NSF by the Numbers

$7.3 billion FY 2015 appropriation

94% funds research, education and related activities

48,100 proposals

11,000 awards funded

1,826 NSF-funded institutions

320,900 NSF-supported researchers

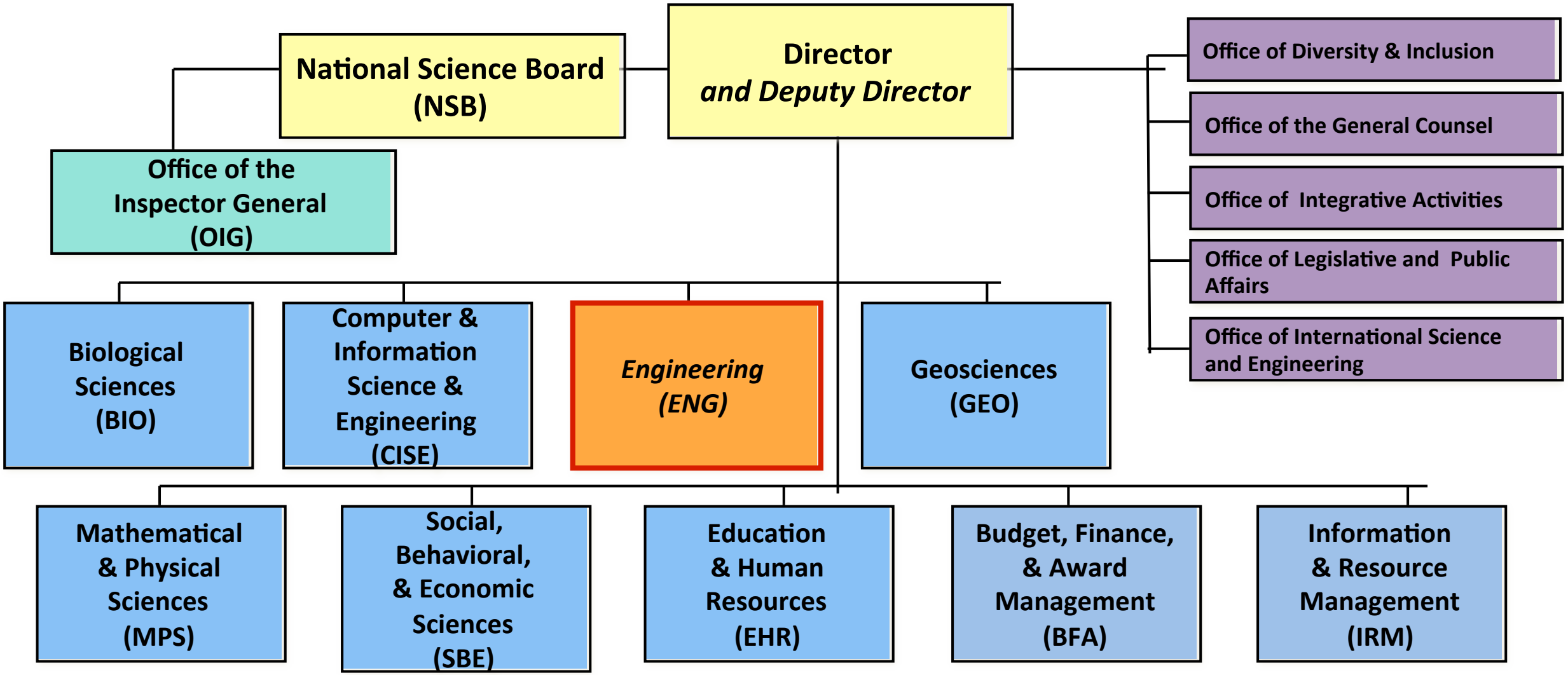
All S&E disciplines funded

Funds research into STEM education

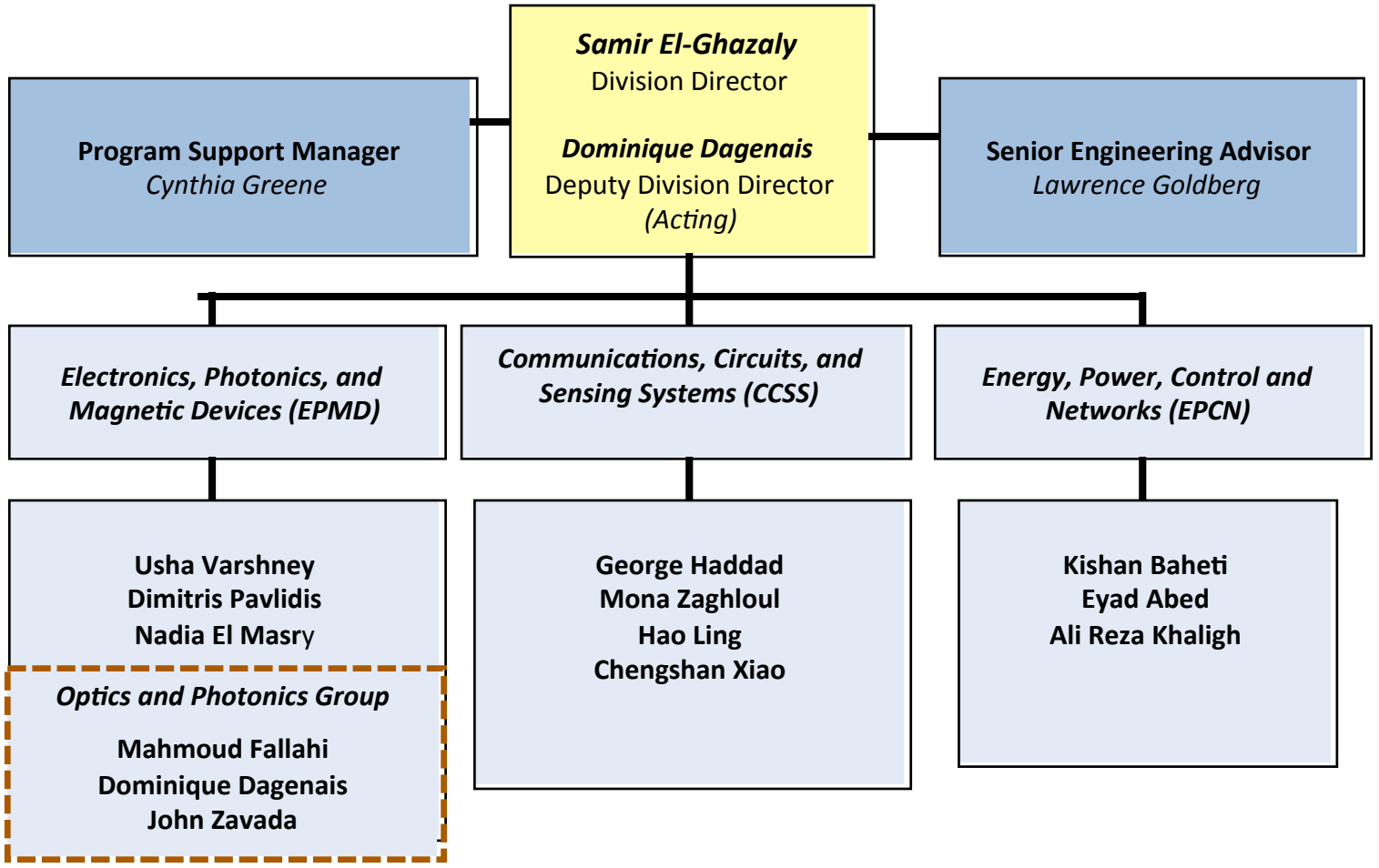
214 Nobel Prize winners

Other than the FY 2015 appropriation, numbers shown are based on FY 2014 activities.

National Science Foundation



Electrical, Communications, and Cyber Systems *(ECCS)*

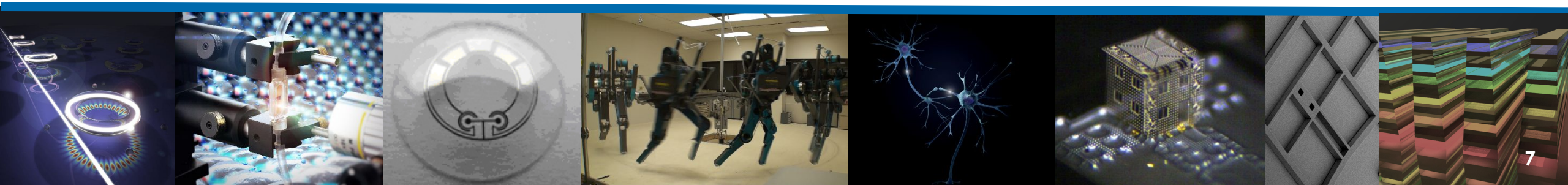


ECCS Mission

- ***Address fundamental research issues at the nano, micro, and macro scales underlying device and component technologies for energy and power, controls, networks, communications, computation and sensing applications***

- ***Support research on systems and networks for advanced engineering applications***

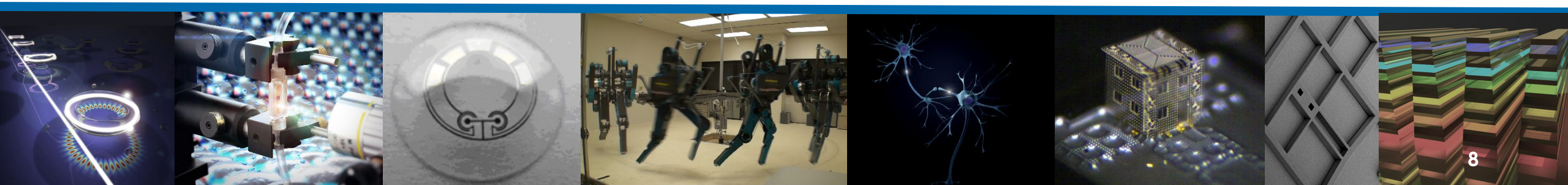
- ***Support education of a diverse workforce in electrical and computer engineering to meet the technological challenges of a 21st century global economy***



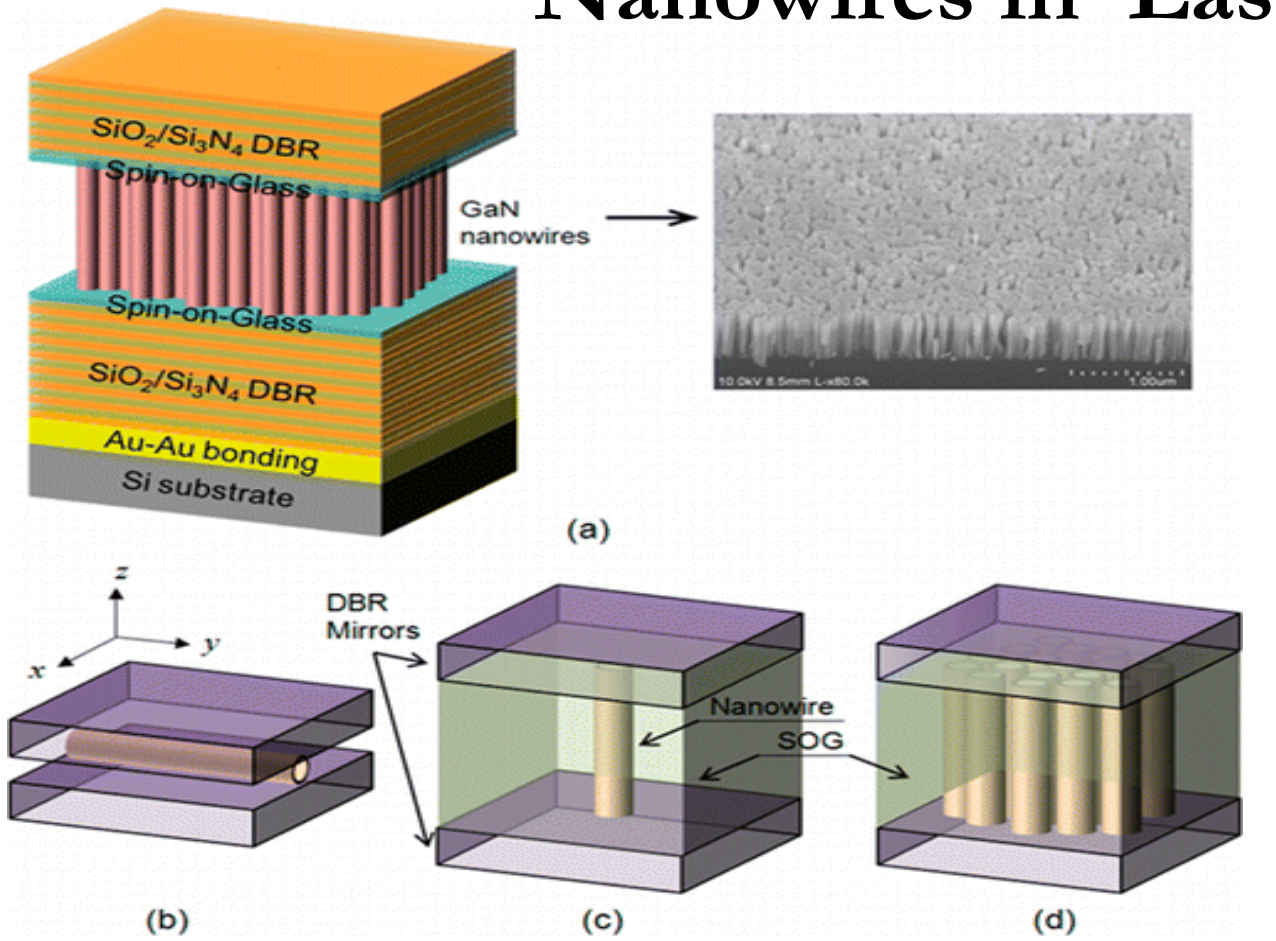
Electronics, Photonics, and Magnetic Devices (EPMD) Program

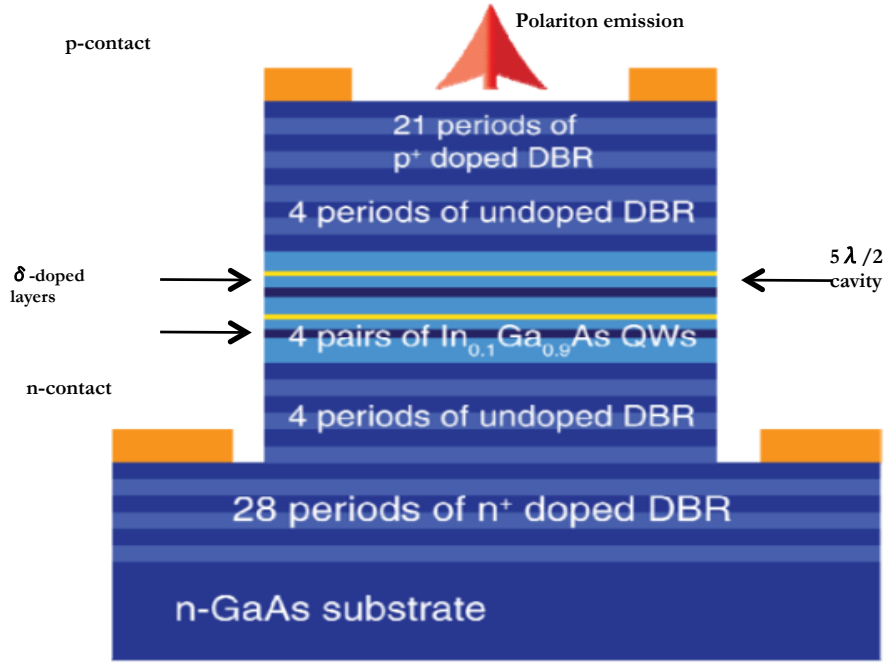
(D. Dagenais, N. El-Masry, M. Fallahi, D. Pavlidis, U. Varshney, John Zavada)

- Enable discovery and innovation advancing the frontiers of nanoelectronics, spin electronics, molecular and organic electronics, bioelectronics, biomagnetics, non-silicon electronics, and flexible electronics.
- Improve the fundamental understanding of devices and components.
- Emphasizes emerging areas of diagnostic, wearable and implantable devices, and supports manipulation and real-time measurement.
- Support cooperative efforts with the semiconductor industry on new nanoelectronics concepts beyond the scaling limits of silicon technology.

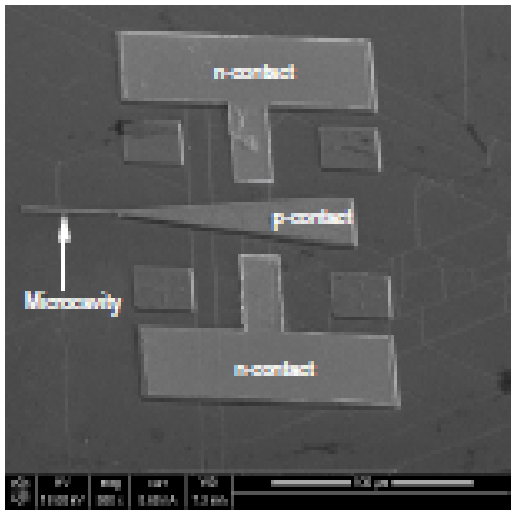


Nanowires in Lasers





Multi-quantum Well Microcavity Diode

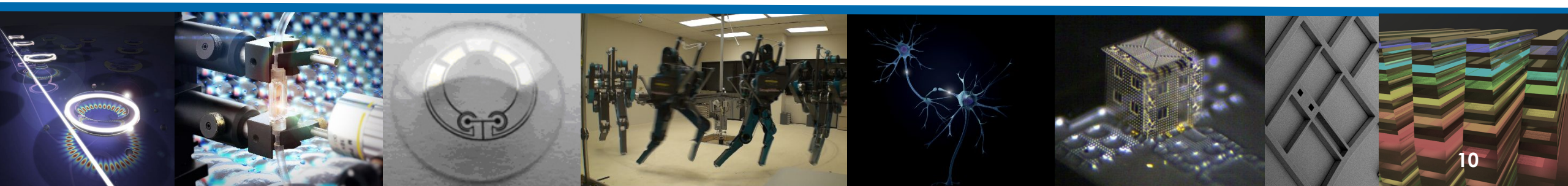


(a) Schematic representation of the GaN nanowire array–dielectric microcavity. Image of an as-grown nanowire sample. (b–d) Nanowires embedded in a dielectric spin-on-glass cavity.

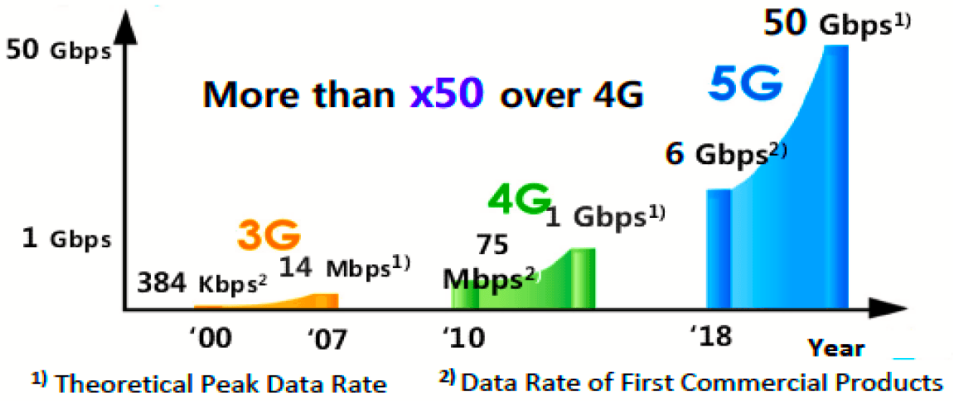
Communications, Circuits, and Sensing-Systems (CCSS) Program

(George Haddad, Mona Zaghloul, Hao Ling, Chengshan Xiao)

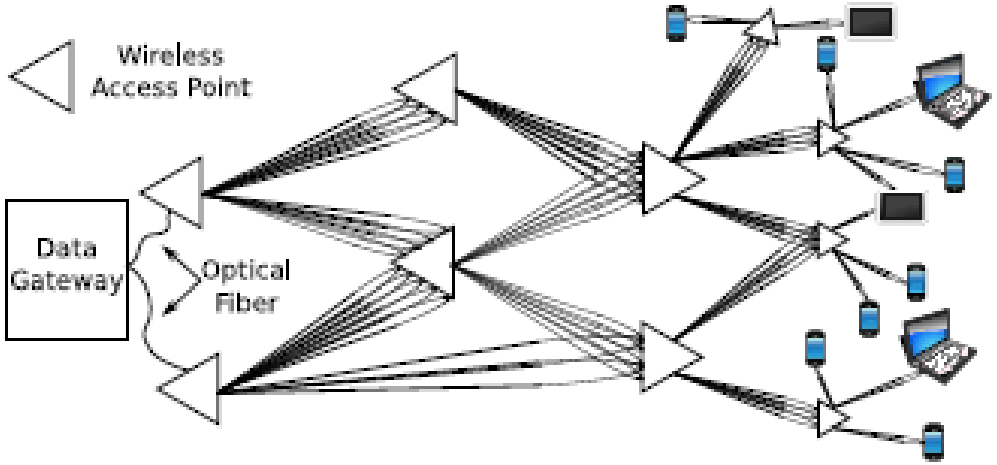
- Supports systems research in hardware, signal processing techniques, and architectures.
- Supports innovative research in micro- and nano- electromechanical systems (MEMS/NEMS), communications and sensing systems, and cyber-physical systems.
- Supports the design, development, and implementation of new complex and hybrid systems at all scales, including nano and macro, that lead to innovative engineering principles and solutions.



EARS: Beamspace Communication for Gigabit Mobile Wireless at Millimeter-Wave *Frequencies*



Plot of generational data rates for 3G, 4G, and 5G networks.
Millimeter Wave spectrum is needed to meet 5G demand .



Two-Level mm-wave network topology

HOME > TECHNOLOGIES > COMMUNICATIONS > MILLIMETER WAVES WILL EXPAND THE WIRELESS FUTURE

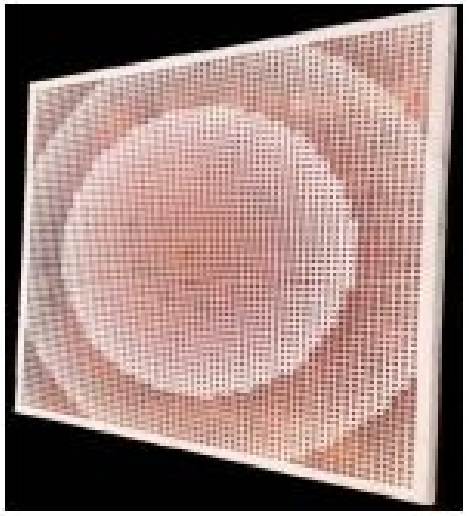
Millimeter Waves Will Expand The Wireless Future

Technology finally makes millimeter waves practical to use, enabling the continued growth of wireless communications before we run out of spectrum.

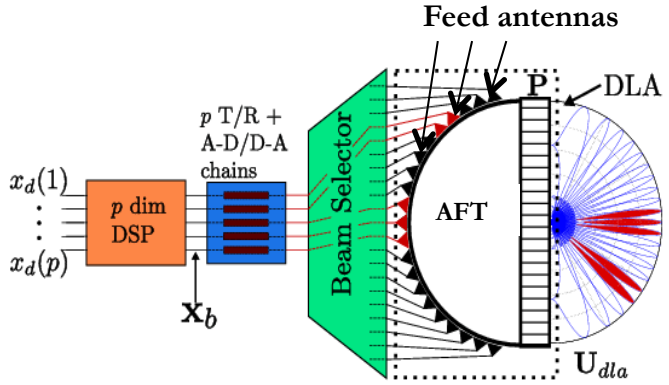
Lou Frenzel | *Electronic Design*

electronic design

Potential Payoff: Transformative enhancements in the access to, and usage of, the electromagnetic spectrum at millimeter-wave frequencies (30-300GHz)



Prototype of a Discrete Lens Array



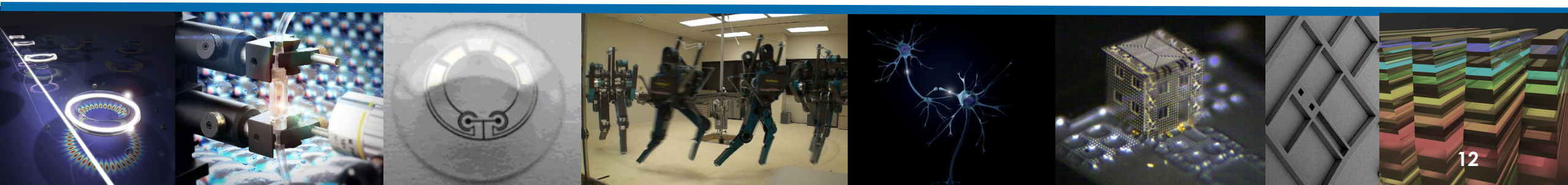
Potential power and spectral efficiency gains due to beamspace multiplexing at 80GHz vs. 3GHz

(ECCS-1247583PI: Akbar M. Sayeed, co-PI: Nader Behdad)

Energy, Power, Control and Networks (EPCN) Program

(Kishan Baheti, Eyad Abed, Alireza Khaligh)

- Emphasizes electric power systems.
- Invests in systems and control methods for analysis and design of cyber-physical systems.
- Invests in adaptive dynamic programing, brain-like networked architectures performing real-time learning, and neuromorphic engineering.
- Supports innovative proposals dealing with systems research in such areas as energy, transportation, and nanotechnology.



Cyber-Security of Controlled Systems

Waze Attacked: Technion Students Create Traffic Jam Cyber Attack On GPS App

Ever more infrastructures and controlled systems exposed to an ever expending varieties of cyber-threats and manipulations.

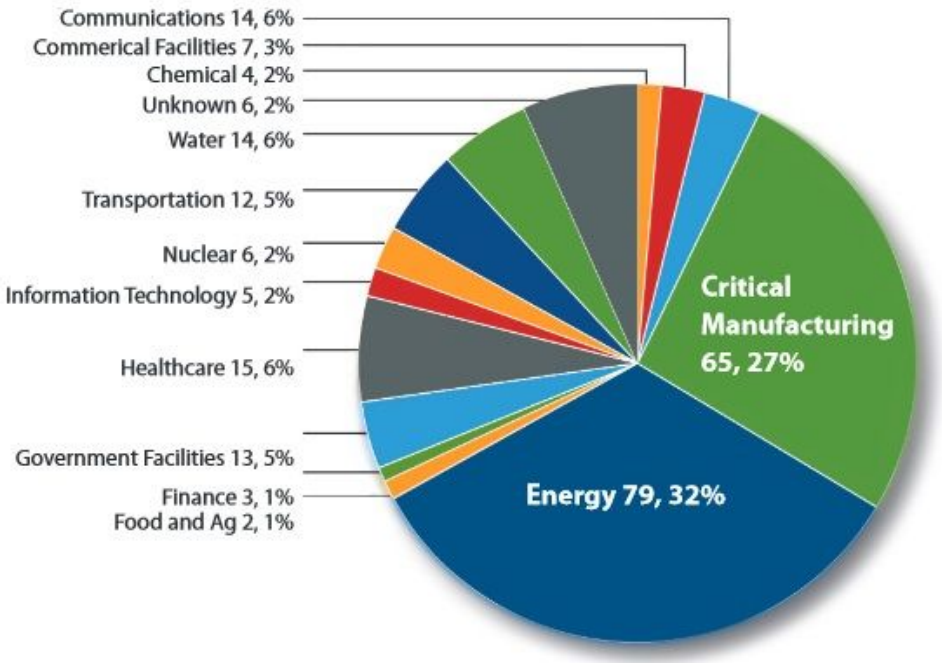
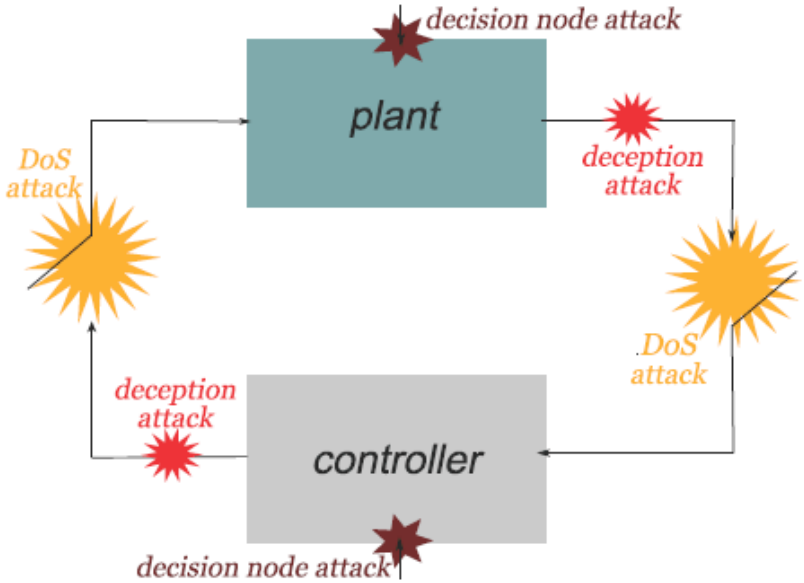


Figure 1. FY 2014 incidents reported by sector (245 total).



Three types of cyber-attacks on a feedback control loop.

Recent Achievement: Characterized new equilibria in estimation games with self-interested, compromised sensors.

(ECCS-1151076, Langbort, University of Illinois at Urbana-Champaign)

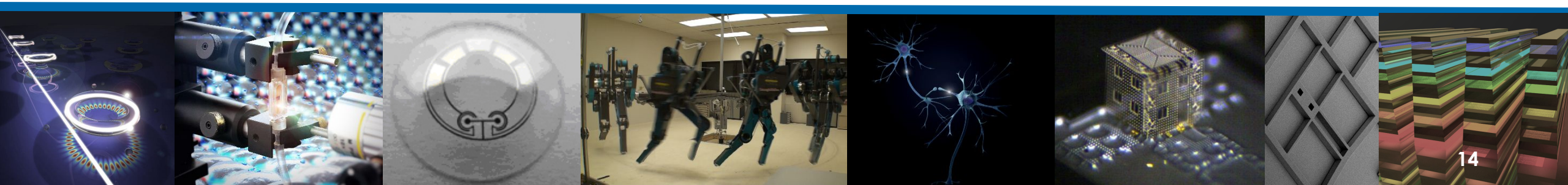
Funding Opportunities

- **Core Programs**
- **Initiatives**

- ✓ ***Collaborative/Interdisciplinary Areas***
- ✓ ***Crosscutting and NSF-wide Programs***

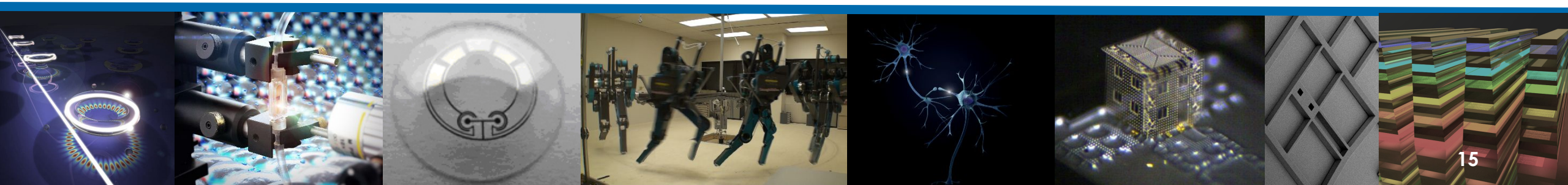
ECCS Unsolicited Proposals

- **Submission Window**
  - *October 1 – November 1 annually*
- **Award Size for Unsolicited**
  - *Typically $360K for three years*
- **Funding Rates**
  - *15-17%*
- **Reviewers**
  - *from university, industry and government*



Examples of Other Programs

- **Core Programs**
  - *Early Faculty Career Development Grants / Presidential Early Career Awards (CAREER/ PECASE)*
  - *EAGER*
- **Workshops**
- **Cross-cutting Programs**
  - *Major Research Instrumentation (MRI)*
- **Supplements**
  - *Research Experiences for Undergraduates (REU)*
  - *Research Experiences for Teachers (RET)*
  - *GOALI*
  - *Equipment*
  - *International*

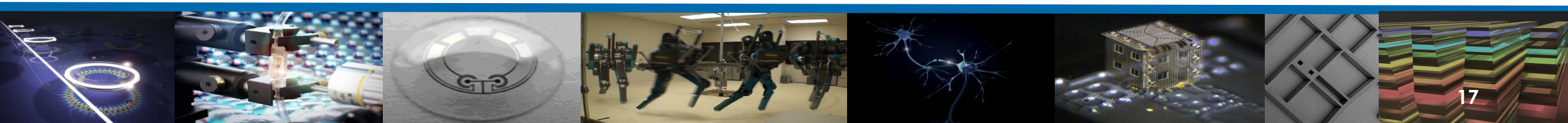


ECCS Involvement in NSF Initiatives

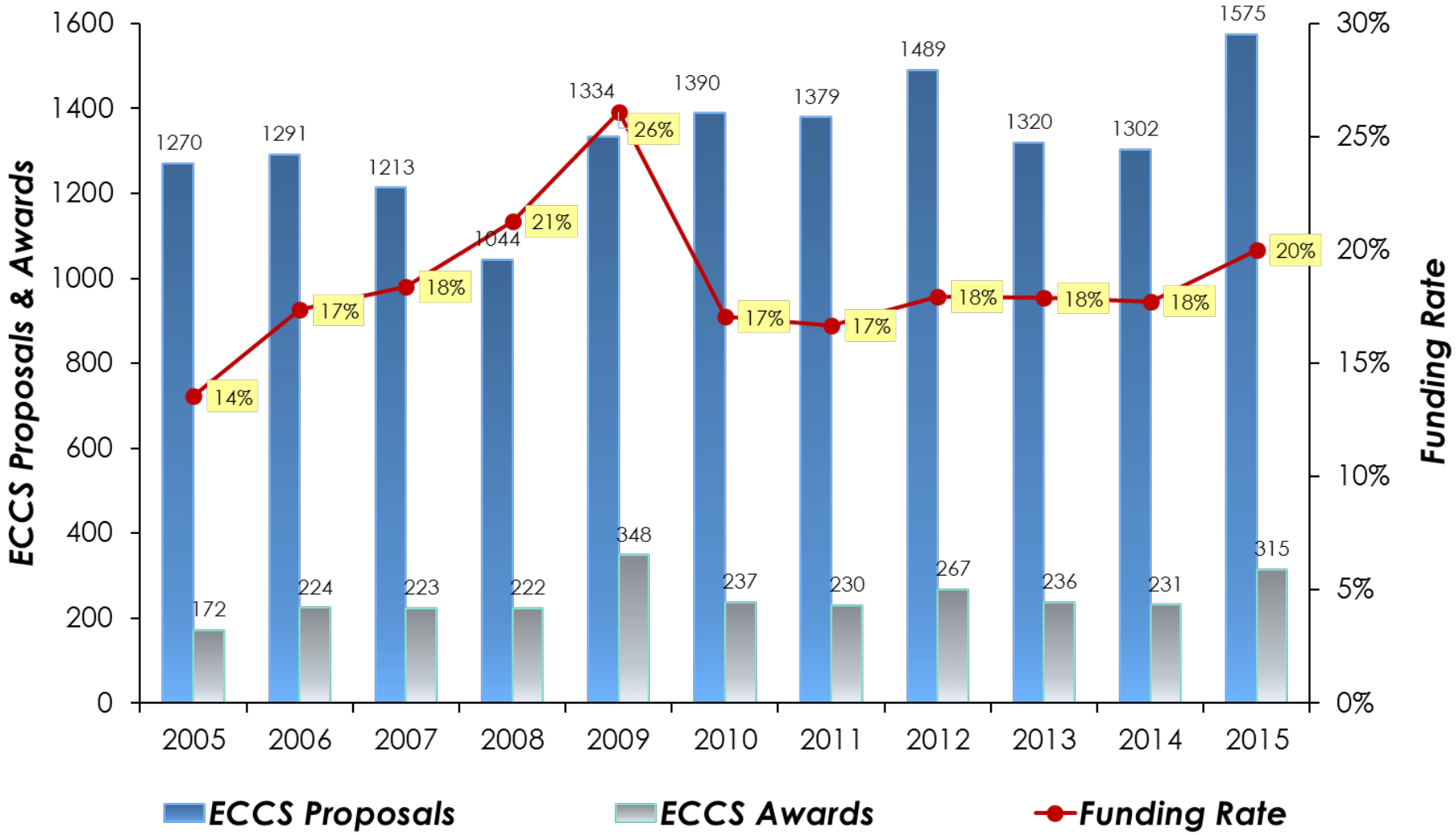
- National Nanotechnology Coordinated Infrastructure (NNCI), replaced National Nanotechnology Infrastructure Network (NNIN).
- Enhancing Access to the Radio Spectrum (EARS)
- BRAIN Initiative
- Cyber-Physical Systems (CPS)
- Computational & Data-Enabled Science and Engineering (CDS&E)
- National Robotics Initiative (NRI)
- Optics & Photonics (OP)
- Secure & Trustworthy Cyberspace (SaTC)
- Critical Techniques and Technologies for Advancing Foundations and Applications of Big Data Science & Engineering (BIGDATA)
- Cyber Science, Engineering and Education for Sustainability (Cyber SEES)
- Designing Materials to Revolutionize and Engineer our Future Program (DMREF)
- Scalable Nanomanufacturing (SNM)
- Failure-Resistant Systems (FRS)
- Revolutionizing Engineering Departments (RED)
- Critical Resilient Interdependent Infrastructure Systems & Processes (CRISP)
- Advancing Communication Quantum Information Research in Engineering (EFMA ACQUIRE)

ENG R&RA Budget ($M)

	FY 2014 Actual	FY 2015 Current Plan	FY 2016 Request	Change over FY 2015 Current Plan	
				Amount	Percent
CBET	$167.76	$177.82	$192.26	$14.44	8.1%
CMMI	195.23	209.52	222.73	13.21	6.3%
ECCS	100.37	110.43	119.24	8.81	8.0%
EEC	119.50	117.49	110.39	-7.10	-6.0%
IIP	205.99	226.98	248.11	21.13	9.3%
SBIR/STTR	*159.99*	*177.11*	*194.36*	*17.25*	*9.7%*
EFMA	44.27	50.07	56.49	6.42	12.8%
ENG TOTAL	$833.12	$892.31	$949.22	$56.91	6.4%



ECCS Funding Rates (Research Grants)



FY14 ENG Priorities

- Advanced Manufacturing
- Clean Energy
- National Nanotechnology Initiative
- Cognitive Science and Neuroscience
- Communications & Cyber-infrastructure
- Cyber-Enabled Materials, Manufacturing, and Smart Systems (CEMMSS)
- Education and Career Development
- Interdisciplinary Research
- Research Centers

ECCS Strategic Plan

- Advance sensor- and model-based smart manufacturing and robotics
- Advance semiconductor and optical device design, fabrication and processing for use in biomedical, communications, computing, energy and sensing systems
- Advance research and engineering of energy materials, use, distribution and efficiency
- Focus on composite nanomaterials, two-dimensional nanolayers, nano-electronic logic devices, metamaterials, plasmonics and nanomedicine
- Advance noninvasive or minimally invasive imaging technologies, neuroprosethetics and new neural engineering & technology research
- Advance "smart" systems that can sense and adapt to environmental change for energy, manufacturing, or infrastructure needs
- Emphasize support for CAREER, NRT, IGERT, IUSE and broadening participation at all levels
- Invest in fundamental research that may overcome scientific and/or national challenges and lead to breakthrough technologies (EFRI)
- Maintain support of ECCS funded STCs

Key Technologies
Twelve potentially economically disruptive technologies*

- Mobile Internet
- Automation of knowledge work
- The Internet of Things
- Cloud technology

- Advanced robotics
- Autonomous and near-autonomous vehicles

- Next-generation genomics

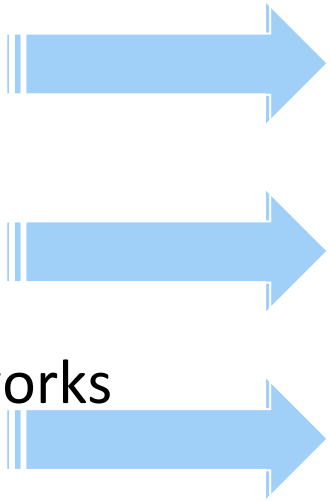
- 3D printing
- Advanced materials

- Renewable energy
- Energy storage
- Advanced oil and gas exploration and recovery

* McKinsey Global Institute, “Disruptive technologies”, 2013

ECCS Emerging Areas & Possible Future Directions

- Smart Cities (Urban Science)
- Low-Power Computing
- Big Data
- Internet of Things
- Sensors and Large Sensor Networks
- Optics & Photonics
- Brain Imaging (Advanced Non-Invasive Medical Imaging)



- Paper & Silk Electronics
- Terahertz Technologies
- Web based Systems Control – Social Networks
- Low cost, high efficiency solar cells
- Valleytronics
- Wireless Energy Transfer
- Exotic, Autonomous & Faint Photonics
- Remote Sensing & Stimulation of Brain Functions
- Man-Machine Interfaces
- Driverless Vehicles
- Flexible, conformable 2D electronics
- Extreme bandgap devices
- Remote Access Testbed
- Cybersecurity of Control Systems
- Physical Layer Security for Wireless Communications
- Green & Reconfigurable Electronics

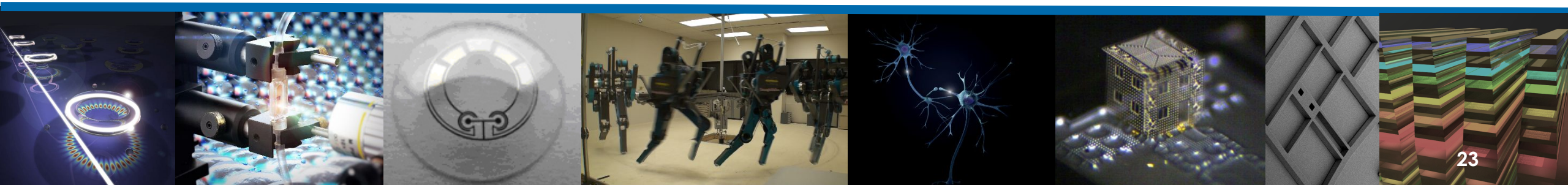
For Further Information

NSF: nsf.gov

ECCS: nsf.gov/div/index.jsp?div=eccs

Thank you!

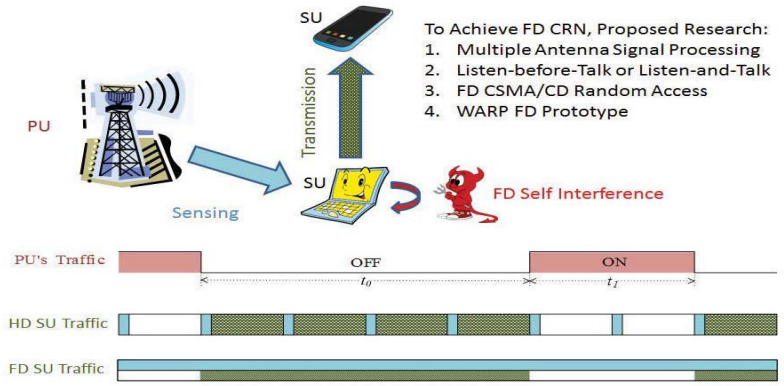
Questions?



Specific Highlights – Full-Duplex Cognitive Radio

Fundamental Research

- Full-duplex reconfigurable transceivers
- Self interference cancellation
- Full-duplex dynamic spectrum access



Evolution of research focus

- 5 years ago: half-duplex cognitive radio
- Today: experimenting full-duplex transceivers
- Next: aiming to deploy full-duplex cognitive radio networks

Broader Technical Impacts

- Wireless communications
- Future generation standards

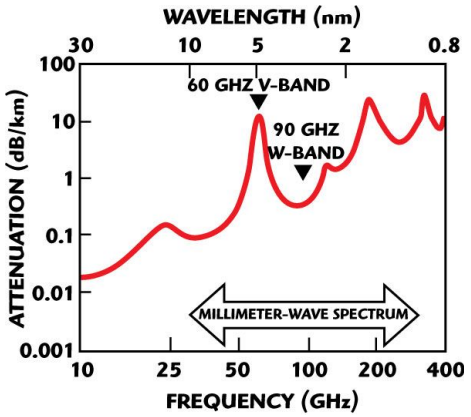
Future Perspectives

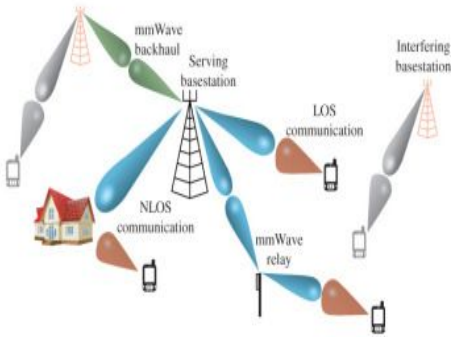
- Significantly increase spectrum utilization
- Enhance spectrum efficiency

Specific Highlights – Millimeter Wave Massive MIMO

Fundamental Research

- Millimeter wave channel characterization and exploitation
- Millimeter wave communications
- Massive MIMO architecture





Evolution of research focus

- 5 years ago: up to 60 GHz, up to 8 x 8 MIMO
- Today: 60 GHz, 64 x 64 MIMO
- Next: higher than 60 GHz, larger than 128 x 128 MIMO

Broader Impacts

- Utilizing higher frequencies to mitigate the spectrum scarcity problem at lower frequencies

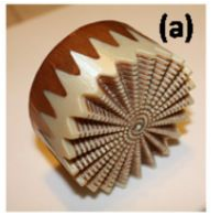
Future Perspectives

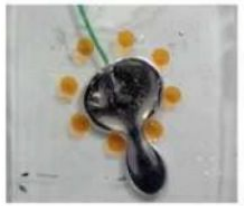
- Much higher data rates for mobile communications
- Enhanced security and reliability of wireless communications

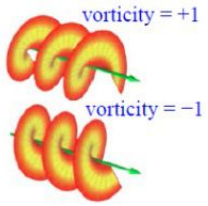
Specific Highlights – Antennas

Fundamental Research

- 3-D printing applied to antennas
- Reconfigurable liquid antennas
- Vortex wave excitation and reception







Evolution of research focus

- Exploiting new materials/fabrication techniques/propagation phenomenology to antenna design and manufacturing

Broader Technical Impacts

- Wireless communications
- Sensor networks
- Security and healthcare monitoring

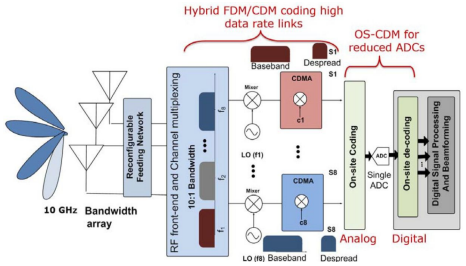
Future Perspectives

- Low-cost, compact, reconfigurable antennas for ubiquitous communications and sensing

Specific Highlights – Millimeter-wave and Terahertz

Fundamental Research

- Broadband phased array technology for mm-wave and THz
- Low-power transceiver architecture
- Pushing CMOS above 100GHz



Evolution of research focus

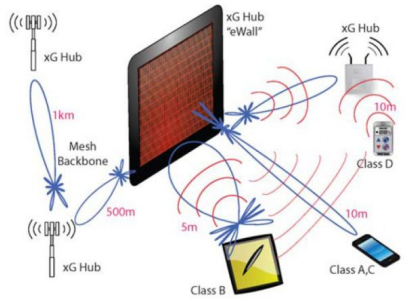
- 5 years ago: CMOS up to 60GHz
- Today: 60-100GHz
- Next: >100GHz

Broader Impacts

- Moving to higher frequencies to solve the electromagnetic spectrum crunch at lower frequencies

Future Perspectives

- High data rate (100Gbits/s) mobile communications



Data-intensive Prediction/Classification for Patient-Centered Medical-Testbed

1054333- Yuichi Motai - Virginia Commonwealth University

I. Recent Outcomes & Accomplishments:

The data-intensive solutions have been applied to several medical problems and have benefited society as a whole. The statistical innovations for the complex systems expanded the Nation's cyber infrastructure and high performance computing capability.

As a result of this award, the PI has achieved the following accomplishments:

- *The PI's research group, called sensory intelligence lab, has published so far 20 journal papers, mostly in high impact IEEE transactions (JIF=3.0+), such as TSMC-B, TRO, TKDE, TIM, TIE, TII, TBME, TITB, TCC, and JTEHM etc.*
- *3 research books have been published in Wiley, ACM Morgan&Calypool, and Springer.*

II. Basic Principles:

The developed methodologies of predicting respiratory motion for precise radiation dose delivery have opened up a new paradigm of customized treatment. Computer-aided cancer detection and assessment in Virtual Colonography systems has substantially advanced the clinical implementation of colon cancer screening using big-data analysis.

- ***Technical*** *Neural networks with Kalman filter iteration have shown the best performance for prediction from learning. A distributed classification method using kernel-based neural network analysis outperformed existing system's classification.*
- ***Non-technical*** *Inter-disciplinary collaboration is required for advanced cancer treatment and diagnosis through the application of sensory intelligence, together with medical physics experts at the Massey Cancer Center in Richmond, and radiology experts at Massachusetts General Hospital in Boston.*

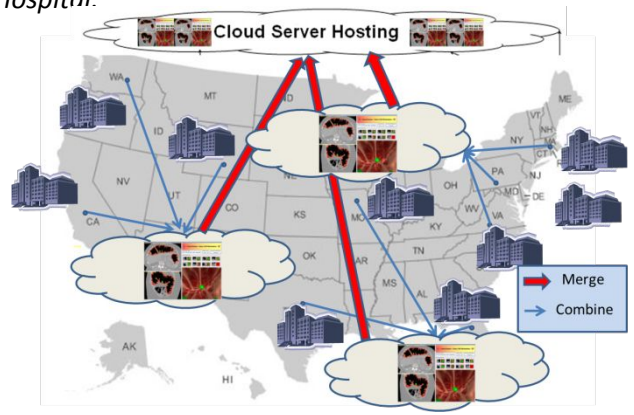
III. Broader Impact:

(a) Intellectual, Industrial and Societal: *The millions of cancer patients every year have enhanced the quality of all their lives through unprecedented advances in the early diagnosis and treatment of cancer.*

(b) Educational: *New graduate-level courses "Pattern Recognition", and "Intelligent Linear Systems", were developed. Undergraduate-level course "Automatic Control " and "Signals and Systems I" were refined by developing a new textbook, called "System Concepts: Student-Centric Lectures" with the Matlab exercises focusing graphics outcomes via linear algebra. All 10+ Capstone projects were completed successfully, including provisional patents and journal papers with REU. The participants were recruited from a diverse group including under-represented populations in STEM.*

III. Compelling Image:

Concept of cloud colonography: Networked computer-aided diagnosis developed by the Virginia Commonwealth University and Massachusetts General Hospital.



An Intelligent Restoration System for a Self-healing Smart Grid (IRS-SG)

ECCS 1552073 – Wei Sun – University of Central Florida

I. Recent Outcomes & Accomplishments:

- ***Developed an adaptive restoration tool for optimal planning and near real-time operation.*** It minimizes the restoration time while preserving power system security.
- ***Developed a novel restoration strategy using large scale wind farms***. It uses two-stage stochastic and robust optimization methods to address wind uncertainty and coordinate wind and pumped-storage hydro units.
- ***Developed a state-of-the-art network partitioning algorithm for efficient restoration.*** It sectionalizes a power grid after a major outage, and coordinates the parallel restoration in multiple islands.

The project outcomes include three submitted journal papers and four panel presentations.

Project Collaborator: Dr. Kumar Venayagamoorthy, Clemson University

II. Basic Principles:

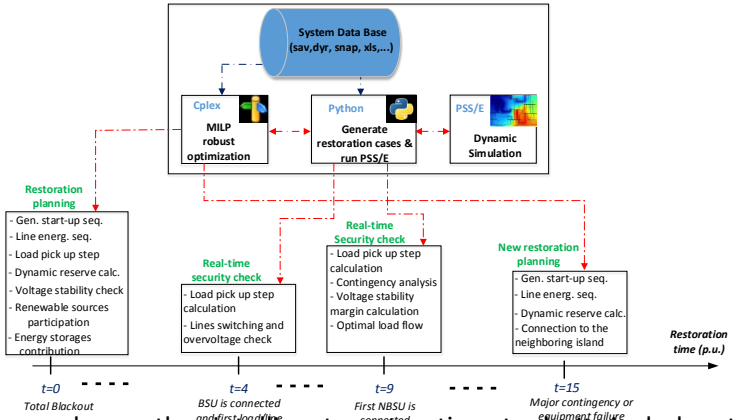
- ***Technical*** : The IRS-SG tool uses the emerging computational intelligence techniques and synchrophasor measurements to provide system operators with real-time adaptive restoration actions. This research uses novel approaches to address different uncertainty sources in power system, including (1) Robust optimization based on a predefined uncertainty set and budget of uncertainty; (2) Stochastic optimization using scenario generation and reduction techniques with Benders' decomposition to dramatically reduce the computational time.
- ***Non-technical:*** The outcome of this research will give the system operators and planners a very good insight into wind behavior throughout the restoration process. Instead of excluding wind power or performing wind curtailment which results in wind energy spillage, the tool provides a plan to harness wind energy without threatening the system security.

III. Broader Impact:

(a) Intellectual, Industrial and Societal: This project has significant impact on national needs – resilience of our national grid, sustainable energy and energy security. The potential economic impact is expected to save several millions of dollars loss resulted from blackouts. Situational intelligence in power system restoration minimizes impacts of blackouts and leads to rapid recovery from natural disasters such as earthquakes, hurricanes and malicious attacks.

(b) Educational: This research will promote teaching, training and learning of smart grid. The research will equip power engineers with hands-on experiences in automated power system restoration. The research will also provide a unique learning platform to cultivate the interest of K-12 students in power and energy systems.

IV. Compelling Image:



This figure shows the intelligent restoration tool. It includes the optimization engine for planning and dynamic analysis for near real time security check. This tool provides the adaptive restoration plan in case of unexpected faults or other events. @ Wei Sun, University of Central Florida

Collaborative Research: An Asynchronous Exterior Calculus Framework for Charge-Conservative Electromagnetic Particle-in-Cell Simulations of Space-Charge Effects on Irregular Grids

1305838 — Teixeira — The Ohio State University

I. Recent Outcomes & Accomplishments:

- A new particle-in-cell (PIC) algorithm was developed for the study of plasma and beam-wave interactions on unstructured grids. The consideration of unstructured grids is of crucial importance for the accurate modeling of complex geometries such as found in modern high-power travelling-wave-tubes and backward wave oscillators, for example.
- This effort provides a transformative approach for the modeling of multiscale plasma phenomena combining field solvers and particle kinetics on unstructured computational meshes.

II. Basic Principles:

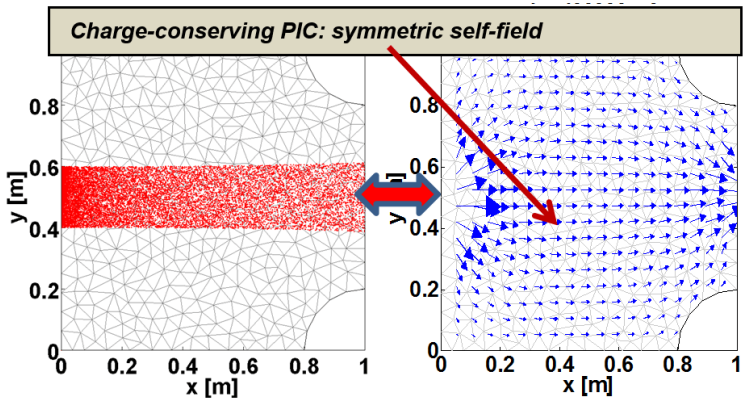
- The PIC algorithms under development are designed to preserve conservation laws and symmetries at the discrete level from first principles. They seek to obviate the need for linear solvers during the simulation and field/particle interactions and overcome the Courant stability limit.
- The tools developed herein are key to the simulation of physical processes involving field and particles wherein their mutual interaction needs to be accounted for very accurately. Current linear solver technology for this type of problems sets an upper limit on the size of problems solvable on unstructured meshes, whereas disparate time scales require enormous resources in terms of computing time when using traditional time-stepping algorithms.

III. Broader Impact:

(a) Intellectual, Industrial and Societal: This research will benefit the analysis and design of new high-power microwave, terahertz, and laser/optical devices with complex geometries, and the simulation of plasma flows

(b) Educational: This research project supports one graduate student (Ph.D. level) at the Ohio State University (OSU) and two senior researchers at OSU and Trinum Research Inc. Results of this research are being integrated into several courses at OSU and the software will be publicly disseminated.

III. Compelling Image:



Unstructured grid simulation of electron beam acceleration (left-to-right: cathode-to-anode) with charge-conserving PIC algorithm illustrating lateral beam (left) expansion and (d) self-consistent electric field (right).

CAREER: Enabling Design of Future Smart Grids via Input/Output Hybrid Systems Tools

ECCS 1150306 – Ricardo G. Sanfelice – University of California

I. Recent Outcomes & Accomplishments:

- *Development of methods for the study invariance in hybrid systems, including a hybrid control algorithm for a single phase DC/AC inverter. Using the forward invariance analysis and the numerical simulations, we found that:*
  - *The output signals from the inverter are sinusoidal like and have desired amplitude and frequencies;*
  - *The closed-loop system is robust to large (~20%) changes in input DC signal;*
  - *The time between consecutive switches are determined by a parameter defining the size of the control band*
- *Generation of control design methods for hybrid systems via control-Lyapunov functions.*
- *Design of stabilizing feedback control laws with minimum pointwise norm.*
- *Design of hybrid observers for state estimation under the presence of measurement noise.*
- *Hosted a grad student from Tu/e, The Netherlands and a professor from Jiangnan University, China.*
- *Application of design methods to power systems.*
- *Publications:*
  9 journal papers, 2 book chapter, and 15 conference papers
- *Received the 2014 ACC Best Student Paper Award Finalist (as advisor)*

II. Basic Principles:

Technical

The research in this project generates the needed tools for modeling, analysis, and design of interconnected hybrid systems emerging in future smart grids. The technical approach is based on stability theory for hybrid dynamical systems. The methods for interconnection analysis and feedback control design are building the core results needed for systematic analysis and control design for input/output hybrid systems, which is currently a missing cornerstone in hybrid control theory.

Non-technical

The increasing necessity of producing more energy, combined with the surging interest in green technologies worldwide, have promoted the need for a highly reliable, cost-efficient, and self-sustained electric power grid. Future energy distribution systems ought to be capable of interconnecting diverse power sources and units (fossil, nuclear, hydropower, photovoltaic, wind turbines, fuel cells, flywheels). The research in this project devises novel methods to design such complex systems to have a unique resiliency to variations of power, which is a key challenge when using renewable sources.

III. Broader Impact:

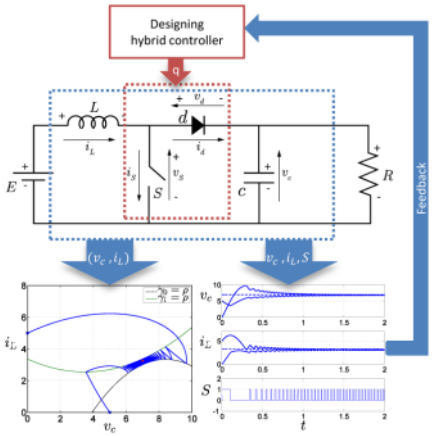
(a) Intellectual, Industrial and Societal:

The proposed research plan contributes to the knowledge base by generating tools for modeling, analysis, and design of interconnected hybrid systems with inputs and outputs. It also advances knowledge in the main fields relating to hybrid systems. It uniquely contributes to the field of power systems through the development of control algorithms guaranteeing robustness and resiliency of future smart grids.

(b) Educational:

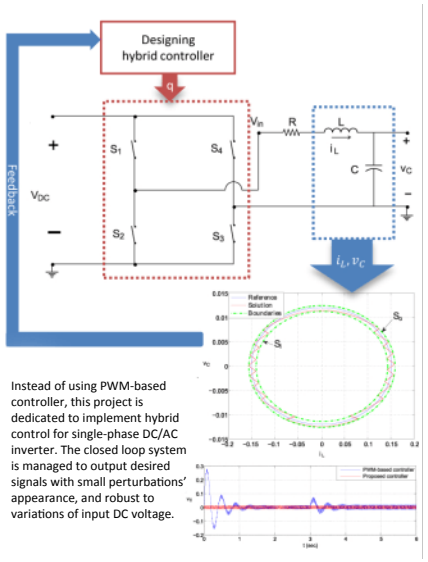
The proposed research plan is tightly integrated with teaching and training activities. The research results are being incorporated in three courses. Moreover, the research results impact impact middle and high school education levels by training instructors and students on engineering and smart grids. In particular, these activities are increasing awareness by informing students of the future energy needs in the world. These activities also promote participation of Hispanic students from low-socioeconomic status.

DC-DC Boost Converter



Instead of using PWM-based controller, this project is dedicated to implement hybrid control for DC-DC boost converter. The closed loop system is managed to output desired signals with small perturbations' appearance.

Single-Phase DC/AC Inverter



Instead of using PWM-based controller, this project is dedicated to implement hybrid control for single-phase DC/AC inverter. The closed loop system is managed to output desired signals with small perturbations' appearance, and robust to variations of input DC voltage.