ANNUAL REPORT

MIT Lincoln Laboratory

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

2013

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE **MIT Lincoln Laboratory Annual Report 2013**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology,Lincoln Laboratory,244 Wood Street,Lexington,MA,02420**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**42**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Massachusetts Institute of Technology

MIT Lincoln Laboratory

MIT LINCOLN LABORATORY 2013

MISSION

Technology in Support of National Security

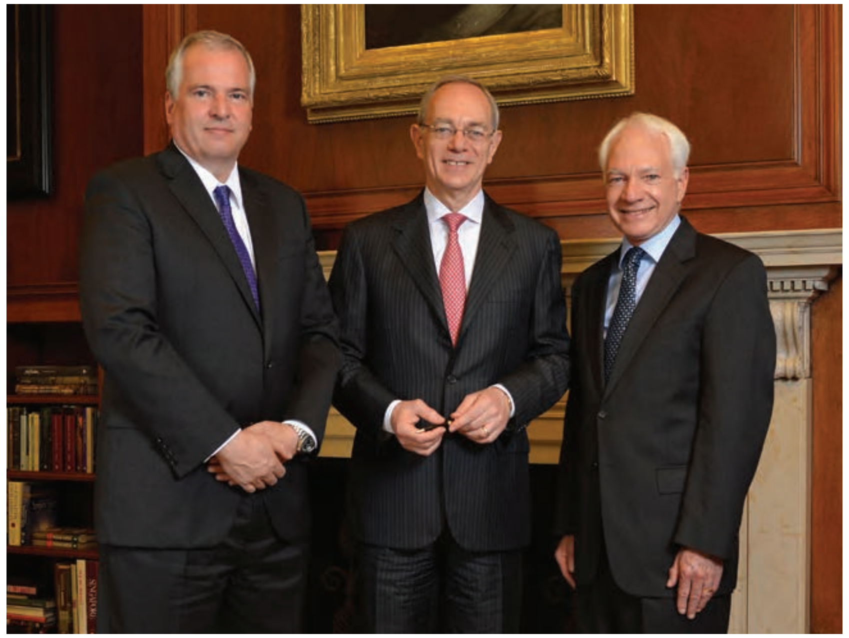
MIT Lincoln Laboratory employs some of the nation's best technical talent to support system and technology development for national security needs. Principal core competencies are sensors, information extraction (signal processing and embedded computing), communications, integrated sensing, and decision support. Nearly all of the Lincoln Laboratory efforts are housed at its campus on Hanscom Air Force Base in Massachusetts.

MIT Lincoln Laboratory is designated a Department of Defense (DoD) Federally Funded Research and Development Center (FFRDC) and a DoD Research and Development Laboratory. The Laboratory conducts research and development pertinent to national security on behalf of the military Services, the Office of the Secretary of Defense, the intelligence community, and other government agencies. Projects undertaken by Lincoln Laboratory focus on the development and prototyping of new technologies and capabilities to meet government needs that cannot be met as effectively by the government's existing in-house or contractor resources. Program activities extend from fundamental investigations through design and field testing of prototype systems using new technologies. A strong emphasis is placed on the transition of systems and technology to the private sector. Lincoln Laboratory has been in existence for 62 years. On its 25th and 50th anniversaries, the Laboratory received the Secretary of Defense Medal for Outstanding Public Service in recognition of its distinguished technical innovation and scientific discoveries.

Table of Contents

MIT and Lincoln Laboratory Leadership

Massachusetts Institute of Technology



Dr. L. Rafael Reif
President

Dr. Chris A. Kaiser (left)
Provost

Dr. Claude R. Canizares (right)
Vice President

MIT Lincoln Laboratory

Dr. Eric D. Evans
Director

Dr. Marc D. Bernstein (left)
Associate Director

Mr. C. Scott Anderson (right)
Assistant Director—Operations

ORGANIZATIONAL CHANGES

C. Scott Anderson

Assistant Director for Operations

C. Scott Anderson joined Lincoln Laboratory as Assistant Director for Operations in July 2013, with responsibility for the Laboratory's operating and capital investment budget, service departments, and prime research contracts with the government. He has had significant experience in acquisition activities and budget management, having served as an acquisition professional and program manager in the U.S. Navy, and most recently as the Director of Integration for Acquisition at MITRE's National Security Engineering Center.

New Laboratory Division

In January 2013, the Communication Systems and Cyber Security Division was restructured into two divisions. The increasing importance of research and development in cyber security and information sciences led to the establishment of a division to focus on these areas. The new division, Cyber Security and Information Sciences, directs the development of cyber systems, human language technologies, and computing and graph analytics. The Communication Systems Division remains the Laboratory's center of excellence in communication technologies.

Stephen B. Rejto

Division Head, Cyber Security and Information Sciences

Stephen B. Rejto was appointed head of the Cyber Security and Information Sciences Division. Formerly an assistant division head in Communication Systems and Cyber Security, he is responsible for programs focused on research and development in cyber technologies and prototype cyber security systems; advanced cryptography; techniques for speech recognition and language identification; and technologies for processing large multisourced datasets.

David R. Martinez

Associate Division Head, Cyber Security and Information Sciences

David R. Martinez, formerly a principal staff member in the Communication Systems and Cyber Security Division, brings extensive experience in high-performance embedded computing, enterprise architectures, system applications, and cloud computing to his role as associate division head. His prior leadership roles at Lincoln Laboratory included leader of the Digital Radar Technology Group and head of the ISR Systems and Technology Division.

Marc A. Zissman

Associate Division Head, Cyber Security and Information Sciences

Dr. Marc A. Zissman was named associate head of the Cyber Security and Information Sciences Divison. Prior to this appointment, he was an assistant division head in the Communication Systems and Cyber Security Division, holding responsibility for development and execution of the Laboratory's strategic plan for growing its cyber security efforts. His earlier leadership positions were associate leader of the Human Language Technology Group and leader of the Wideband Tactical Networking Group.

James Ward

Assistant Division Head, Communication Systems

Dr. James Ward joined the Communication Systems Division as assistant division head. Formerly, he was an assistant division head in the ISR and Tactical Systems Division, where he led programs in advanced sensing, signal processing, and data exploitation. He has served as leader of the Advanced Sensor Techniques Group and is a past recipient of the Laboratory's Technical Excellence Award.

MIT Lincoln Laboratory Fellow

The Fellow position recognizes the Laboratory's strongest technical talent for their outstanding contributions over many years.

Marilyn M. Wolfson

Dr. Marilyn M. Wolfson is a key contributor to Lincoln Laboratory's efforts in air traffic control. She has developed algorithms for the FAA Terminal Doppler Weather Radar and Integrated Terminal Weather System. As the leader of the FAA's Convective Weather Product Team, she developed automated short-term storm forecast technology for air traffic management applications. She has published more than 70 journal articles, holds five U.S. patents, been awarded a Lincoln Laboratory Technical Excellence Award, and is a Fellow of the American Meteorological Society.

Letter from the Director

Today we define Lincoln Laboratory's mission as "technology in support of national security." This broad mission evolved from the Laboratory's original single focus on the creation of a strategic air defense system in the 1950s. Over the years, we have grown to become a multidisciplinary laboratory providing innovative systems and technologies for a widely diverse set of national security problems.

In 2013, we are continuing to align our efforts to meet the evolving challenges identified by the Department of Defense. In January, the Laboratory created a Cyber Security and Information Sciences Division to address the increasing significance of cyber situational awareness and information system protection for national security. Analysts in all mission areas are confronting the consequences of "big data," the enormous volume and variety of sensor data generated at an increasingly rapid pace. Our Advanced Technology mission area is directing attention to novel nanotechnology applications, and our biomedical programs are seeing strong growth as the demand intensifies for technological solutions for soldiers' and civilians' health needs. The diversity and depth in our programs create an exciting research and development environment.

Some highlights from our past year's accomplishments include:

- In mid-October, the Lunar Laser Communication Demonstration, launched aboard NASA's Lunar Atmospheric and Dust Environment Explorer (LADEE) satellite in September, transmitted data from the moon to Earth at a speed of 622 megabits per second, a data rate significantly faster than the rates of typical RF links flown to the moon.
- A novel ground penetrating radar system demonstrated on a Husky route-clearance vehicle detected and referenced soil inhomogeneities to determine the vehicle's location to within a few centimeters relative to previous route passes. The system enables the vehicle to "drive itself" during revisits by using drive-by-wire actuators connected to the radar, freeing the operator to perform other missions.
- Lincoln Laboratory tested its ultra-compact, nine-channel microwave spectrometer prototype under the NASA Advanced Component Technology program. This new technology enables high-performance microwave atmospheric sensing from very small platforms, including cubesats and unmanned air vehicles.
- A ground mobile terminal capable of connecting to the recently launched Advanced Extremely High Frequency (AEHF) satellites was successfully demonstrated. The small-form-factor modem in this terminal is the first implementation that follows stringent new security rules.
- The RF Enhanced Digital System on Chip program developed a fully integrated system-on-chip design that achieves record receiver performance in a very small size, weight, and power package.
- A Laboratory-developed ultrahigh-data-rate multiple-input multiple-output (MIMO) system sets new standards for non-line-of-sight, low-power communication links and enables efficient data exchange among ground-based intelligence, surveillance, and reconnaissance (ISR) systems.

The Laboratory's community outreach program continues to grow. The science, technology, engineering, and mathematics (STEM) educational outreach initiative now includes 30 active programs. We have expanded the Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE), a two-week summer radar workshop, to reach more high-school seniors. Science on Saturday events continue to fill our auditorium, and 80 schools scheduled classroom presentations by Laboratory technical staff. Our robotics teams made strong showings at regional competitions, and the CyberPatriot team of high-school "cyber defenders" again reached the national competition. Our extensive outreach program is a high priority and an important element of our strategic directions.

This report provides a comprehensive overview of our 2013 technical accomplishments, technology investments, and educational programs. We encourage you to read through the report and contact us if you have any questions. As always, we look forward to meeting future national security challenges with innovative solutions sustained by technical excellence and integrity.

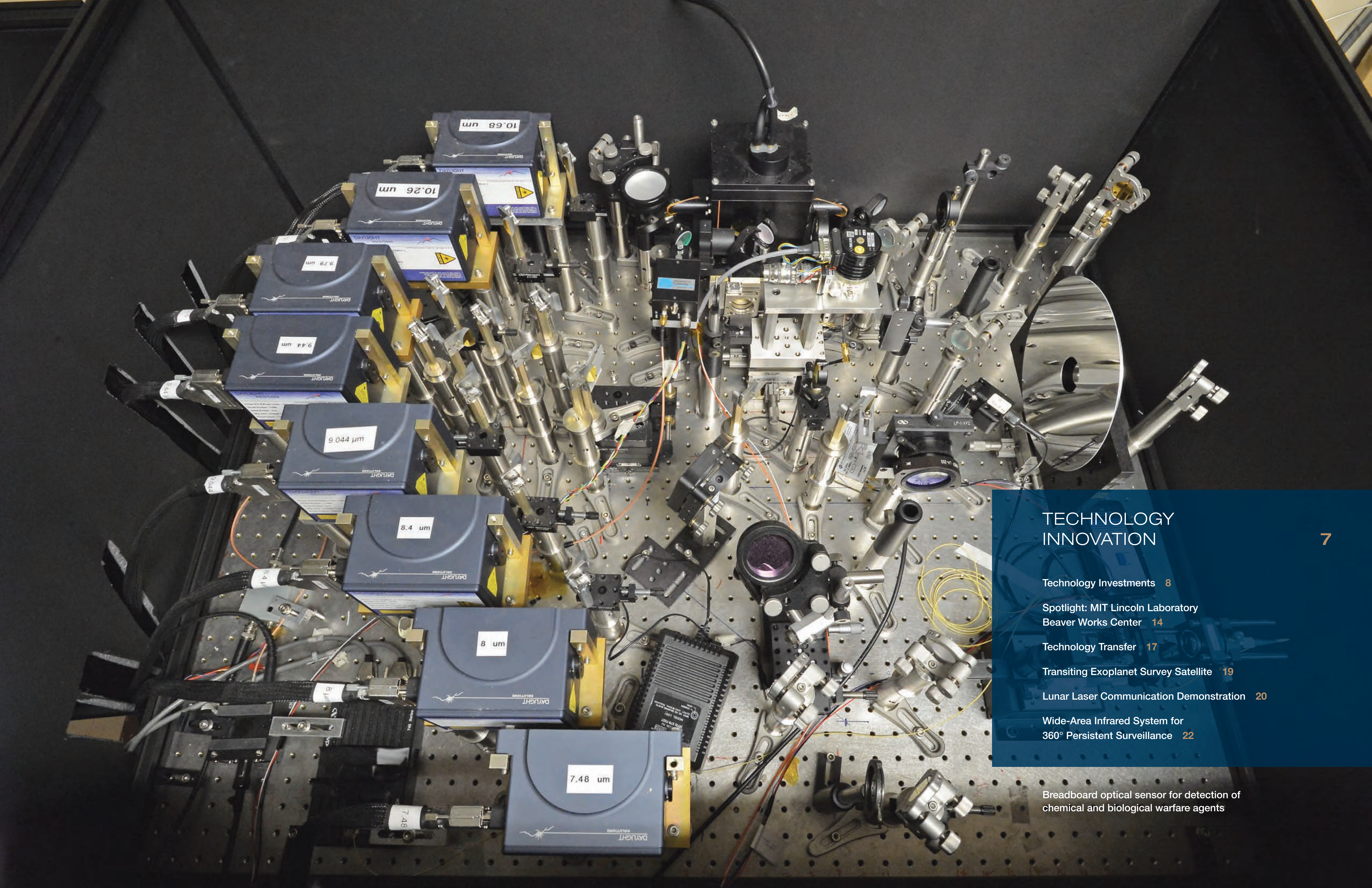
Sincerely,

Eric D. Evans
Director

Lincoln Laboratory Strategic Directions

The strategic directions below are based on a Director's Office and senior management update of the Laboratory's strategic plan and a review of national-level studies, such as the National Defense Strategy, the Quadrennial Defense Review, and recent Defense Science Board recommendations.

- Identify new mission areas, based on current and emerging national security needs
- Strengthen and evolve the current Laboratory mission areas
- Strengthen the core technology programs
- Increase MIT campus/Lincoln Laboratory collaboration
- Strengthen technology transfer to acquisition and user communities
- Increase outside connectivity and communications
- Improve Laboratory diversity and inclusion
- Expand community outreach and education
- Continue improving Laboratory administration and infrastructure



TECHNOLOGY INNOVATION

7

Breadboard optical sensor for detection of chemical and biological warfare agents

Technology Investments

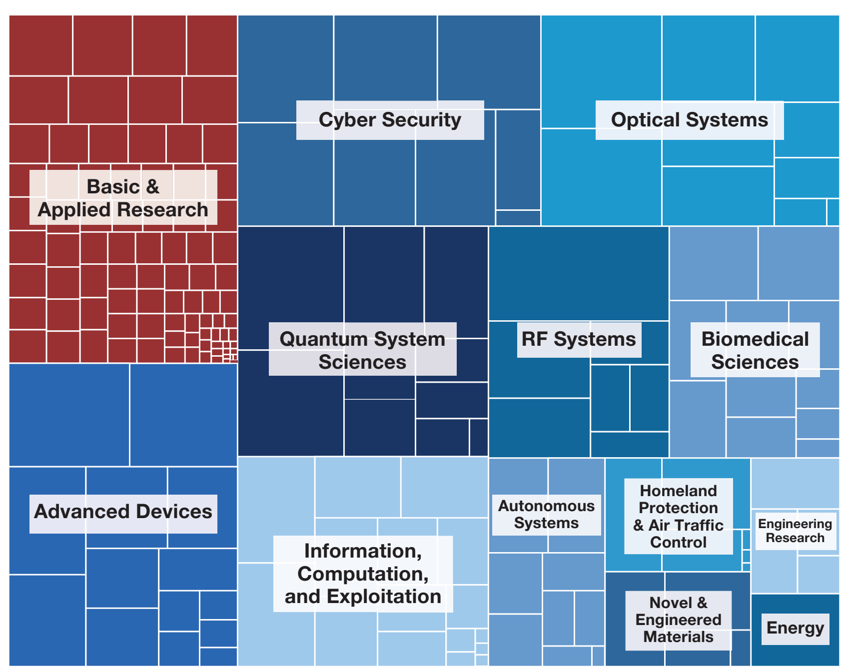
Lincoln Laboratory invests in the development of advanced technologies and capabilities to support the strategic needs of its missions and to promote research in emerging technology areas of relevance to national security.

The Technology Office is responsible for developing and directing strategic research at the Laboratory, through focused investments in existing and emerging mission areas. The office seeks out capabilities to address critical problems that threaten national security, and derives technology requirements from strategic assessments of the Laboratory's primary mission areas and from our government sponsoring agencies. Members of the office interact regularly with the Assistant Secretary of Defense for Research and Engineering (ASD [R&E]) and other government agencies to maintain awareness of critical defense problems and to grow strategic technical relationships. The office also collaborates with and supports university researchers and, in doing so, aids in the translation of new technologies from laboratory scale to end-user needs. The internal research and development (R&D) investment portfolio is developed through a number of mechanisms, including competitive solicitations, open calls for proposals in specific technical areas, focused infrastructure investments, and activities designed to promote innovative thinking and creative problem solving.

R&D Investment Portfolio

Internal research funding at Lincoln Laboratory derives primarily from Congressional appropriations administered by ASD(R&E). The focus of this funding is on long-term, high-impact research that is relevant to Department of Defense (DoD) needs. Additional funding is also available to support laboratory and engineering capability maintenance, to develop and operate broad-use test beds, and to support innovative research in basic and applied science areas. The internal R&D investment portfolio reflects this distribution and is strategically developed to both address the critical technology needs of the Laboratory's existing mission areas and to provide the technical foundation to address emerging national security challenges.

LEADERSHIP
Dr. Bernadette Johnson, Chief Technology Officer
Dr. Eric Dauler, Associate Technology Officer (left)
Dr. Andy Vidan, Associate Technology Officer (right)



The Laboratory's internal R&D portfolio supports investments across emerging and core Laboratory mission areas. This infographic displays the relative magnitude of 2013 internal funding in each of these areas. The smaller divisions within each block represent individual projects executed in that category.

» MISSION-CRITICAL TECHNOLOGY INVESTMENTS

In 2013, investments were aligned by technology categories selected to represent both core and emerging areas of relevance to the Laboratory's missions.

Optical Systems and Technology

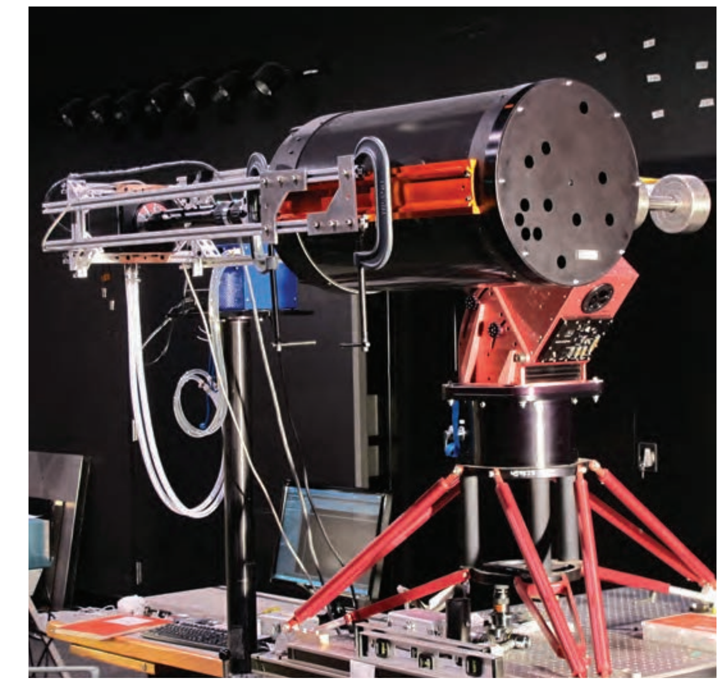
Research into optical technology encompasses the development, analysis, and demonstration of novel concepts, technology, and systems to inform the next generation of optical systems for the nation's defense needs. The primary goal is to invest in game-changing technologies that fill the critical technology gaps in traditional and emerging DoD mission areas.

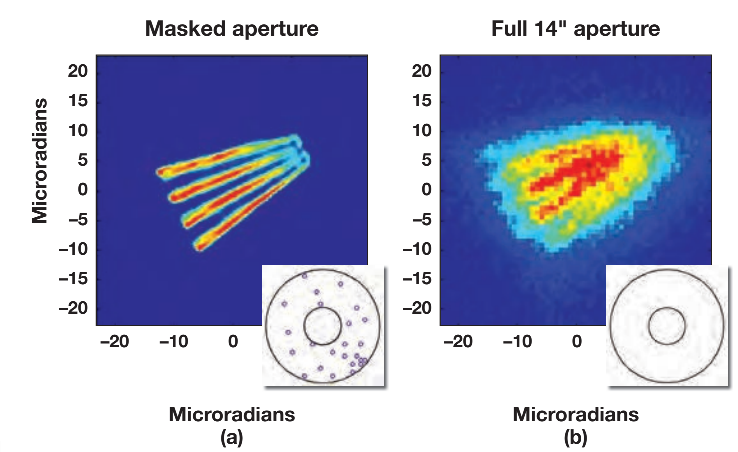
The 2013 projects cover a range of technologies:

- Novel ladar technology
- Multiaperture passive imaging systems for space surveillance
- Dual-wavelength synthetic aperture ladar for low-power, long-range, high-resolution imaging
- Large-format photon-counting array technology for small-form-factor 3D ladar
- High-power mid-wave and long-wave infrared laser technologies using beam combining and quantum cascade lasers

Cyber Security

Lincoln Laboratory is conducting four research projects designed to improve the security of computer networks, hosts, and applications in anticipation of DoD and intelligence community requirements. The Cyber Situational Awareness project is designing, creating, and demonstrating a platform to assist network defenders in identifying, tracking, and thwarting malicious activities. The platform displays the current state of a network and provides detailed knowledge and history of all entities on the network. In a second effort, the Laboratory is improving the fidelity of cyber range experimentation by developing scenario-driven cyber simulations that combine measured statistics about real user behavior with realistic agent behavior in the face of never-before-seen circumstances. Also under development is a portfolio of tools to dramatically improve an analyst's ability to perform rapid, low-level, reverse engineering of both software and hardware systems. Finally, techniques for secure storage, processing, access to, and sharing of data in the cloud are being developed.





The passive optical imaging system uses multiaperture Fizeau interferometry to enhance image resolution and mitigate the effects of atmospheric turbulence on image quality. Recently, the concept was demonstrated using a single telescope with a masked aperture, performing successful reconstruction of this calibration target (a); traditional imaging using the full telescope aperture is severely degraded by atmospheric turbulence (b). The program is currently building a multi-telescope prototype with fiber optics that will have a resolution better than 200 milliarcseconds.

>> *Technology Investments, cont.*

Advanced Devices

The Laboratory is developing unique and innovative components, subsystems, and sensing modalities that enable new system-level solutions to important national security problems.

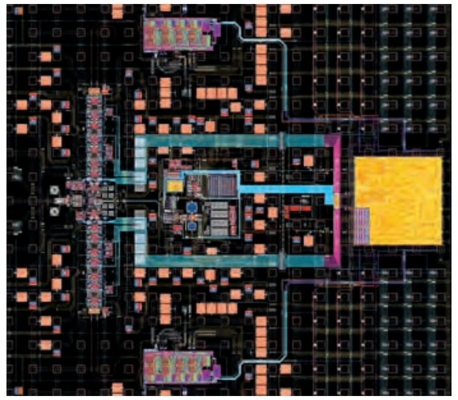
Research is focusing on a broad range of devices:

- Specialized silicon and compound semiconductor-based devices for radio frequency (RF), analog, mixed-signal, and digital electronics
- Imaging arrays with integrated readout and processing circuits
- Optoelectronics, integrated photonics, and laser technologies
- Novel devices for chemical, biological, and radiation sensing

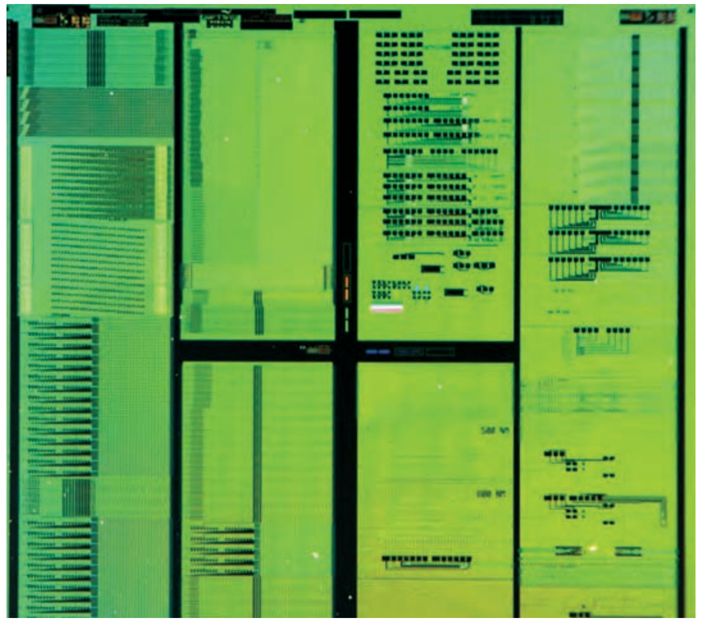
In 2013, a variety of advanced-device technologies are being developed, including ultralow-power microelectronics; low-cost integration of quantum cascade lasers with passive waveguides; surface-emitting slab-coupled optical waveguide laser arrays; bulk germanium detectors for visible through short-wavelength infrared imaging; extended-wavelength, single-photon-sensitive avalanche photodiodes; and microwave photonics for radar and electronic warfare systems.

Radio-Frequency Systems

Work on RF systems focuses on research and development of innovative technologies for evolving DoD needs in radar, signals intelligence, communications, and electronic warfare applications. Key RF challenges include a rapidly expanding threat spectrum, platforms with severely constrained payloads, operations in strong clutter and interference environments, detection of difficult targets, and robustness against sophisticated electronic attack. In 2013, four initiatives in RF systems are being supported: RF Enhanced Digital System on Chip (REDSOC), Micro-sized Microwave Atmospheric Satellite, Time-Varying Quantization, and Comb-Based Receiver Architecture.



The REDSOC project is developing a new co-design methodology applied to a high-performance receiver system on chip. A power-efficient circuit architecture and critical system parameters are optimized in terms of power efficiency and linearity.



Photograph of a silicon photonic chip processed using the recently upgraded 90 nm fabrication toolset available in Lincoln Laboratory's Microelectronics Laboratory. The layers of the thin-film materials used to implement the silicon photonic chip create a filter that accentuates the reflection of the green portion of the optical spectrum, thereby causing the image to appear to "glow" green.

Information, Computation, and Exploitation (ICE)

The ICE initiative encompasses research and development in data processing, computation, exploitation, and visualization, with an emphasis on the emerging "big data" challenges posed by the enormous growth in the volume, variety, and collection rates of data available for DoD and intelligence community applications.

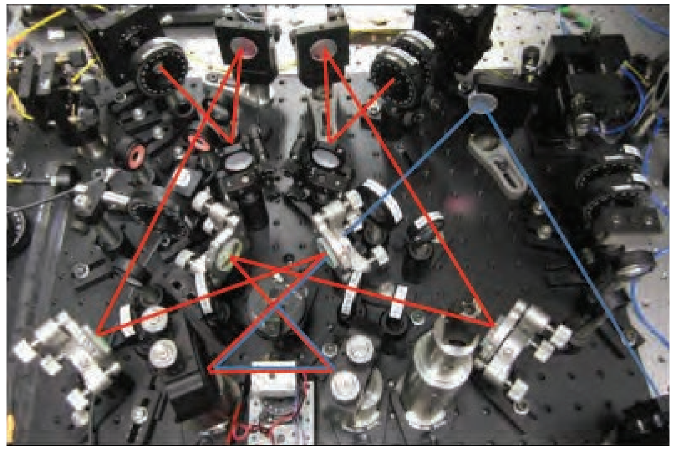
To respond to these challenges, ICE initiatives are concentrated on four key areas:

- Large-scale multi-intelligence exploitation analytics
- Extreme computing technologies and form-factor-efficient systems
- High-bandwidth, secure data-delivery technologies for high-volume datasets
- Processing infrastructure, tools, and operations research to streamline the employment of advanced analytics

In 2013, specific efforts include the development of routing algorithms for dynamic networks; composable analytics platforms; customizable video analytics engines; anomalous subgraph detection theory; image compression techniques; and high-performance, configurable, application-specific integrated circuit embedded processors.

Quantum System Sciences

Through the exploitation of the superposition and entanglement qualities of the quantum mechanical description of nature, the quantum system sciences program seeks to develop systems that have sensing, communication, and/or processing power unachievable in classical systems. The 2013 portfolio of tasks covers a broad range of quantum information science applications. Two tasks center on building the foundation for larger-scale quantum computing; one uses the superconducting quantum bit (qubit) modality, and the other uses the trapped-ion qubit modality. Other efforts are focused on quantum photonics—the development of single-photon detectors and sources of entangled photons for communication and random-number-generation applications (photo below). The Laboratory is also investigating how its unique laser and detector technology can advance the state of development in gravitational and magnetic sensing.

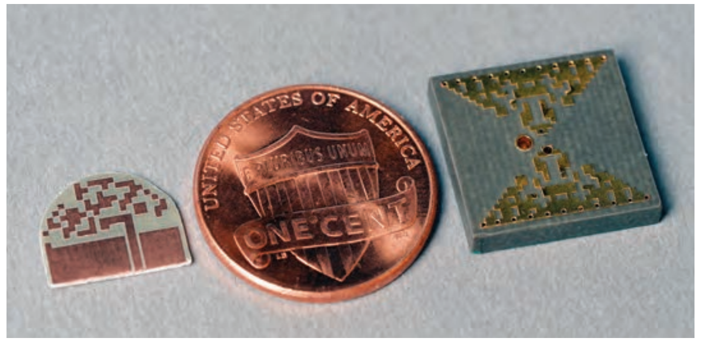


Entangled photons are generated by using parametric down conversion in a Sagnac interferometer to enable verifiable random-number generation.

Biomedical Sciences

The biomedical sciences initiative exploits Lincoln Laboratory's expertise in advanced signal processing, optoelectronics, biology, and chemistry to develop technologies that increase human performance and that prevent and predict injury through individualized biological monitoring, analysis, and interventions. Laboratory staff collaborate with top biomedical researchers at major universities and medical institutions.

This year, projects include developing pilot assemblies of microRNA sensors for cancer-cell identification and building a high-density molecular gene-assembly system with 256 microfluidic assembly chambers. The Laboratory is fielding a multimodal, mild-traumatic-brain-injury (mTBI) triage system and is creating a cognitive assessment framework that measures objective biomarkers that correlate with cognitive fatigue. To address the musculoskeletal injury epidemic in the military, researchers are using a new tissue spectroscopy test bed at the Laboratory to develop noninvasive optical tools for quantifying muscle damage and repair.



A miniature tunable antenna (2 GHz–2.5 GHz) is on the left, and an ultrawideband pixelated antenna (7.5 GHz–12.5 GHz) is on the right.

Novel and Engineered Materials

The new (in 2013) initiative to investigate novel and engineered materials is aimed at establishing world-class capabilities in engineered materials with properties that greatly enhance performance characteristics of devices and components. Current efforts are centered on infrared, optical, and RF metamaterials. The infrared materials program explores the development of active plasmonics for fast nonmechanical scanning. The optical materials effort targets the application of aluminum as a plasmonic metal, enabling large-scale production of plasmonic devices. The RF metamaterials effort is looking at using negative impedance circuits to extend the bandwidth and reduce loss of artificial magnetic surfaces for electrically small conformal antennas (photo above).

Autonomous Systems

The Laboratory's applied research in autonomy and robotics enables unmanned systems to perform useful tasks in uncertain environments without continuous human operator control. Building on prior years' progress, the continuing Cognitive Robotics program is pursuing emergent autonomous behavior by emulating neurobiological and cognitive processes. The Digital Vision Sensor and Robust Vehicle Localization projects leverage Laboratory sensing expertise to detect obstacles in cluttered environments at high speeds and to maintain precise location knowledge in adverse conditions. The Automated Dynamic Resource Allocation program is developing stochastic and robust optimization algorithms for problems with uncertain dynamics and a large state space. The goal of the Semantic Modeling task is to create labeled topological maps of interior spaces suitable for efficient interaction with human teammates.

>> *Technology Investments, cont.*

Homeland Protection and Air Traffic Control

The Deployable Radar and Imaging Tower is being developed to advance the state of sensing and processing techniques for land-border, maritime, and low-altitude air surveillance. This platform will synthesize radar, camera imaging, and video processing technologies to perform reference data collections in homeland security domains, such as U.S. land borders and coastal port areas. The datasets will help advance techniques for the automated determination of behavior patterns and threat identification in cluttered environments.

Lincoln Laboratory's air traffic control simulation infrastructure, which is being extended through the integration of its unmanned aircraft ground control station with a high-fidelity tower simulation environment (photo above), will enable a range of new airspace integration studies. The infrastructure will include terminal and en route controller components, as well as connectivity with partner laboratories for distributed simulation studies. In parallel, serious gaming technologies are being developed for the dynamic analysis of complex air traffic management decision-making problems.

Engineering Research

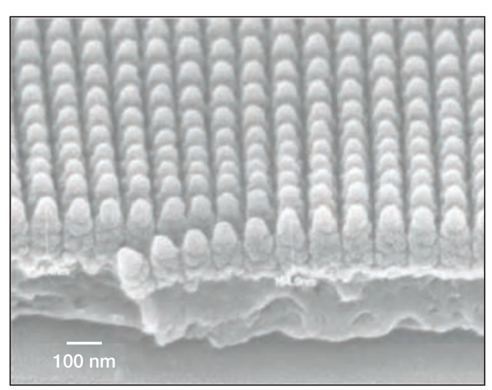
Lincoln Laboratory is investing in the advancement of its technical engineering capabilities in order to facilitate the application of state-of-the-art engineering to the development of prototype systems. The current research is focused in four areas: integrated modeling and analysis tools, advanced materials, optical capabilities, and process development. In 2013, researchers are exploring modeling and analysis tools for shock analysis, structural modeling of printed circuit boards, and microfluidics. Research into advanced materials is focusing on damping materials, properties of additive manufactured metals, active metal matrix composites, and silicon carbide mirrors. Additional initiatives include building a thermal chamber for optical interferometry and performing measurements of the properties of O-ring seal materials.

Energy

Lincoln Laboratory is engaged in research focused on improving both DoD energy security as well as the national energy system's sustainability. The 2013 projects include work on advanced microgrids for installations and forward operating bases, electric vehicles with vehicle-to-grid capability, and energy-efficient, soldier-scale capabilities for increased endurance during special operations. These projects involve collaborations with MIT researchers, other laboratories, and companies.

A major new initiative is the development of a "living laboratory" microgrid test bed at Lincoln Laboratory that can serve as a model for advanced DoD installation deployments. The ongoing work includes a broad array of efforts—developing modeling and analysis software; developing real-time monitoring and simulation tools; deploying a 1-megawatt solar array that will be capable of "off-grid" operation; and conducting a study of cogeneration and hybrid electric vehicles.

The energy initiative is also investigating novel photovoltaic modules using Earth-abundant materials. As one example, a Lincoln Laboratory/MIT team developed a three-dimensional solar-cell architecture for enhancing optical coupling in organic-based solar cells. With organics, the fabrication techniques are inherently low temperature and can be applied directly on light-weight flexible substrates without sacrificing performance.



An example structure is shown in the scanning electron micrograph at left, where an n-type semiconducting fullerene (C_{60}) film is conformally deposited over a 100 nm scale array of semitransparent nanoelectrodes imprinted in a conductive plastic. At this subwavelength regime, light propagates primarily longitudinally through the semiconductor film, increasing net light absorption while maintaining similar charge transport efficiency as in thin-film bilayer hetero-junction devices.

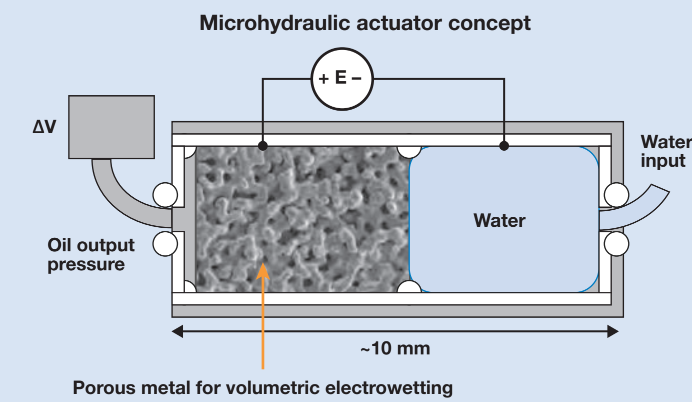
>> BASIC AND APPLIED RESEARCH

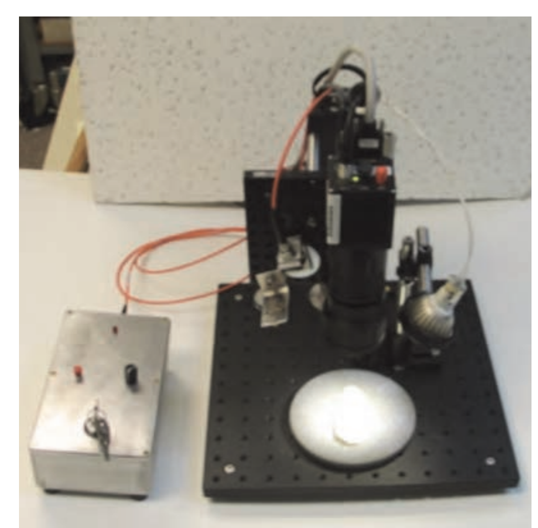
The basic and applied research projects focus on concept development that considers, but is not limited to, specific mission needs. Funding is administered directly from the Technology Office and through committees established to solicit and review proposals from the Laboratory staff as well as from MIT campus; awards are typically for one year and represent early-stage proof-of-concept research. The significant investment in basic and applied research supports many projects, as shown in the infographic on page 8; two unique projects are highlighted here.

Demonstration of Volumetric Electrowetting for Microhydraulic Actuators

Microfluidic systems requiring high flow rates or high volume displacement present a unique challenge. To enable actuation of larger volumes of liquid in microfluidic systems, Lincoln Laboratory is developing a new type of microhydraulic actuator that takes advantage of the large surface area and open volume associated with a porous material. By exploiting a phenomenon known as electrowetting, an "electric sponge" will be created using a porous conductor. When voltage is applied across the porous conductor, a conducting liquid (e.g., water) in contact with the surface of the porous conductor will be drawn into the pores. If the pores are filled with a second immiscible liquid, that liquid is displaced out of the porous material. When voltage is removed, the conducting liquid is expelled from the pores because of their hydrophobic nature. By controlling this behavior, researchers can create high-volume actuators.

These microhydraulic actuators are expected to efficiently move 1 to 30 µL per actuation. This approach requires a porous conductor having micron-sized pores and continuous paths for both liquid and electric voltage. Additionally, a conformal dielectric compatible with electrowetting must be deposited over all the conductive surfaces to avoid electrical breakdown. Finally, the interface between the porous surface and fluid must be properly engineered to provide suitable electrowetting properties. Despite these engineering challenges, volumetric electrowetting actuators would greatly enhance energy efficiency for microhydraulics.





The prototype rodent-scale fluorescence imaging test bed includes an InGaAs camera and near-infrared lens, a fiber-coupled diode laser pump source, and a visible illuminator.

Biomedical Imaging

In collaboration with Professor Angela Belcher and her research team at MIT, Lincoln Laboratory researchers are working to develop a small, flexible fluorescence imaging system that could collect imagery during a surgical procedure. Dr. Belcher's team develops novel infrared single-walled nanotube (SWNT) fluorophores for detecting small, deeply embedded tumors. Recent research conducted by MIT and ovarian cancer specialists at Massachusetts General Hospital (MGH) in Boston has shown that fluorescence imaging can improve the ability to both detect and successfully remove micro-tumors (those <2 mm in diameter). The Laboratory's fluorescence imaging test bed will allow the MIT/MGH team to improve the imaging efficacy of their SWNT fluorophores for ovarian cancer detection in rodents. This new test bed will provide real-time video imagery during surgery and will offer the flexibility to exchange or update hardware components, such as illumination or laser-pump sources. The test bed utilizes robust state-of-the-art detection algorithms developed by Lincoln Laboratory researchers. It will also include an interactive graphical user interface that will display real-time imaged and processed data to further characterize shallow tumor features, such as extent and depth estimates.

SPOTLIGHT
MIT Lincoln Laboratory Beaver Works Center
Research and Innovation Through Project-Based Learning

MIT students in the Mechanical Engineering Department's Engineering Systems Design course developed the Autonomous Underwater Vehicle Energy Subsystem as their capstone project. At their final project presentation in spring 2013, they showcased this functional system that produces electricity and heat from an aluminum energy source.

The MIT Lincoln Laboratory Beaver Works (LLBW) Center conducts research and educational programs that strengthen and expand collaborative efforts between the Laboratory and MIT campus. This collaboration provides opportunities for both institutions to make an impact on pressing global problems through science, research, and education.

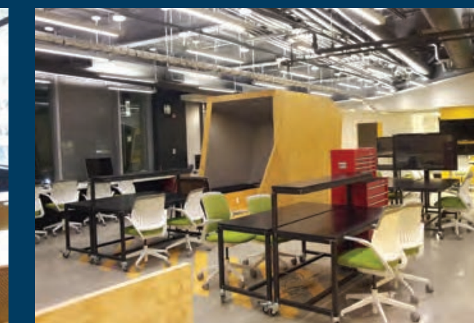
Benefits to Lincoln Laboratory

- Greater access to MIT students, faculty, and technology
  - Strong coupling to world leaders in advanced technology development
  - Opportunity to strengthen science and technology base
  - Staff exposure to entrepreneurial culture
  - Campus location for sparking new collaborations
- Opportunity to advance system and technology development through joint capstone and research projects
  - Ability to leverage faculty expertise, and student innovation and enthusiasm

Benefits to MIT Campus

- Strong project-based learning opportunities for students
  - Opportunities for system-level funded capstone and research projects
  - Access to Lincoln Laboratory mentors
  - Access to full-featured prototyping, research, and classroom facilities
- Enhanced MIT participation in addressing national security challenges
  - Strong coupling to national expertise in systems and missions

NEW FACILITY OPENS IN 2013



In November 2013, LLBW opened the doors to a new dedicated facility designed to facilitate research, workshops, and classwork. Approximately half of the facility is devoted to common-use activities such as prototyping, brainstorming, and classwork. The balance of the space will support collaborative projects and project-based educational initiatives.

Captions, clockwise from top left: At the official opening ceremony for the center, Dr. Robert Shin, Head of the ISR and Tactical Systems Division, MIT President Rafael Reif, and Dr. Eric Evans, Director, Lincoln Laboratory, were greeted by MIT mascot Tim the Beaver; classroom space in the center; work space for projects; and the main entrance to the center.

Research Projects

The core mission of LLBW is to foster innovative, impactful research that benefits MIT campus and Lincoln Laboratory. This research can be pursued in many ways, but all projects share a common theme of harnessing and strengthening campus and Laboratory interaction. These research interaction approaches include the following:

Capstone Projects
One-year development projects, executed in conjunction with a two-semester course, in which students work together to carry an idea from initial design all the way through to prototype fabrication and testing.

Joint Research Projects
Cutting-edge research projects that explicitly leverage the strengths of both institutions to efficiently solve critical problems.

Individual Research
Guided research for individual development in a focused research area; examples include the Undergraduate Research Opportunities Program (UROP), some research assistantship opportunities, and internships.

The technical scope of these research programs bridges a wide area of common interests between the Laboratory and campus, and includes the following areas that are opportune for strong collaboration:

- Unmanned aerial vehicle (UAV) systems
- Autonomy and robotics
- Cyber security
- Supercomputing
- Transportation
- Energy systems
- Imaging sciences
- Social Dynamics Observatory
- System-on-a-chip
- Multiple-input multiple-output (MIMO) signal processing
- Earth remote sensing
- Advanced decision support
- Biomedical research and bioinformatics

>> *Spotlight: Lincoln Laboratory Beaver Works Center, cont.*

Students in the Flight Engineering course offered in MIT's Department of Aeronautics and Astronautics built these flight prototypes of scalable unmanned aerial vehicles. This Beaver Works capstone project challenged students to utilize common design features that would enable rapid customization, design, and fabrication.

2013 Projects

Unmanned aerial vehicle (UAV) work

- Capstone project: Deployable mini-UAV
- Capstone project: Modular UAV concepts
- Research project: Flexible UAV design
- Research project: Perdix, a low-cost micro-UAV

Robotics work

- Capstone project: Energy subsystem for autonomous underwater vehicle
- Biomimetic research into humanoid and cheetah locomotion

Cyber security work

- Research project: Language modeling for cyber security
- Research project: Automated reverse engineering
- Research project: Large system cyber analysis
- Cyber Capture the Flag competition for Boston-area college students

Education

Lincoln Laboratory Beaver Works facilitates enrichment courses through its extensive network of technical and educational expertise on campus and at the Laboratory. These courses are intended for a broad audience. In 2013, Lincoln Laboratory technical staff members conducted six educational activities during MIT's Independent Activities Period (IAP). The IAP activities are designed to generate enthusiasm for engineering endeavors while providing an educational introduction to many of the technical missions encountered at the Laboratory. More about the Laboratory's 2013 IAP courses can be found in the Technical Education section of this report.

Campus Collaborators

The Beaver Works Center will initially work with the following MIT departments, laboratories, and centers to provide funded research project opportunities and capstone projects; to develop new joint project opportunities; and to support ongoing and new initiatives aligned with Lincoln Laboratory's missions and contributing to the Innovation Ecosystem at MIT.

- Department of Civil and Environmental Engineering
- Department of Mechanical Engineering
- Department of Electrical Engineering and Computer Science
- Department of Aeronautics and Astronautics
- Center for Transportation and Logistics
- Computer Science and Artificial Intelligence Laboratory (CSAIL)
- The Deshpande Center for Technological Innovation
- Gordon-MIT Engineering Leadership Program
- MIT International Design Center
- Microsystems Technology Laboratories
- Wireless@MIT

Technology Transfer

Lincoln Laboratory's research and development activities help strengthen the nation's technology base.

The Laboratory's continuing development of new capabilities and emerging enabling technologies that are transitioned rapidly to the military services, government agencies, and industry helps ensure that advanced technology is available to the U.S. military services and government agencies, and that U.S. industry is at the forefront of technical innovation.

Technology transfer is accomplished through deliveries of hardware, software, algorithms, or advanced architecture concepts; Small Business Technology Transfer joint research partnerships with local businesses; Cooperative Research and Development Agreements that are privately funded by businesses; and the licensing of MIT patents to companies.

2013 TECHNOLOGY TRANSFER ACTIVITIES

Cyber Security and Information Sciences

During the past year, the Laboratory's key management software was packaged for use by Draper Laboratory. In addition, software to test and measure the performance of newly developed cryptographic protocols was transferred to multiple industry and academic partners for the Security and Privacy Assurance Research program.

The Lincoln Adaptable Real-Time Information Assurance Testbed (LARIAT) traffic-generation tools were transferred to more than 10 new users.

The Lincoln Automated Malicious Binary Data Analyzer (LAMBDA) and BETA malware analysis and transformation tools were transitioned to the sponsor and users.

Communication Systems

The Laboratory completed a flight test of an advanced satellite communications (SATCOM) antenna aboard a C-130J aircraft.

The design of a high-altitude electromagnetic pulse (HEMP) hardened transportable SATCOM terminal was tested, and industry-built versions were delivered to the Air Force.

A simulation model of a future protected SATCOM waveform was developed and delivered to 16 industry teams for use in analysis and early prototyping.

The Laboratory provided the Defense Information Systems Agency with a guide for core radio management information base and proxy implementation. This document defines the management of current and future radio systems with a Common Network Management interface.

Tactical Systems

The Laboratory is supporting and further developing a sensor approach designed for route-clearance engineer teams to use on a robotic platform. The initial robotic capability has been transitioned to industry for production. The Laboratory continues to assess and prototype significant advancements to this technology.

A field-hardened prototype of a new ground-penetrating radar technology significantly advances the state of the art in antenna array and processing technology. This prototype has been integrated on a military vehicle and transitioned to the Army for operational use.

Space Control

The Laboratory contributed core algorithm technology to the Atmospheric Infrared Sounder (AIRS) Atmospheric Product Suite, released to the public on 1 March 2013. AIRS, which is onboard the NASA Aqua satellite, produces high-resolution atmospheric soundings in clear and cloudy conditions.

Air and Missile Defense Technology

Lincoln Laboratory developed a Phased Array Radar Simulation System to design and test open system architecture technical concepts and radar processing algorithms for ground-based air defense radar systems. These technologies were transferred to the government to support technology development for the Three-Dimensional Expeditionary Long-Range Radar.

Under U.S. Navy sponsorship, radar signal processing and calibration algorithms were developed and transferred to government contractors for subsequent integration into the E-2D Advanced Hawkeye. The E-2 Hawkeye is the Navy's all-weather, carrier-based tactical battle management airborne early-warning and command-and-control aircraft.

>> *Technology Transfer Activities, cont.*

SELECTED PATENTS

Agile-Beam Laser Array Transmitter
Gary A. Shaw and Lawrence M. Candell
Date issued: 30 October 2012
U.S. Patent no.: 8,301,027

Method and System for in situ Aerosol Thermo-Radiometric Analysis
William D. Herzog
Date issued: 25 September 2012
U.S. Patent no.: 8,274,655

Method and Apparatus for Measuring a Position of a Particle in a Flow
Thomas H. Jeys, Antonio Sanchez-Rubio, Ronald H. Hoffeld, Jonathan Z. Lin, Nicholas M.F. Judson, George S. Haldeman, and Vincenzo Daneu
Date issued: 27 November 2012
U.S. Patent no.: 8,319,965

Inorganic Resist Sensitizer
Theodore H. Fedynyshyn and Russell B. Goodman
Date issued: 4 December 2012
U.S. Patent no.: 8,323,866

Single-Electron Detection Method and Apparatus for Solid-State Intensity Image Sensors with a Charge-Metering Device
David C. Shaver, Bernard B. Kosicki, Robert K. Reich, Dennis D. Rathman, Daniel R. Schuette, and Brian F. Aull
Date issued: 4 December 2012
U.S. Patent no.: 8,324,554

Annular Solid Immersion Lenses and Methods of Making Them
Zong-Long Liau
Date issued: 4 December 2012
U.S. Patent no.: 8,325,420

Optical Limiting Using Plasmonically Enhancing Nanoparticles
Vladimir Liberman and Mordechai Rothschild
Date issued: 1 January 2013
U.S. Patent no.: 8,345,364

Notch Antenna Having a Low Profile Stripline Feed
Glenn A. Brigham, Marat Davidovitz, Sean M. Duffy, and Jeffrey Herd
Date issued: 8 January 2013
U.S. Patent no.: 8,350,767

Method for Low Sidelobe Operation of a Phased Array Antenna Having Failed Antenna Elements
Steven I. Krich, Cory J. Prust, and Ian Weiner
Date issued: 15 January 2013
U.S. Patent no.: 8,354,960

Iterative Clutter Calibration with Phased-Array Antennas
Steven I. Krich and Ian Weiner
Date issued: 22 January 2013
U.S. Patent no.: 8,358,239

Method and Apparatus for Synchronizing a Wireless Communication System
Daniel W. Bliss and Peter A. Parker
Date issued: 22 January 2013
U.S. Patent no.: 8,358,716

Modulator for Frequency-Shift Keying of Optical Signals
Bryan S. Robinson, Don M. Boroson, Scott A. Hamilton, and Shelby J. Savage
Date issued: 19 March 2013
U.S. Patent no.: 8,401,398

Grazing-Incidence-Disk Laser Element
Daniel J. Ripin, Tso Yee Fan, Anish K. Goyal, and John Hybl
Date issued: 26 March 2013
U.S. Patent no.: 8,406,267

Polyphase Nonlinear Digital Predistortion
Joel I. Goodman, Benjamin A. Miller, Matthew A. Herman, and James E. Vian
Date issued: 2 April 2013
U.S. Patent no.: 8,410,843

CMOS Readout Architecture and Method for Photon-Counting Arrays
Brian F. Aull, Matthew J. Renzi, Robert K. Reich, and Daniel R. Schuette
Date issued: 23 April 2013
U.S. Patent no.: 8,426,797

Method and Apparatus for Spectral Cross Coherence
Christ D. Richmond
Date issued: 23 April 2013
U.S. Patent no.: 8,428,897

Micro-electromechanical Tunneling Switch
Carl O. Bozler, Craig L. Keast, and Jeremy Muldavin
Date issued: 30 April 2013
U.S. Patent no.: 8,432,239

Very Large Mode Slab-Coupled Optical Waveguide Laser and Amplifier
Robin K. Huang and Joseph P. Donnelly
Date issued: 28 May 2013
U.S. Patent no.: 8,451,874

Waveguide Coupler Having Continuous Three-Dimensional Tapering
Steven J. Spector, Reuel B. Swint, and Milos Popovic
Date issued: 25 June 2013
U.S. Patent no.: 8,472,766

Method and Apparatus for Hypothesis Testing
David W. Browne
Date issued: 25 June 2013
U.S. Patent no.: 8,473,446

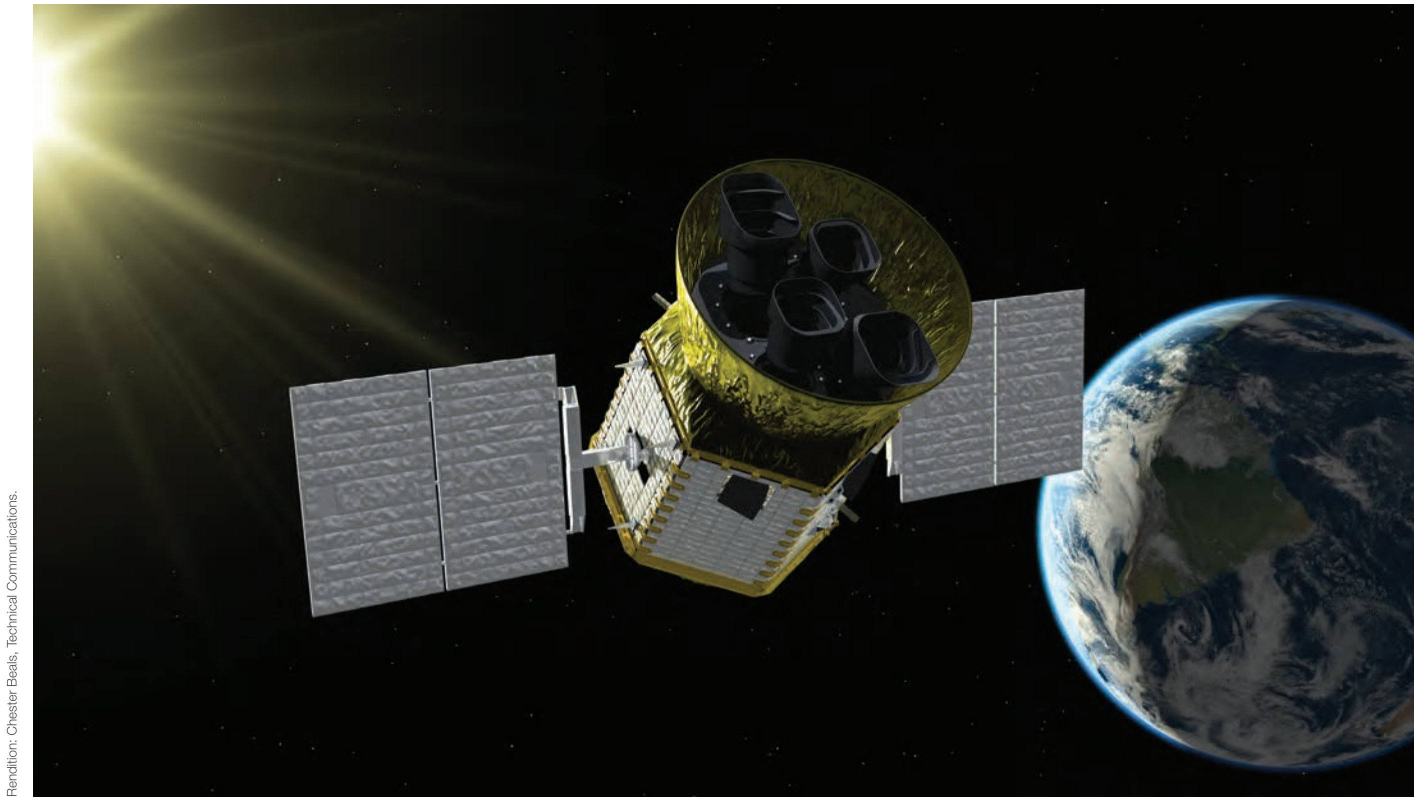
Method and Apparatus for Audio Source Separation
Tianyu Wang and Thomas F. Quatieri
Date issued: 30 July 2013
U.S. Patent no.: 8,498,863

Filter-Based DPSK Receiver
David O. Caplan and Mark L. Stevens
Date issued: 6 August 2013
U.S. Patent no.: 8,503,889

Time Varying Quantization-Based Linearity Enhancement of Signal Converters and Mixed-Signal Systems
William S. Song
Date issued: 13 August 2013
U.S. Patent no.: 8,508,395

Terahertz Sensing System and Method
Mohammad Jalal Khan, Jerry C. Chen, and Sumanth Kaushik
Date issued: 20 August 2013
U.S. Patent no.: 8,514,393

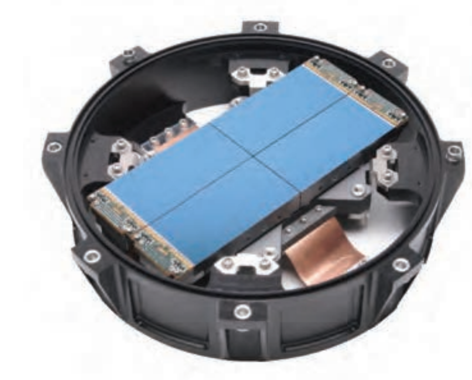
Transiting Exoplanet Survey Satellite



Rendition: Chester Beals, Technical Communications.

Rendering of the Transiting Exoplanet Survey Satellite.

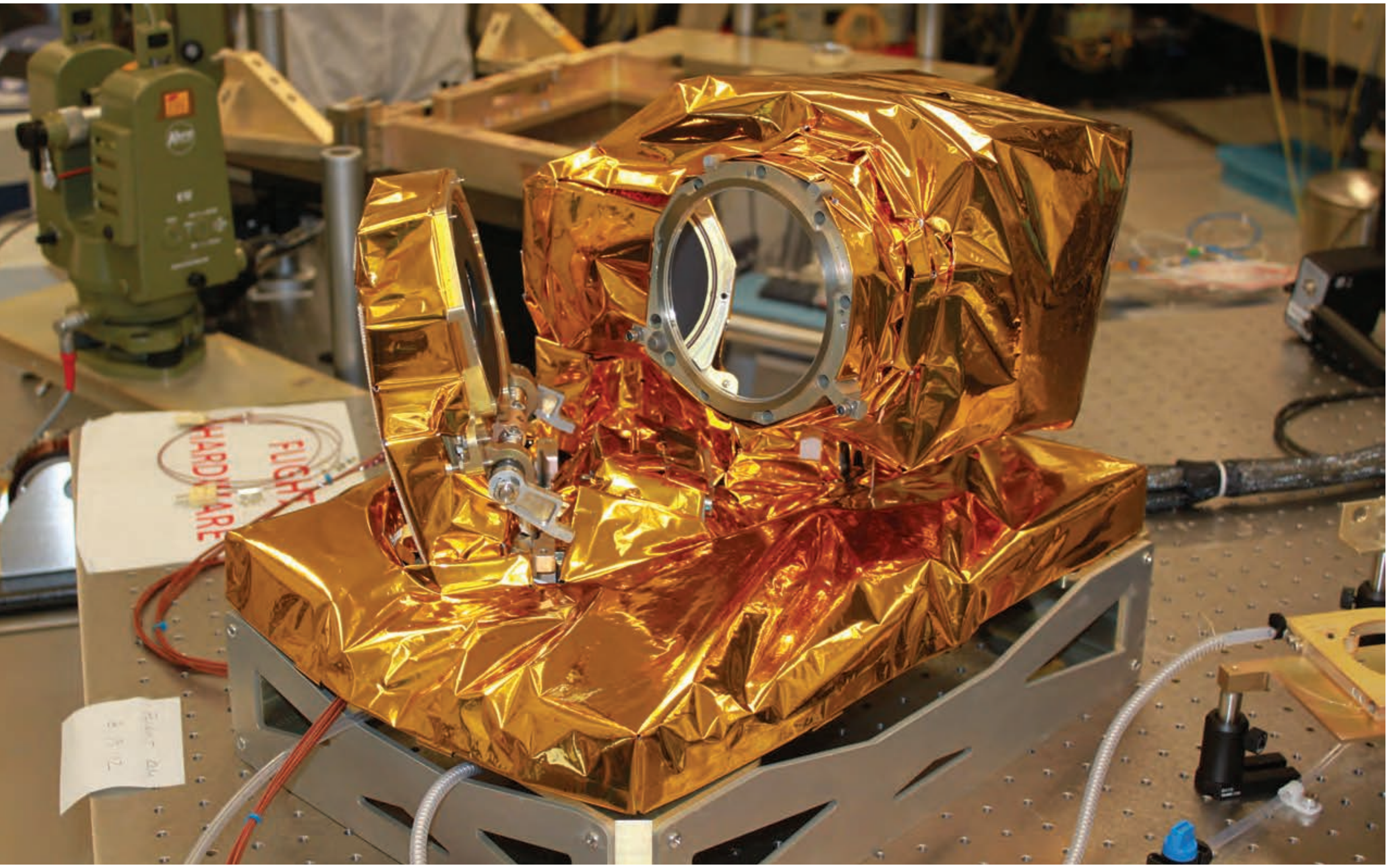
In April 2013, the National Aeronautics and Space Administration (NASA) selected the Transiting Exoplanet Survey Satellite (TESS) as the next mission in its Explorer Program. The TESS mission proposal was led by the MIT Kavli Institute for Astrophysics and Space Research (MKI), with Lincoln Laboratory partnering to provide key components of the mission's payload.



Prototype charge-coupled-device detector for TESS.

TESS will use an array of wide-field cameras to perform an all-sky survey to discover transiting exoplanets. In a two-year survey following launch in 2017, TESS will monitor 500,000 stars for temporary drops in brightness caused by planetary transits. This first-ever space-borne all-sky transit survey will identify planets, ranging from Earth-sized to gas giants, around a wide range of stellar types and orbital distances. Data from TESS will allow scientists to study the masses, sizes, densities, orbits, and atmospheres of a large number of small planets, including a sample of rocky worlds in the habitable zones of their host stars. TESS will provide targets for follow-up observation with the James Webb Space Telescope, as well as other large ground-based and space-based telescopes of the future.

The Laboratory's role in the development of TESS is threefold: camera detector design, development, and testing; optical system design, development, and testing; and satellite payload management. The TESS effort will utilize the expertise of the Advanced Technology, Engineering, and Aerospace Divisions. The principal investigator for the TESS project is Dr. George Ricker of MKI. MKI is providing the payload electronics, overall program management, and the scientific research program. Other TESS collaborators are the NASA Goddard Space Flight Center, NASA Ames Research Center, Orbital Sciences Corporation, the Harvard-Smithsonian Center for Astrophysics, the Space Telescope Science Institute, and the Aerospace Corporation.



The Lunar Laser Communication Demonstration space terminal's optical module is shown during laboratory system testing. This view shows the mostly reflective "window" covering the 10 cm telescope, the open launch latch, and the multilayer insulation blanketing that helps preserve a controlled thermal environment.

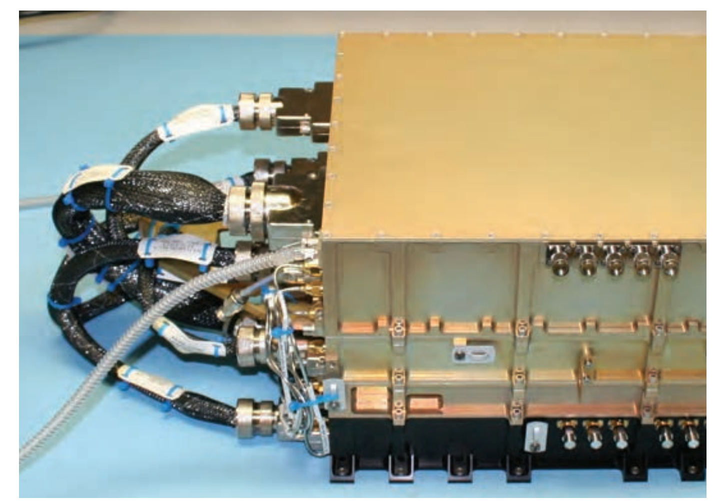
Lunar Laser Communication Demonstration

For more than 30 years, the National Aeronautics and Space Administration (NASA) has been seeking to develop technologies that could someday greatly increase the amount of data that can be returned from its deep-space science probes. The distances involved are thousands of times greater than those for which present-day communication satellites are configured, and traditional satellite communication methods do not scale to solve the problem of extremely long-distance data transmittal. Optical communications, with its very narrow beams and extremely wide and unregulated electromagnetic spectrum, has long been considered a promising solution to NASA's deep-space communication needs.

Lincoln Laboratory has designed and built the Lunar Laser Communication Demonstration (LLCD) system for NASA as the first step toward meeting such needs. The system consists of a very small space terminal that will fly in orbit around the moon and a transportable ground terminal that will reside for the experiment in White Sands, New Mexico.

The space terminal includes a 10-centimeter gimbaled telescope and a fiber-coupled modem carrying an uplink receiver and a 0.5-watt laser transmitter. The system is designed to support data rates of up to 20 megabits per second (Mbps) on the uplink and up to 622 Mbps on the downlink. These rates are somewhat higher than rates achieved by the best radio systems ever fielded to the moon and much higher than those achieved during most typical space missions. The LLCD system also has the capability to use its wide bandwidth signals to create continuous-time ranging estimates with subcentimeter accuracy. Pointing and stabilizing the very narrow beam are enabled by a novel inertial stabilization subsystem. These two modules plus a controller module ride aboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft, launched on a Minotaur V rocket from Wallops Island, Virginia, on 6 September.

The closed-up clamshell dome for LLCD's ground terminal sits adjacent to the converted shipping container that houses all the control and modem electronics, laser transmitters, and the unique receiver, as well as the control room.



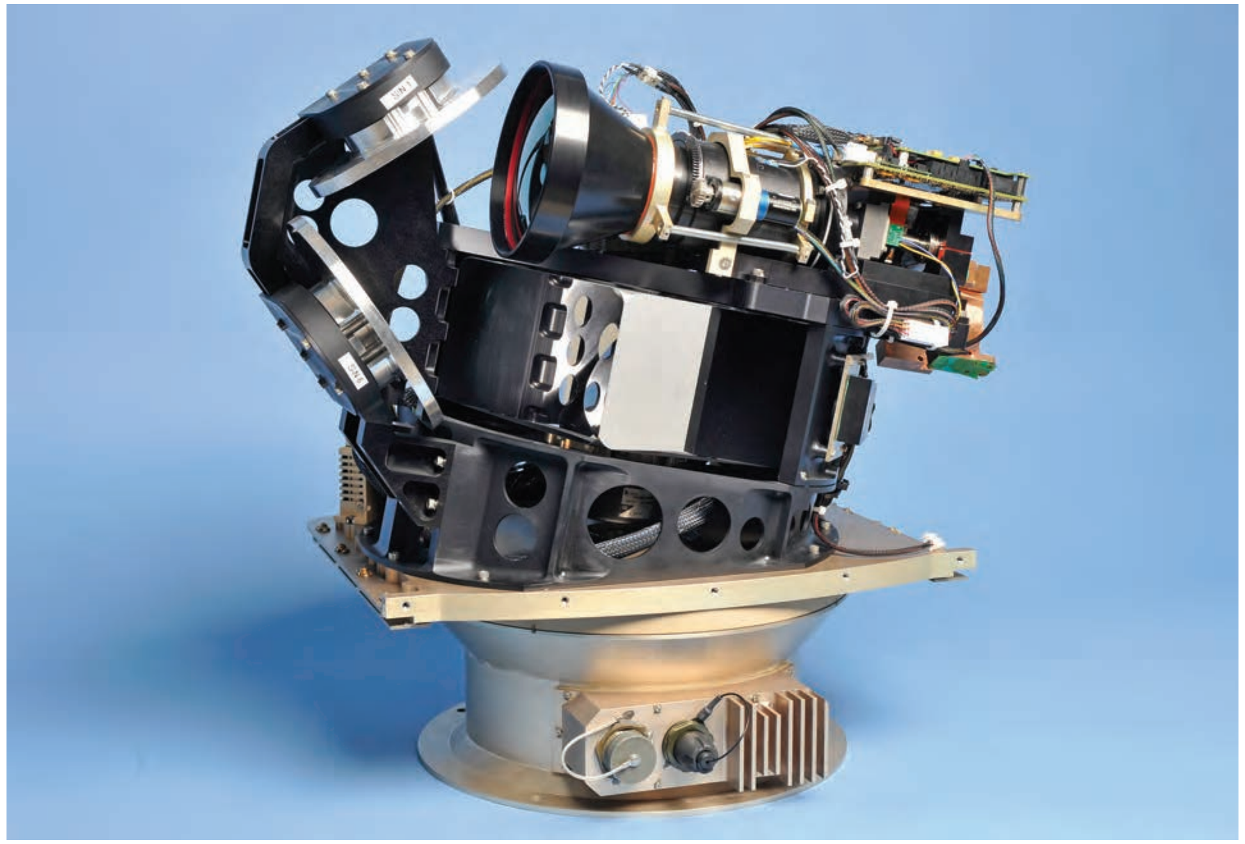
The space terminal's modem is connected to the optical module by optical fibers that can be seen in the tube off to the left.

In this photo of the LLCD's transportable ground terminal, an array of four large downlink telescopes and an array of four small uplink telescopes are shown. The spherical enclosure keeps the system at a constant temperature, and the here-opened clamshell dome protects the system from the elements.

The LLCD ground terminal consists of an array of four uplink telescopes and an array of four downlink telescopes, all connected to modems via optical fibers. The downlink receiver is the most sensitive high-speed laser communications receiver ever fielded. It uses arrays of single-photon-detection technologies based on superconducting nanowires, all of which were designed and fabricated at Lincoln Laboratory.

The goals of the LLCD are to validate the specific system and terminal designs, corroborate the models of atmospheric and environmental effects on such systems, and demonstrate the great utility of the technology to potential users.

The combination of the two-hour lunar orbit, the turning of the Earth, and the small spacecraft battery constrained laser communication operations to a few 20-minute periods per day during the one-month demonstration period beginning in mid-October. On 17 October, the LLCD used a pulsed laser beam to transmit data over the 239,000 miles from the moon to Earth at a record-breaking data-download speed of 622 Mbps. LLCD also demonstrated a data-upload speed of 20 Mbps on a laser beam transmitted from a ground station in New Mexico to the LADEE spacecraft; this speed is 5000 times faster than the upload speed of the best radio system ever flown to the moon.



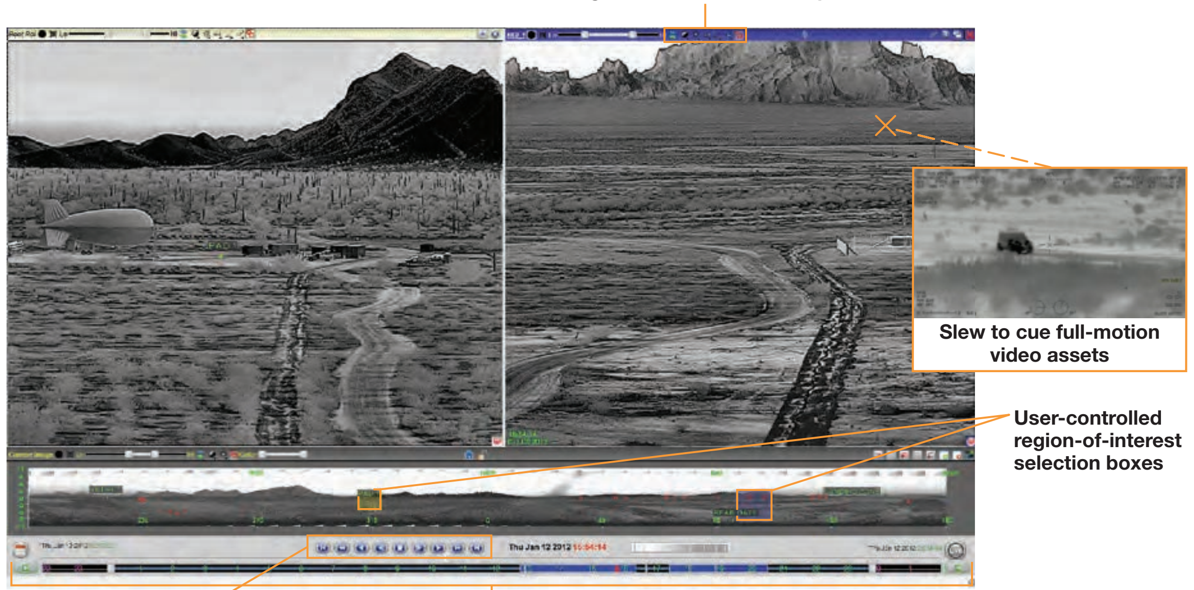
This interior view of WISP-360 shows the lens and the folding mirrors.

Wide-Area Infrared System for 360° Persistent Surveillance

The Wide-Area Infrared System for 360° Persistent Surveillance (WISP-360) is a long-wave infrared imaging system that produces and records 360° × 20° 100-megapixel-class panoramic video data at a rate of one frame every two seconds. This tower-mounted system utilizes real-time processing and exploitation tools to provide daytime and nighttime 360° persistent surveillance of a ground area and enables automatic detections of moving targets.

The system was designed for monitoring remote sites and critical infrastructure, providing a 24-hour, seven-days-a-week situational awareness that is vital for the protection of military outposts and national assets. Six WISP-360 systems have been successfully transitioned to the Army to help protect forward operating bases. Since WISP's deployment, the Laboratory has focused on the reduction of the camera's size, weight, and power, and on the incorporation of higher pixel-count detector arrays. These advances target the demonstration of a 300-megapixel-class capture system contained within a modified MX-15 turret (Mini-WISP) in 2013.

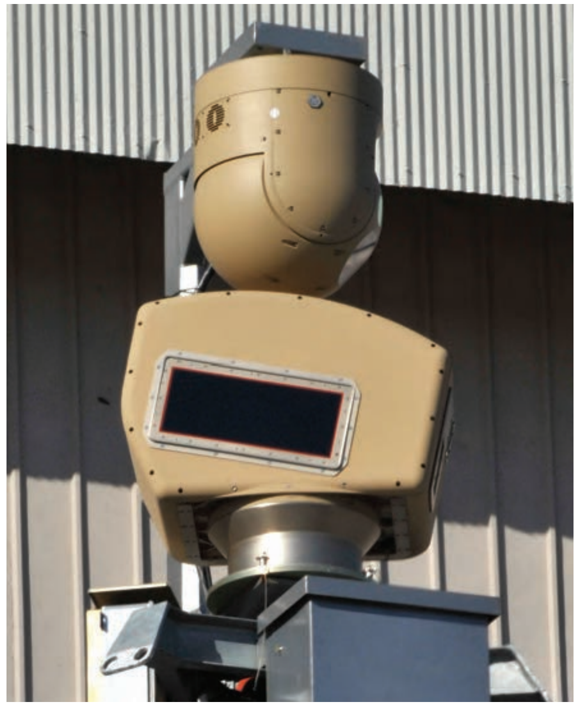
WISP-360 has significantly enhanced infrared video surveillance capabilities by expanding the field of view (FOV) that can be achieved. Traditional infrared video systems produce high-resolution imagery, but only through "soda straw" views that make surveillance inefficient because multiple images must be captured sequentially to provide a wide-area observation of a site.



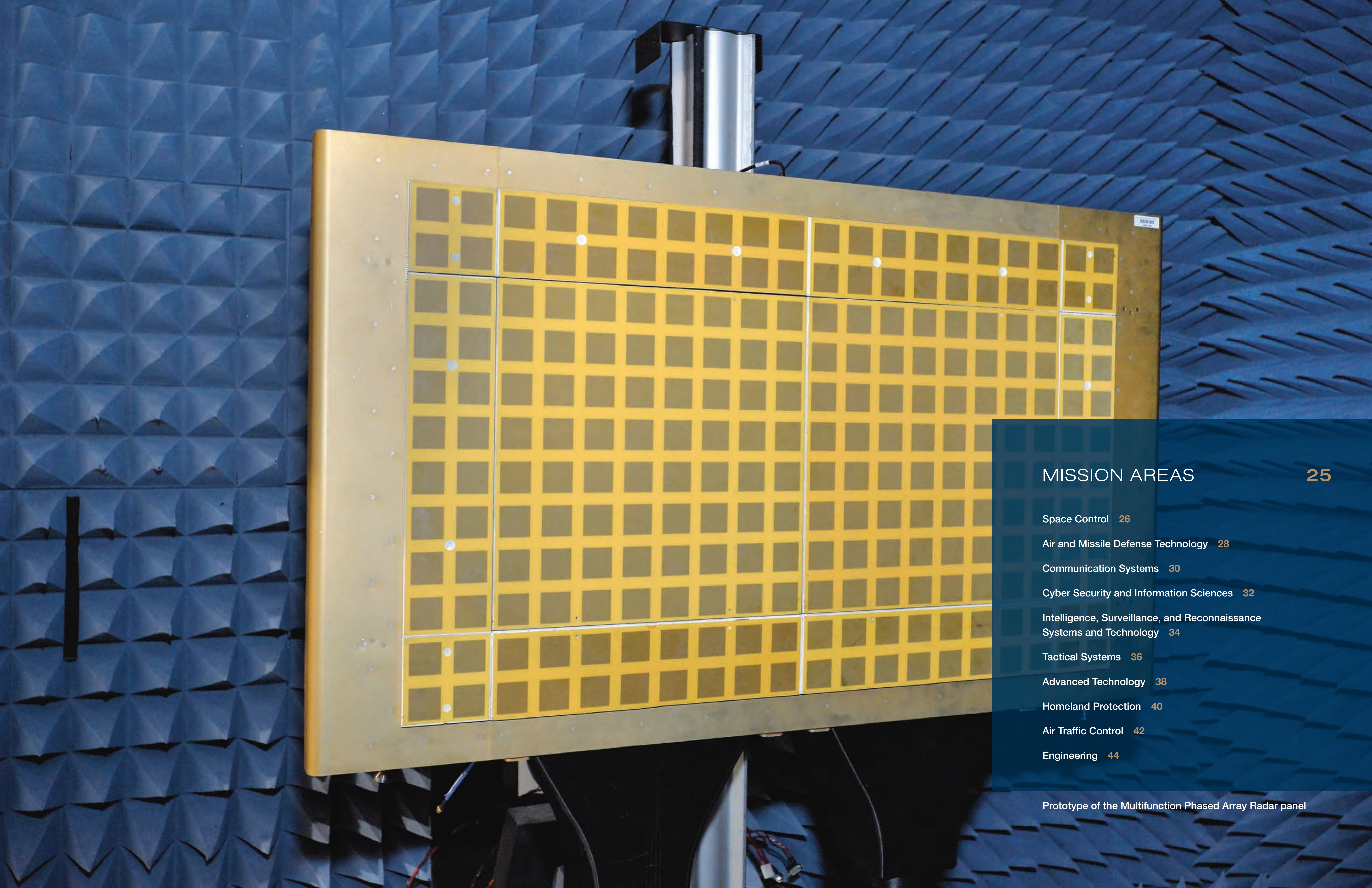
Processed data are served to a custom viewer that runs on a separate workstation. The system can support multiple viewers with up to 20 simultaneous regions of interest per viewer. Because of the extensive preprocessing prior to storage, tiled compression, and fast access enabled by solid-state drives, the viewer is able to access imagery at a high rate. Playback speed of archived data is approximately 20 times that of the collection speed. Because users can skip video durations with no region-of-interest detections, they can perform forensic observations quickly in parallel to supporting real-time monitoring. In addition, annotated subimages from the video can be generated and disseminated for targets of interest.

WISP-360 records video data within a large FOV at full resolution for one month. This video data, which has been stitched, gain balanced, nonuniformity corrected, geo-calibrated, and compressed in real time, not only can be examined in real time to observe ongoing activity at a site, but also can be reviewed forensically to analyze the dynamics of past activities.

The WISP-360 camera head is a two-dimensional scanning system that uses the unique digital focal plane array, developed by Lincoln Laboratory, to capture the scanned scene. Video data and metadata recorded from an inertial measurement unit and from position encoders on the azimuth and scanning mirror drives are sent to a processing server over a single fiber at rates exceeding 1 gigabyte per second. The near-real-time processing chain is run on a multicore 3U server and leverages graphics processing units and custom JPEG-2000 compression boards to handle the high raw-data rates. The processed data are stored on a bank of high-speed drives and made available to any user on the Internet protocol network via a client server application, called WISPView, that allows the user to monitor the full 360° scene.



WISP-360 has a ruggedized housing that is sealed against dust, moisture, and humidity. The window in the casing is made of germanium and has a scratch-resistant carbon exterior coating.



MISSION AREAS

Prototype of the Multifunction Phased Array Radar panel

Space Control

Leadership

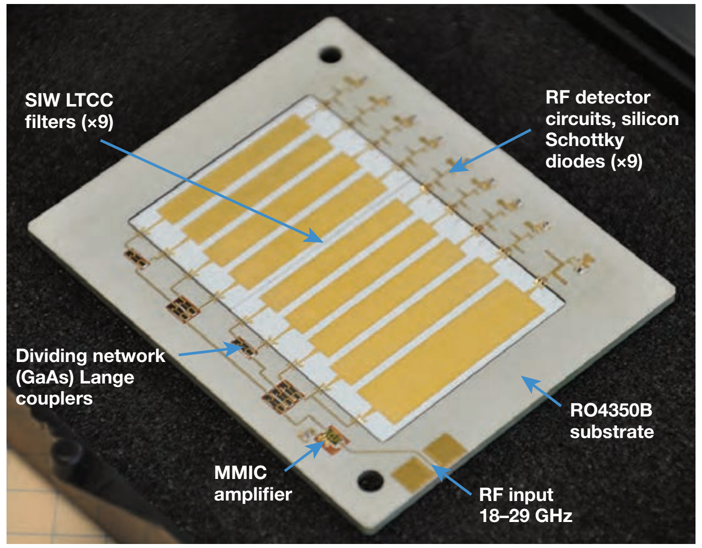
Dr. Grant H. Stokes

Mr. Lawrence M. Candell

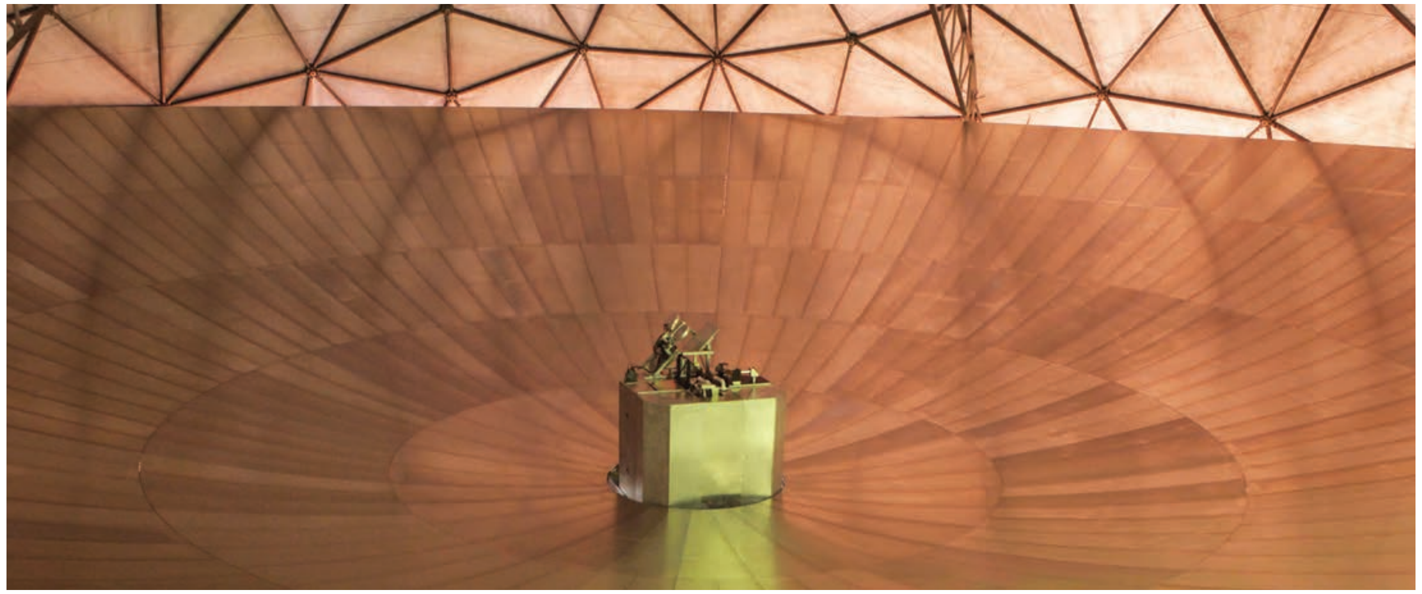
Dr. William J. Donnelly III

Mr. Craig E. Perini

Lincoln Laboratory develops technology that enables the nation's space surveillance system to meet the challenges of space situational awareness. The Laboratory works with systems to detect, track, and identify man-made satellites; collects orbital-debris detection data to support space-flight safety; performs satellite mission and payload assessment; and investigates technology to improve monitoring of the space environment, including space weather and atmospheric and ionospheric effects. The technology emphasis is the application of new components and algorithms to enable sensors with greatly enhanced capabilities and to support the development of net-centric processing systems for the nation's Space Surveillance Network.



The ultra-compact nine-channel microwave spectrometer subassembly prototype utilizes low-temperature co-fired ceramic (LTCC) and substrate integrated waveguide (SIW) technology to enable high-performance microwave atmospheric sensing from very small platforms, including cubesats and unmanned aerial vehicles.



The Haystack Ultrawideband Satellite Imaging Radar (HUSIR) 37-meter-diameter primary reflector surface achieved its final precision alignment goal, allowing final dual-band (X and W) integration and testing to proceed in preparation for transitioning HUSIR to operational use in the U.S. Space Surveillance Network.

Principal 2013 Accomplishments

- The Space Surveillance Telescope (SST), a 3.5-meter telescope for searching deep space, is nearing completion of its full checkout. Formal testing and evaluation has shown that the SST exceeds preprogram expectations.
- The final precision alignment of the 37-meter-diameter primary reflector surface of the Haystack Ultrawideband Satellite Imaging Radar (HUSIR) was successfully completed. The aligned surface focuses the beam of the W-band radar to less than 0.006 degrees.
- Lincoln Laboratory developed and tested an ultra-compact, nine-channel microwave spectrometer prototype under the NASA Advanced Component Technology program. The packaged, flight-ready subassembly consumes 363 mW of power with a mass of 87.7 g. This new technology enables high-performance microwave atmospheric sensing from very small platforms, including cubesats and unmanned air vehicles.
- To inform the development of a robust architecture for space situational awareness, the Laboratory conducted trade studies examining how existing and planned capabilities supporting other mission areas may be leveraged for application to space situational awareness.
- Lincoln Laboratory participated in an experiment jointly sponsored by Air Force Space Command and the Missile Defense Agency to demonstrate the utility and concept of operation for sharing operational sensors between mission areas. This effort involved the development of a tasking interface for an AN/TPY-2 X-band radar and the integration of a sidecar to enable real-time exposure of the AN/TPY-2 data net-centrically over the Global Information Grid.
- A new field site facility in Colorado Springs, Colorado, was opened. It will provide mission planning and data analysis in support of the operations of the Space-Based Space Surveillance (SBSS) spacecraft, and will serve as an integration and test facility for introducing new capabilities for space situational awareness.
- The Tactical Space Situational Awareness initiative integrates Laboratory sensor technology programs with net-centric, multisensor fusion test beds to operate the Lincoln Space Surveillance Center as an operational prototype for a modern space control architecture. Initial testing demonstrated a robust new object-discovery system, routine tactical handoffs from optical search sensors to radar, and a dramatically improved surveillance capacity of existing sensors.
- The Laboratory contributed to on-orbit checkout of the Suomi National Polar-orbiting Partnership satellite launched on 28 October 2011. Data processing algorithms of the Cross-Track Infrared Sounder, the Advanced Technology Microwave Sounder, and the Visible/Infrared Imaging Radiometer Suite were optimized and validated and are now entering operational use.

Future Outlook

- After completing a Military Utility Assessment, it is anticipated that the SST will become a contributing sensor in the U.S. Space Surveillance Network (SSN).
- After final integration and testing, HUSIR will be the first new Lincoln Space Surveillance Complex sensor since the addition of the Haystack Auxiliary Radar in the early 1990s. Staff from the Lexington Space Situational Awareness Center have begun training and preparations to help ensure a smooth transition of this unique dual-band (X and W) asset into SSN operations. Future efforts will focus on data exploitation and on an increase in transmitter power to enable imaging of deep-space objects.
- Lincoln Laboratory will continue to support SBSS operations and assist Air Force personnel in exploring novel tactics, techniques, and procedures to employ SBSS capabilities to fill gaps in U.S. space situational awareness.
- The Laboratory will contribute technical advice and execute risk-reduction activities for the Joint Space Operations Center (JSpOC) Mission System acquisition program, which is delivering a modernized, net-centric command-and-control system to enable multiple JSpOC missions in support of U.S. Strategic Command and its Combatant Commanders.

Air and Missile Defense Technology

Leadership


Dr. Hsiao-hua K. Burke

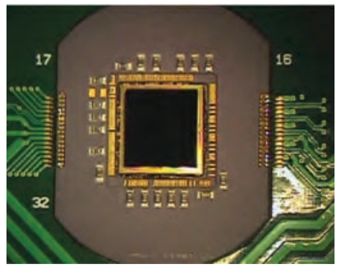

Dr. Andrew D. Gerber

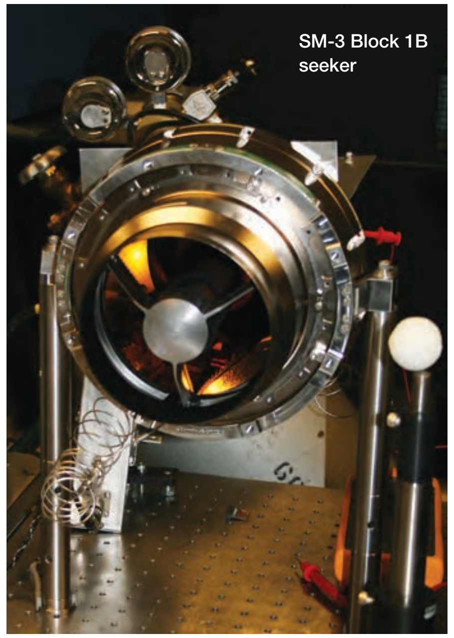

Mr. Gerald C. Augeri


Mr. Dennis J. Keane

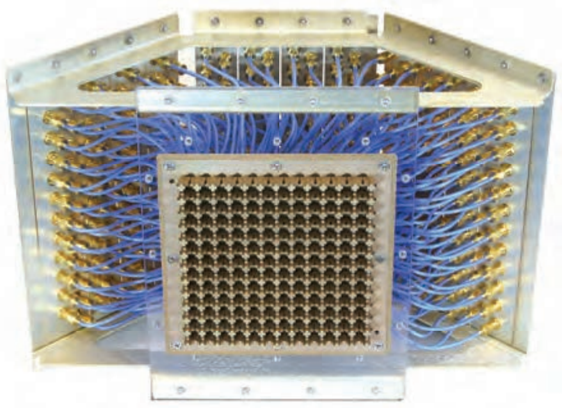
Lincoln Laboratory develops and assesses integrated systems for defense against ballistic missiles, cruise missiles, and air vehicles in tactical, regional, and homeland defense applications. Activities include the investigation of system architectures, development of advanced sensor and decision support technologies, development of flight-test hardware, extensive field measurements and data analysis, and the verification and assessment of deployed system capabilities. A strong emphasis is on rapidly prototyping sensor and system concepts and algorithms, and on transferring resulting technologies to government contractors responsible for developing operational systems.


The gimbaled slotted planar array in the Gimballed Airborne Test Radar test bed collects coherent range-Doppler measurements to demonstrate and evaluate the performance of advanced radar tracking and discrimination algorithms.





Lincoln Laboratory has made significant contributions to the SM-3 Block 1B program, including sensor development, modeling and simulation, ground and captive-carry data collection, and real-time processor development. At left is the SM-3 Block 1B seeker. Potential future upgrades to the system include the insertion of digital focal plane array technology (above).


The Laboratory is prototyping an electronic attack payload, including an advanced, wideband, scanning, dual-polarized antenna array and a modular, channelized processing chain.

Principal 2013 Accomplishments

- Key contributions were made to the planning, execution, and post-mission evaluation of the October 2012 FTI-01 and the September 2013 FT0-01 events, the most complex integrated live-fire missile defense tests ever conducted. Activities in Lexington, Mass.; Huntsville, Ala.; and the Reagan Test Site (RTS) at Kwajalein spanned the entire test cycle and focused on the significant challenges to test success.
- The Missile Defense Agency (MDA) Sensors Directorate fielded a debris-mitigation real-time experiment (sidecar) built by the Laboratory on the AN/TPY-2 forward-based radar during the FTI-01 test. This experiment provided early testing of near-term pre- and post-intercept debris-mitigation algorithms. The sidecar was also employed for additional experimentation using the AN/TPY-2 and Ground-Based Radar Prototype (GBR-P) radars on regional and strategic missile defense tests in 2013.
- Lincoln Laboratory led the MDA Counter-Countermeasure (CCM) team, providing technical guidance as CCM Chief Scientist for MDA. Activities focused on the development of mitigation techniques and algorithms effective against a broad spectrum of advanced ballistic missile defense (BMD) countermeasures. Guidance was provided for the Integrated System-Level Discrimination effort.
- The Laboratory supports development of countermeasure concepts as part of the Ballistic Missile Defense System (BMDS) development. As the Red Team, the Laboratory has developed countermeasures to test counter-countermeasure techniques for the emerging BMDS.
- Several milestones were achieved under the RTS Improvement and Modernization Program. The Optics Modernization Program achieved initial operational capability (IOC) for two telescope systems, and the Real-Time Open Systems Architecture project reached IOCs with the Millimeter-Wave, ARPA Lincoln C-band Observables Radar (ALCOR), and MPS radars. The Real-Time Telemetry Open Systems and RTS mission Automation and Decision Support development projects also achieved important early milestones.
- A design and risk-reduction effort continued for ship-based electronic countermeasure that will improve the Navy's capability to defend ships against advanced antiship missile threats.
- Work continued on a Future Naval Capabilities (FNC) program entitled Integrated Active and Electronic Defense, which provides integrated hard-kill and soft-kill engagement scheduling for future shipboard combat systems. This project builds on a previous program and extends the coordination approach to the multiship force level.
- The Laboratory's increased role in the development and assessment of over-the-horizon radar capabilities included the development and demonstration of new signal processing techniques to mitigate clutter and ionospheric propagation challenges, development and demonstration of a next generation of fully digital array architectures, and investigation of the impact of various forms of interference on system performance.

Future Outlook

- The increasing vulnerability of deployed U.S. forces and friends and allies to large attacks by medium- and intermediate-range ballistic missiles mandates greater emphasis on improving regional BMD battlespace and raid-handling capabilities. Lincoln Laboratory will continue to have key responsibilities in Aegis BMD global requirements and specifically the Phased Adaptive Approach.
- The Department of Defense has begun to focus on the anti-access/area denial (A2/AD) problem. As a result of this new focus, detailed kill-chain assessments are needed to determine vulnerabilities of current capabilities, and new concepts will be needed for the United States to effectively maintain its freedom of action in an A2/AD environment.
- The Navy has begun investing heavily in electronic warfare capabilities, with an eye toward developing more advanced soft-kill capabilities to complement the conventional hard-kill capabilities. The Laboratory is helping the Navy shape a technology portfolio to ensure that electronic warfare capabilities are adequately addressed across naval platforms and weapons systems.
- The RTS will continue to enhance its capabilities to meet future challenging test scenarios and real-world events. Efforts will focus on state-of-the-art telemetry and range safety systems, more flexible sensor utilization and concepts of operation, improved decision aids, enhanced connectivity and interoperability, and increased capability to efficiently track and characterize complex scenarios.

Communication Systems

Leadership


Dr. J. Scott Stadler


Dr. Roy S. Bondurant

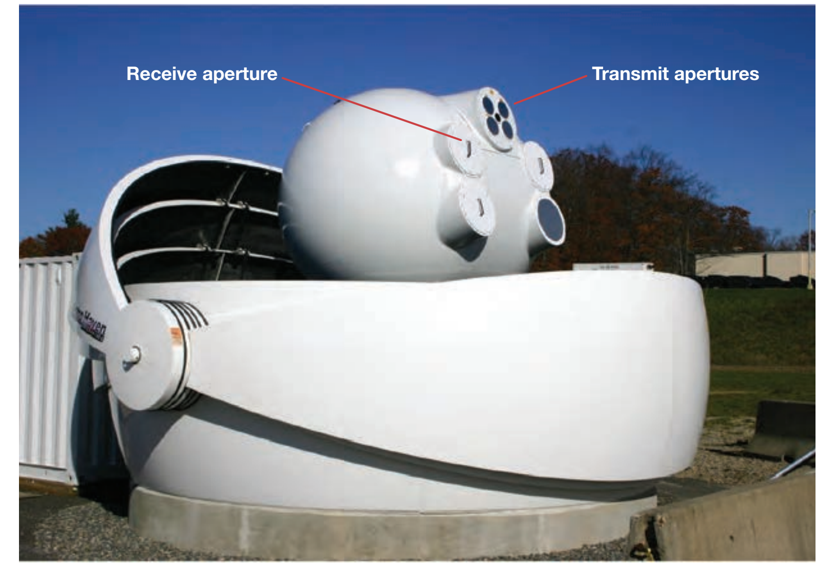

Dr. James Ward


Dr. Don M. Boroson

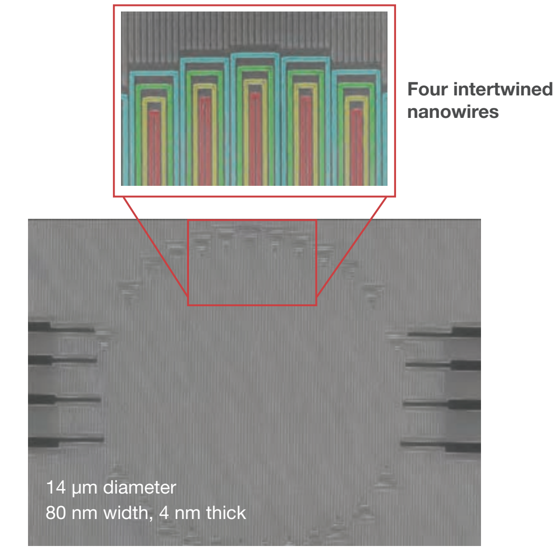

Dr. David R. McElroy

Lincoln Laboratory is working to enhance and protect the capabilities of the nation's global defense networks. Emphasis is placed on synthesizing communication system architectures, developing component technologies, building and demonstrating end-to-end system prototypes, and then transferring this technology to industry for deployment in operational systems. Current efforts focus on radio-frequency military satellite communications, free-space laser communications, tactical network radios, quantum systems, and spectrum operations.


Researchers in the Optical Communications Technology Group prepare to verify electrical interconnections prior to powered testing of the Lunar Laser Communication Demonstration terminal that is integrated onto the spacecraft.



The Lunar Laser Communication Demonstration ground terminal makes use of four 15 cm transmit apertures and four 40 cm receive apertures to achieve data rates of 622 Mbits/sec from a Lunar orbiter to Earth.



Superconducting nanowire detector arrays developed by Lincoln Laboratory enable receiver sensitivities of ~2 bits/photon. Interleaving multiple nanowire detectors results in shorter equivalent reset times and enables higher data rates.

Principal 2013 Accomplishments

- Lincoln Laboratory shipped the space payload for the Lunar Laser Communication Demonstration to NASA Ames Research Center for integration onto the Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft. The optical ground terminal was also shipped to White Sands Missile Range, New Mexico. This mission, launched in September 2013, demonstrated high-rate laser communication from the lunar-orbiting LADEE spacecraft back to Earth.
- A digital-transmitter-on-chip phased array under development uses custom silicon-germanium and gallium-arsenide application-specific integrated circuits and nonlinear waveform predistortion techniques to achieve linear efficient power transmitters. This technology is applicable to future communications, radar, and electronic warfare systems.
- Lincoln Laboratory successfully completed the preliminary design of a compact airborne laser communication terminal that operates in an aggressive environment over a wide field of regard.
- The Laboratory's reference terminals for the Advanced Extremely High-Frequency (AEHF) military satellite communications systems were utilized by the government and were instrumental in the checkout, calibration, and characterization efforts leading to the successful integration of the second AEHF satellite into the nation's military satellite communications (SATCOM) architecture.
- A ground mobile terminal capable of connecting to the recently launched AEHF satellites was developed by the Laboratory and demonstrated in operational scenarios. The small-form-factor modem in this terminal is the first implementation that adheres to the future security and robustness requirements of the system.
- A tactical airborne communications road map study was completed by the Laboratory and provided to the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics to set the direction for next-generation wireless tactical systems.
- The Laboratory successfully completed shock-vibration and thermal-vacuum qualification of a space-compatible optical differential phase-shift-keyed modem that operates over a wide range of rates (2 Mbps–1.25 Gbps) with near quantum-limited sensitivity.
- The Lincoln Ka-Band Test Terminal was used to perform operational testing of the Wideband Global SATCOM System's wideband bypass mode for high-rate communications.
- Near-quantum-limited sensitivity was demonstrated in an optically preamplified coherent modem operating at 10 and 20 Gbps with world-record 2 photon-per-bit sensitivity.

Future Outlook

- Lincoln Laboratory will be developing advanced radio-frequency hardware, signal processing, and network protocols that optimize the effectiveness of future communication, sensing, and electronic warfare systems in contested environments.
- Lincoln Laboratory's protected SATCOM terminals will continue to be used to control the nation's protected SATCOM constellations and to provide post-launch calibration.
- A test bed developed by Lincoln Laboratory will be used by multiple industry teams to demonstrate compatibility with a new waveform for protected military SATCOM.
- The Laboratory will continue to influence the evolution of airborne tactical wireless networks by developing prototype systems and characterizing their performance in flight and field testing.
- Lincoln Laboratory will continue maturing the design of the prototype compact airborne lasercom terminal to critical design stage and will complete the development of a high-fidelity optical test bed to support functional testing.
- The Laboratory's advances in laser communications technology and recent studies suggest that useful undersea laser communications concepts may now be technically feasible. Additional analysis, experimentation, and concept development targeted at Navy applications will be pursued.

Cyber Security and Information Sciences

Leadership

Mr. Stephen B. Rejto

Dr. Marc A. Zissman

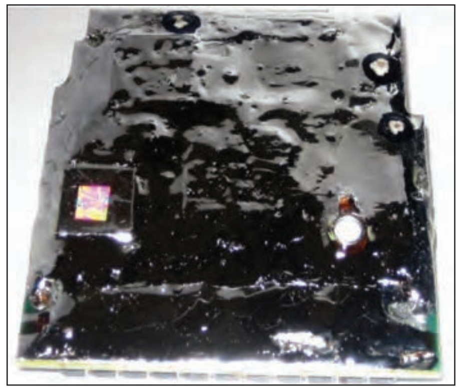
Mr. David R. Martinez

Lincoln Laboratory conducts research, development, evaluation, and deployment of prototype components and systems designed to improve the security of computer networks, hosts, and applications. Efforts include cyber analysis; creation and demonstration of architectures that can operate through cyber attacks; development of prototypes that demonstrate the practicality and value of new techniques for cryptography, automated threat analysis, anti-tamper systems, and malicious code detection; and, where appropriate, deployment of prototype technology to national-level exercises and operations. To complement this work, advanced hardware, software, and algorithm technologies are developed for processing large, high-dimensional datasets from a wide range of sources. In the human language technology area, emphasis is placed on realistic data and experimental evaluation of techniques for speech recognition, dialect identification, speech and audio signal enhancement, and machine translation.

Photo: T. Marius © 2013

A student from the Defense Language Institute Foreign Language Center is using Lincoln Laboratory's pronunciation assessment tool (NetProF) to improve her Arabic speaking skills.

In the coming year, the Cyber Systems and Operations Group will be working on systems for command and control of the cyber domain and will continue to transition these capabilities to the user community.



The Laboratory developed a technology that protects stored information without standby power. The technology is based on a physical unclonable function made of a planar optical waveguide coating, shown on the printed circuit board above. The physical unclonable function forms a unique "fingerprint" that can only be read from inside the coating. Attempts to read the information from outside alter the structure, destroying the stored information. Providing such a response without constant standby power simplifies logistics and reduces costs.

Principal 2013 Accomplishments

- A novel approach for measuring network security by using continuous monitoring techniques was developed. The methods will become the basis for Federal Information Security Management Act security guidelines.

- The Lincoln Open Cryptographic Key Management Architecture (LOCKMA) software implementation won a 2012 R&D 100 Award, and the stand-alone crypto processor implementation, known as SHAMROCK, won an award for one of the best Laboratory inventions in 2012.

- A team of researchers participated in two large Combatant Command military exercises and delivered two novel cyber situational awareness tools into cyber operational cells.

- The Laboratory assisted in the modernization of the U.S. Air Force Air Operations Center by developing and assessing a proof-of-concept integrated air and missile defense planner.

- The Lincoln Adaptable Real-time Information Assurance Testbed (LARIAT) supported several national cyber exercises, including Cyber Flag, Red Flag, and Terminal Fury.

- Lincoln Laboratory developed a new system that applies speech recognition technology to aid foreign language learners in developing their pronunciation skills; the initial system, which addresses Arabic pronunciation, has been delivered to the Defense Language Institute Foreign Language Center (DLIFLC), and is being pilot-tested by DLIFLC students and faculty.

- A study of cyber ranges was expanded to support the Test Resources Management Center. The study defined national needs, architectures, and standards for interoperability for all Department of Defense cyber ranges.

- New techniques were developed for characterizing, analyzing, and searching large datasets; these techniques employ content graphs based on speaker and topic similarity metrics.

- The Laboratory made significant progress in developing background models for social interaction networks and demonstrated the applicability of statistical graph analytics on a variety of datasets, including structured and unstructured reports, cyber security log files, and geointelligence.

- A novel synchronous computer architecture that takes advantage of on-chip silicon photonics inter-networking was developed.

- A suite of shared cloud computing technologies was demonstrated; it included the simultaneous launch and execution of a virtual machine, database, and data analytics.

Future Outlook

- Lincoln Laboratory will continue developing novel analytics, visualizations, and systems for cognition and control of the cyber domain, and will continue to work with operational communities to transition these capabilities.

- Research and development efforts will continue to enable the U.S. government to effectively protect its data and services for strategic and tactical use, to develop effective cyber decision support, and to enable efficient use of government and commercial resources.

- Lincoln Laboratory will strengthen its position as the leader in cyber range capabilities and in the performance of tests and evaluations for research systems. The Laboratory expects to have national impact across core areas: red teaming, system protection, range infrastructure, and test and evaluation.

- The Laboratory will extend its work on machine translation and document analysis to enable effective cross-language search and information retrieval from foreign language documents by analysts operating in English.

- Several new high-performance computing clusters will enable a capability for rapidly prototyping a wide array of data analytics and simulations across the technical areas. Researchers will also be demonstrating statistical graph analytics on more varied datasets and at greater scales that will impact the way intelligence fusion is conducted.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Leadership


Dr. Robert T-I. Shin

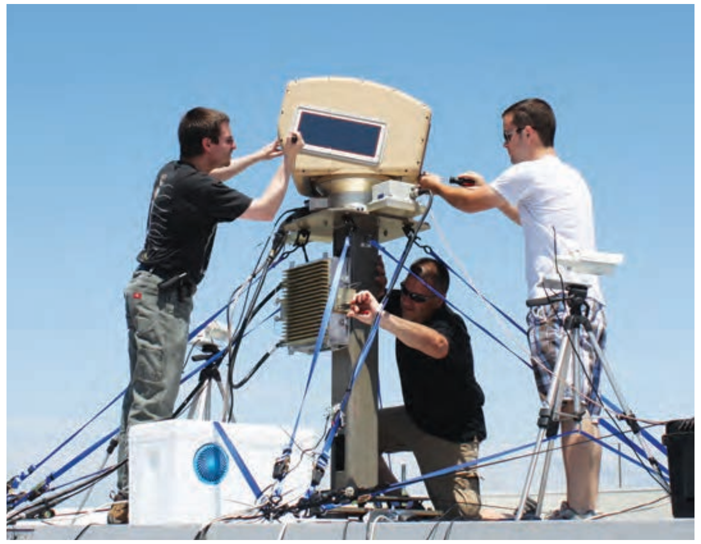

Mr. Robert A. Bond

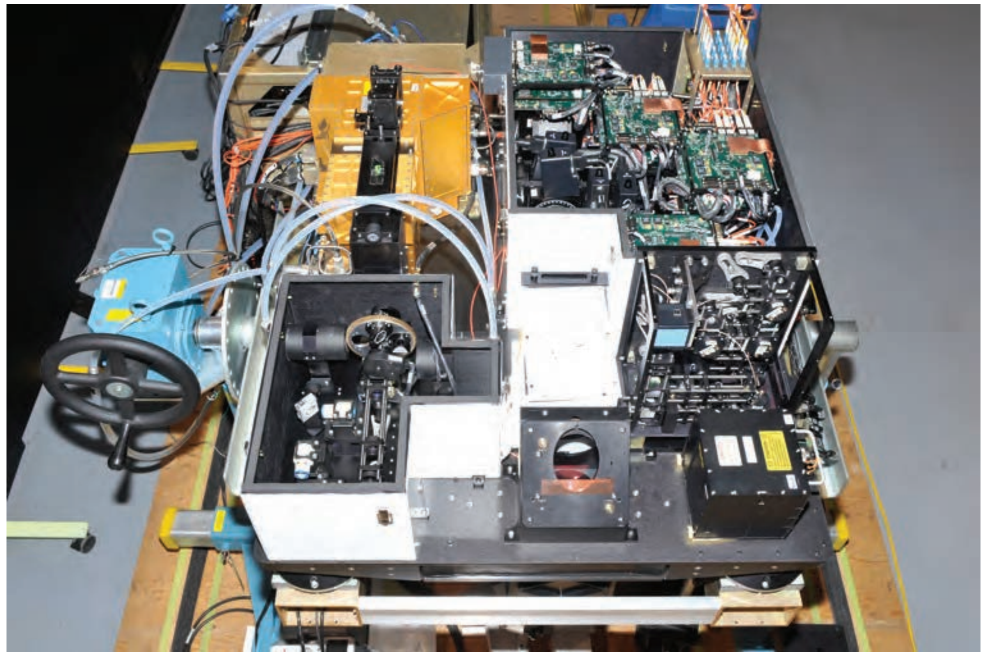

Dr. Justin J. Brooke


Dr. Melissa G. Choi


Dr. William D. Ross

To expand intelligence, surveillance, and reconnaissance (ISR) capabilities, Lincoln Laboratory conducts research and development in advanced sensing, signal and image processing, automatic target classification, decision support systems, and high-performance computing. By leveraging these disciplines, the Laboratory produces novel ISR system concepts for both surface and undersea applications. Sensor technology for ISR includes passive and active electro-optical systems, surface surveillance radar, radio-frequency (RF) geolocation, and undersea acoustic surveillance. Increasingly, the work extends from sensors and sensor platforms to include the processing, exploitation, and dissemination technologies that transform sensor data into the information and situational awareness needed by operational users. Prototype ISR systems developed from successful concepts are then transitioned to industry and the user community.


Laboratory staff installed the Wide-Area Infrared System for 360° Persistent Surveillance (WISP-360) on the deck of a ship in preparation for system testing. Shawn Adams, Edwin LeFave, and Matthew Karas were part of the team that helped demonstrate the system capability for maritime situational awareness.


The Laboratory is leveraging the success of the Airborne Ladar Imaging Research Testbed system to develop a 3D imaging ladar system for the U.S. Southern Command to uncover clandestine activity in heavily foliated areas. The system's high area collection rates are enabled by quad 64 × 256 Geiger-mode avalanche photodiode arrays. The system is being integrated onto an aircraft for transition to operation in 2014. The Lincoln Laboratory–developed ground processing station will employ sophisticated algorithms to facilitate timely exploitation of imagery.

Principal 2013 Accomplishments

- The Laboratory developed three wide-area, motion imaging systems for visible and infrared persistent surveillance that are now operating in deployed situations. The Wide-Area Infrared System for 360° Persistent Surveillance (WISP-360) is an infrared, ground-based sensor that is integrated with existing tower-based surveillance systems. The Multi-Aperture Sparse Imager Video System (MASIVS), an 880-megapixel, color, airborne sensor, was deployed for collection of wide-area motion imagery. The Imaging System for Immersive Surveillance (ISIS), a 240-megapixel, color, optical sensor, was deployed for critical infrastructure protection.
- The Laboratory's Airborne Ladar Imaging Research Testbed (ALIRT) system completed its 500th flight in support of overseas operations. This system has proven to be very valuable to U.S. ground operations. Also, a new 3D ladar for the U.S. Southern Command is nearing completion. The ladar is optimized for detection and characterization of structures under foliage cover, provides enhanced area coverage, and can help to distinguish natural from man-made targets.
- Radar processing techniques were developed to improve detection of small land and maritime targets. Several of these techniques were selected for transition into operational systems and systems under development.
- A Laboratory-developed ultrahigh-data-rate multiple-input multiple-output (MIMO) system sets new standards for non-line-of-sight, low-power communication links and enables efficient data exchange among ground-based ISR systems. Several prototypes were delivered to sponsors for operational testing.
- Automation techniques were developed to reduce operator workload for distributed maritime surveillance systems. The Laboratory also developed and optimized sonar technology employed by autonomous undersea vehicles in antisubmarine warfare. The sonar signal processing provides computationally efficient target detection and classification, and was selected for inclusion into other Navy distributed surveillance systems.
- The Laboratory supported the development of the Air Force's new Dismount Detection Radar, which will provide wide-area persistent ground moving target indication (GMTI) for vehicles and dismounted personnel. This pod-based radar was designed to be integrated and fielded on an MQ-9 unmanned air vehicle. The Laboratory is incorporating advanced dismount signal processing modes into the contractor-developed system to provide warfighter capability and to verify the open architecture design.
- For automated exploitation of GMTI radar data, the Laboratory's Pyxis software was operationally deployed. Pyxis enhances detection of subtle activity patterns, supporting real-time cross-cueing of other assets. The Laboratory also delivered cloud-based software analytics for analyzing massive unstructured intelligence datasets. These tools have proven effective at automated data mining and analysis, and were deployed to multiple government agencies.

Future Outlook

- Significant efforts supporting the Air Force with architecture engineering, systems analysis, technology development, and advanced capability prototyping are expected, but with increasing emphasis on security challenges in the Asia-Pacific region.
- Enhanced activities in electronic warfare and Navy maritime and undersea surveillance are expected as part of the national shift to security challenges in the Asia-Pacific region.
- Emphasis on ISR data exploitation will continue as new wide-area sensing capabilities are fielded. Research will focus on automation techniques to address the growing analyst workload, as well as on techniques for fusion and statistical inferencing with multisource sensor data and non-sensor data sources.
- The Laboratory will help the government develop, prototype, and employ open-system architecture paradigms for sensors, avionics payloads, unmanned system ground control stations, and future common ground systems for data exploitation.
- Enhanced activity in airborne RF geolocation systems will evolve in response to the evolution of commercial computing and networked communications technology.
- Laser-based sensing will expand into new applications as the technology for optical waveforms and coherent laser-based sensing improves.

Tactical Systems

Leadership


Dr. Robert T-I. Shin


Dr. Justin J. Brooke


Dr. Melissa G. Choi


Dr. Kevin P. Cohen


Dr. Marc N. Viera

Lincoln Laboratory assists the Department of Defense (DoD) in improving the development and employment of various tactical air and counterterrorism systems through a range of activities that include systems analysis to assess technology impact on operationally relevant scenarios, detailed and realistic instrumented tests, and rapid prototype development of U.S. and representative threat systems. A tight coupling between the Laboratory's efforts and DoD sponsors and warfighters ensures that these analyses and prototype systems are relevant and beneficial to the warfighter.


The dual-band, pod-mounted sensor developed for the Airborne Seeker Test Bed is used for airborne infrared imaging and data collection.


Lincoln Laboratory is developing new technology for conducting military missions with ground-penetrating radar. A prototype system is shown integrated on an Army Husky vehicle for combat evaluation.

Principal 2013 Accomplishments

- Lincoln Laboratory continues to provide a comprehensive assessment of options for U.S. Air Force airborne electronic attack against foreign surveillance, target acquisition, and fire-control radars. This assessment includes systems analysis of proposed options, development of detailed models of threat radars and their electronic protection systems, and testing of various electronic attack systems.

- The Laboratory developed a common open-systems architecture to upgrade legacy systems and to allow evaluation of foreign air defense threats. The architecture has been applied to upgrade older surveillance and target-acquisition radars to include advanced signal processing and electronic protection, as well as instrumentation to support high-speed data recording and analysis capabilities.

- Assessments of the impact of exporting advanced military systems were performed for the Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics and Congress to help inform the decision-making process for major export programs.

- The Laboratory continued a detailed analysis of the impact of digital radio-frequency memory-based electronic attack on air-to-air weapon system performance. Results from flight testing, systems analysis, and hardware-in-the-loop laboratories have been used to improve U.S. electronic protection systems and to inform senior DoD leadership's decision-making process for future system capabilities and technology investments.

- An assessment of the capabilities and limitations of infrared sensors and seekers to support beyond-visual-range passive air-to-air engagements included systems analysis, development of detailed models of infrared search and track systems and imaging infrared missile seekers, and both laboratory and captive-carry testing of various surrogate systems.

- The Laboratory is developing advanced architectures and technologies for use in next-generation counter-improvised explosive device (IED) electronic attack systems. Activities this year culminated in a field demonstration of a significantly advanced capability intended for use in future Counter Radio-Controlled IED Electronic Warfare (CREW) systems.

- Development is continuing on a number of significant U.S. Air Force quick-reaction capabilities designed to field prototypes of critical new intelligence, surveillance, and reconnaissance technology supporting counterterrorism missions. These efforts leverage existing Air Force MQ-9 unmanned aerial vehicle assets and provide pod-based sensors and additional processing, exploitation, and dissemination capabilities. An initial set of prototype pods has been completed, integrated on MQ-9 aircraft, and designated for transition.

Future Outlook

- Lincoln Laboratory will continue to develop, assess, and demonstrate innovative concepts for enhancing the survivability of U.S. air vehicles. Advanced technology will enable novel countermeasure, sensor, and system architecture solutions. Assessments and concept demonstrations will support new capability development and future technology road maps.

- Under several new programs, the Laboratory will provide innovative and novel concepts and prototype systems for countering terrorism. Increased emphasis will be on enduring global protection challenges as the Afghanistan drawdown continues.

- The Laboratory will support the U.S. Air Force tactical community through systems analysis, advanced capability prototyping, and measurement campaigns. These efforts will address a broad spectrum of needs, particularly the evolving security challenges in the Pacific region.

- Growth is expected in the Laboratory's electronic warfare contributions to the DoD community, predominantly in the areas of electronic protection for tactical aircraft and ground vehicles, and electronic support measures for airborne signals intelligence (SIGINT) capabilities.

- The Laboratory will continue to develop and deploy novel quick-reaction prototype capabilities for the U.S. Air Force and Army.

Advanced Technology

Leadership

Dr. Robert G. Atkins

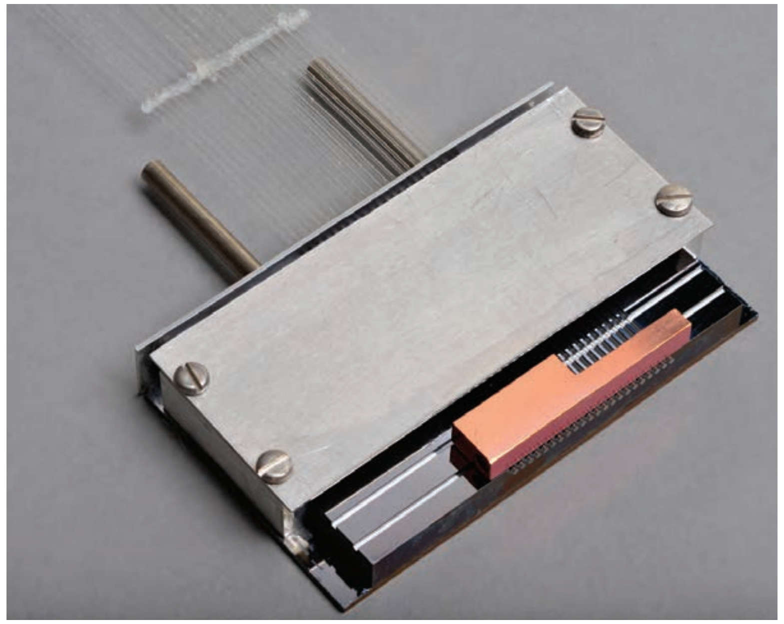
Dr. Craig L. Keast

Dr. Simon Verghese

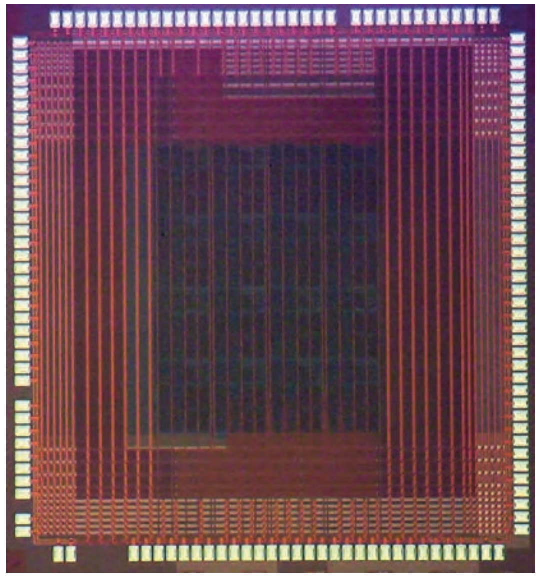
Dr. Barry E. Burke

The Advanced Technology mission supports national security by identifying new phenomenology that can be exploited in novel system applications and by then developing revolutionary advances in subsystem and component technologies that enable key, new system capabilities. These goals are accomplished by a community of dedicated employees with deep technical expertise, collectively knowledgeable across a wide range of relevant disciplines and working in unique, world-class facilities. This highly multidisciplinary work leverages solid-state electronic and electro-optical technologies, innovative chemistry, materials science, advanced radio-frequency (RF) technology, and quantum information science.

This Ku-band airborne sense-and-avoid radar, shown during installation on a Twin Otter aircraft, has separate transmit and receive apertures. The radar electronically performs a two-dimensional scan every 2 seconds and can search a 10 nmi area to locate a target as small as 10 dBsm.



In this high-energy laser fiber array, the spacing between elements is 1.5 mm.



The subthreshold field-programmable gate array test chip demonstrated a record low programming voltage (0.26V) by replacing static random-access memory with latches.

Principal 2013 Accomplishments

- A novel technique with the potential for highly sensitive remote detection of trace vapors and/or aerosols was demonstrated for the first time.
- A significant milestone in the combining of fiber lasers was recently reached with the demonstration of record power with high beam quality and electrical efficiency.
- An engineering development unit version of the Rapid Agent Aerosol Detector (RAAD) was completed. RAAD provides an upgrade to the Joint Biological Point Detection System, enabling bioaerosol triggering at lower false trigger rates and providing better maintainability than current state-of-the-art bioaerosol triggers.
- A record optical power of 50 W in a diffraction-limited beam was achieved by coherently combining a 47-element array of 1.06 µm wavelength slab-coupled optical waveguide (SCOW) amplifiers. The Laboratory also collaborated with Science Research Laboratory to demonstrate over 200 W continuous power (uncombined) from 100-element dense SCOW laser arrays for use as high-brightness fiber-laser pumps.
- The RF Enhanced Digital System on Chip (REDSOC) effort has developed a fully integrated system-on-chip design and submitted that design for fabrication at a silicon foundry. The design achieves record receiver performance in a very small size, weight, and power.
- Record coherence times were achieved in two-dimensional and three-dimensional transmon superconducting qubits for quantum computing applications. These devices used larger mode volumes and epitaxial materials to achieve these results.
- An additional curved focal surface, consisting of back-illuminated charge-coupled-device (CCD) imagers, is being prepared for use by the Space Surveillance Telescope program, developed by the Defense Advanced Research Projects Agency.
- The Laboratory has applied the ultralow-power (ULP) complementary metal-oxide semiconductor (CMOS) technology to a ULP field-programmable gate array (FPGA). A small-scale demonstration FPGA is currently being fabricated in the Microelectronics Laboratory, and a larger array is being designed for fabrication in 2014.
- In the area of heterogeneous integration of electronic-photonic components, the Laboratory, in collaboration with MIT campus, has completed the design of silicon photonic components and electronic circuits that will be three-dimensionally integrated via oxide bonding.

Future Outlook

- A need to perform worldwide monitoring will grow, motivating the development of new sensor capabilities in a variety of areas, including ladar, passive imaging, and radar.
- Growing emphasis in defending the global commons (Earth's collective natural environment and shared services) will require advanced capabilities designed for contested environments, prompting component developments in RF electronics, lasers, imagers, computation, and microsystems.
- Continuing concerns with irregular warfare will motivate the scaling of sensor capabilities to a more distributed battlefield, allowing advanced sensing at lower echelons.
- The increasing importance of sensing chemical, radiological, and explosive threats will heighten the demand for new systems capable of detecting these threats.
- Highly scaled computation systems will be needed to exploit large datasets acquired from new sensing modalities; this need will drive the exploration into low-power computing approaches.
- The proliferation of autonomous systems will compel the development of additional capabilities for vision, navigation, power, and communications.

Homeland Protection

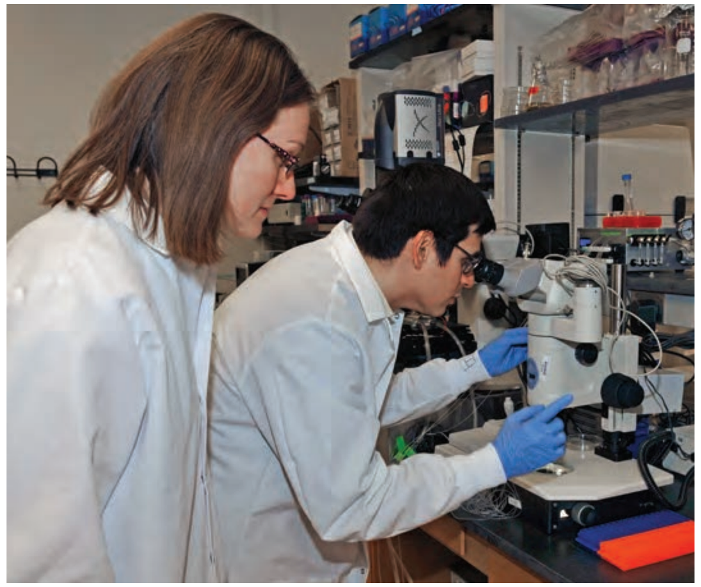
Leadership


Dr. Israel Soibelman


Mr. James M. Flavin

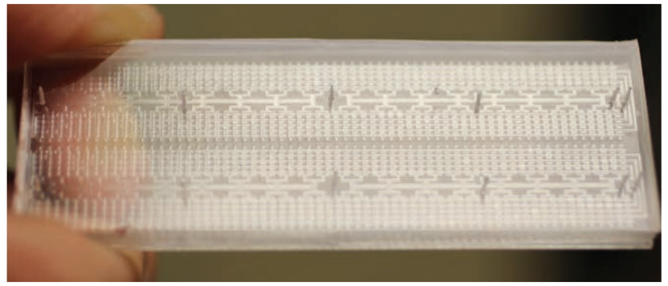

Dr. Timothy J. Dasey

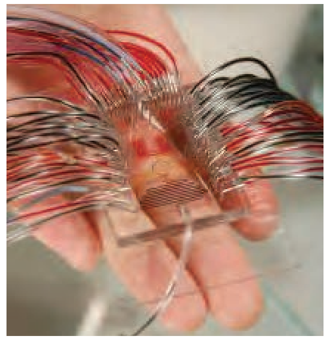
The Homeland Protection mission supports the nation's security by innovating technology and architectures to help prevent terrorist attacks within the United States, to reduce the vulnerability of the nation to terrorism, to minimize the damage from terrorist attacks, and to facilitate recovery from either man-made or natural disasters. The broad sponsorship for this mission area spans the Department of Defense, the Department of Homeland Security (DHS), and other federal, state, and local entities. Recent efforts include architecture studies for the defense of civilians and facilities, new microfluidic technologies for DNA assembly and transformation and for gene synthesis, improvement of the Enhanced Regional Situation Awareness system for the National Capital Region, the assessment of technologies for border and maritime security, and the development of architectures and systems for disaster response.



Dr. Carlos Aguilar (right) and Tara Boettcher of the Bioengineering Systems and Technologies Group examine a microfluidic integrated nanopore device (MIND) designed to measure chromatin modifications on single molecules.

Researchers are using the systems in the Bioengineering Systems and Technologies Group's newly created Biomedical Speech and Hearing and Neurocognitive Laboratory.





The Laboratory's biomedical sciences research includes enabling revolutionary, portable biomedical systems through the advancement of microfluidic devices. For example, the second-generation advanced Microfluidic Gene Assembler chips (above) now integrate 256 high-throughput microbiochemical reactors—a significant advancement beyond the first-generation devices (left) that prototyped single microbiochemical reactors.

Principal 2013 Accomplishments

- The Next-Generation Incident Command System (NICS), developed in partnership with the California Department of Forestry and Fire Protection (CAL FIRE), is being deployed statewide by CAL FIRE and operationally evaluated by first responders from multiple state emergency management agencies and the Fire Department of New York.
- The Laboratory continues to lead technology development and architectures for countering chemical threats and weapons of mass destruction. Accomplishments include threat phenomenology measurements, gap and technology analysis, and design and testing of new capabilities for warfighters and the homeland.
- The Laboratory is working with the U.S. Army Research Institute of Environmental Medicine to develop advanced physiological monitoring sensors, signal processing algorithms, and open architectures that will reduce heat casualties, noise-induced hearing loss, and musculoskeletal load injuries among service members.
- Advanced video analytics technology is being developed for a variety of applications, including crowded domains such as transportation centers and sparsely populated scenes such as at border regions. Emphases include attribute video-content search, detection and tracking across large camera arrays, and summarization tools.
- The Laboratory is developing serious game capabilities to engage end-users in exploring emerging decision support technologies and to enhance experiential learning for decision makers. Game applications areas include law enforcement, public health, and disaster response.
- The Imaging System for Immersive Surveillance (ISIS) consists of a custom 240 Mpixel sensor and automated video-exploitation algorithms for ground-based surveillance supporting critical infrastructure protection. Sponsored by the DHS Science and Technology Directorate (DHS S&T), ISIS is undergoing operational testing in multiple venues.
- The Laboratory is developing advanced incident-response capabilities for the U.S. Coast Guard, and is informing acquisition strategies through assessments for search and rescue, port security, cargo-vessel targeting, and environmental protection missions.
- The Laboratory is providing assessment support to the DHS S&T Homeland Security Advanced Research Projects Agency. Activities are focused on informing technology investment directions and strategies. These efforts span a broad range of missions, with key examples in border security technologies.
- A Grand Challenge being led by Lincoln Laboratory for the Defense Threat Reduction Agency is focused on metagenomic algorithms to rapidly and accurately characterize DNA sequence information that is mixed within complex clinical and environmental samples.

Future Outlook

- National needs for improved critical infrastructure protection, cyber security, and urgent incident and disaster response will prompt advanced information-sharing architectures, decision support algorithms, and data-visualization techniques for the homeland security enterprise. Solutions will leverage Lincoln Laboratory's strengths in systems analysis, open system architecture, and advanced sensors.
- The Laboratory will continue to lead the development, analysis, and testing of advanced architectures for chemical and biological defense, including biometrics and forensic technologies for theater and homeland protection. Key areas include sensors, rapid DNA sequencing and identification techniques, and data-fusion algorithms.
- The Laboratory is applying its strengths in sensors and signal processing to address the Department of Defense's biomedical research goals of protecting the health and performance of soldiers in both training and operational environments. Strong contributions toward these objectives are expected in synthetic biology, miniaturized sensors for physiological monitoring, microfluidics, biomedical sensing, and analysis.
- Securing and defending U.S. borders will motivate studies to define an integrated air, land, and maritime architecture and will spur advanced sensor, data fusion, and decision support technology development.

Air Traffic Control

Leadership

Dr. Mark E. Weber

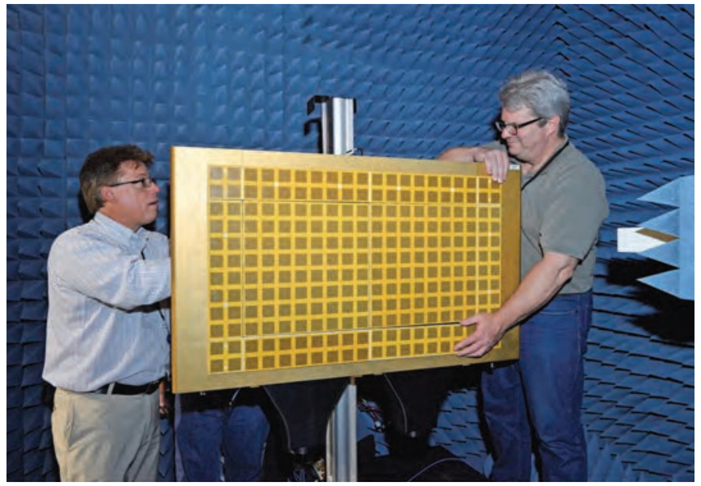
Mr. James M. Flavin

Dr. James K. Kuchar

Dr. Gregg A. Shoults

Dr. Marilyn M. Wolfson

Since 1971, Lincoln Laboratory has supported the Federal Aviation Administration (FAA) in the development of new technology for air traffic control. This work initially focused on aircraft surveillance and weather sensing, collision avoidance, and air-ground data link communication. The program has evolved to include safety applications, decision support services, and air traffic management automation tools. The current program is supporting the FAA's Next Generation Air Transportation System (NextGen). Key activities include development of the next-generation airborne collision avoidance system; refinement and technology transfer of NextGen weather architectures, including cloud-processing and net-centric data distribution; and development of standards and technology supporting unmanned aerial systems' integration into civil airspace.



In 2013, Lincoln Laboratory is continuing the development and extension of its 64-element Multifunction Phased Array Radar prototype, building toward a 10-panel demonstration array.

The team seen here flight-tested the unmanned air vehicle sense-and-avoid radar prototype developed under sponsorship of the Department of Homeland Security.

Principal 2013 Accomplishments

- System performance studies and hardware development were conducted for the Multifunction Phased Array Radar (MPAR) to mitigate risks associated with cost, siting, frequency interference, and hazardous wind-shear detection capability. The program is constructing a 10-panel demonstration array to quantify performance parameters and to collect field data for signal processing and calibration technique refinement.

- Lincoln Laboratory continued to support the technology transfer of the Route Availability Planning Tool (RAPT), currently operational in New York and Chicago, to deployment in Philadelphia and the Potomac region. RAPT is also being extended to include departure demand information and to aid in arrival route management in the presence of convective weather.

- The Laboratory supported flight tests, human-in-the-loop simulations, and fast-time computer modeling of advanced Flight Management Systems on aircraft performing NextGen trajectory-based operations. Results from these activities are being used to develop requirements for automation systems and winds-aloft forecasts that will enable aircraft to establish more efficient and robust arrival metering times and spacing intervals.

- The NextGen Weather Processor (NWP) consolidates multiple legacy FAA weather processing platforms and introduces new functionality, such as the 0–8 hr thunderstorm-forecasting technology developed by Lincoln Laboratory. The Laboratory is leading efforts to define requirements for NWP, to refine and test a reference technical architecture, and to provide technology exhibits for use by the FAA in requests for proposals from industry.

- The Laboratory is developing standards and requirements to provide safe unmanned aircraft system (UAS) sense-and-avoid (SAA) capability. Also under development are collision avoidance algorithms for ground-based and airborne SAA. The Laboratory supported the successful engineering demonstration of its algorithms in Army and Air Force ground-based architectures deployed to Dugway, Utah, and Gray Butte, California, respectively. The Laboratory's prototype lightweight, low-power, airborne radar for SAA was successfully flight-tested to collect data to refine sensing and algorithm requirements.

- Lincoln Laboratory continues to play a key role for the FAA in developing the NextGen airborne collision avoidance system, ACAS X, which will support new flight procedures and aircraft classes. Efforts in 2013 focused on tuning ACAS X to meet operational suitability and pilot acceptability performance metrics by lowering collision risk while producing fewer disruptive alerts than current systems.

Future Outlook

- Lincoln Laboratory will apply its expertise in surveillance processing, data management, algorithms, and human systems integration to increase its role in developing future NextGen concepts, including Automatic Dependent Surveillance–Broadcast applications, advanced data communications, and surface operations management.

- The Laboratory will continue requirements definition, prototyping, and technology transfer support for next-generation weather capabilities. These include improvements in sensing technology, decision support tools for managing arrivals into congested airports during severe weather, and algorithms for estimating the capacity reductions caused by thunderstorms in en route sectors.

- Support for FAA safety systems will continue. The Laboratory will monitor current Traffic Alert and Collision Avoidance System (TCAS) performance, and will perform flight tests and develop international standards for a next-generation airborne collision avoidance system (ACAS X) for manned aircraft. The FAA plans to flight test the unmanned aircraft variant of ACAS X in 2014.

- As a key contributor to the UAS community working with the FAA and RTCA, Inc., the Laboratory will help develop standards and requirements to fulfill UAS sense-and-avoid requirements. The Laboratory is working with the Army on the certification of an initial ground-based sense-and-avoid capability. Support to the Navy and Air Force efforts continues to be strong as those services develop an airborne sense-and-avoid capability for their UAS platforms.

Engineering

Leadership

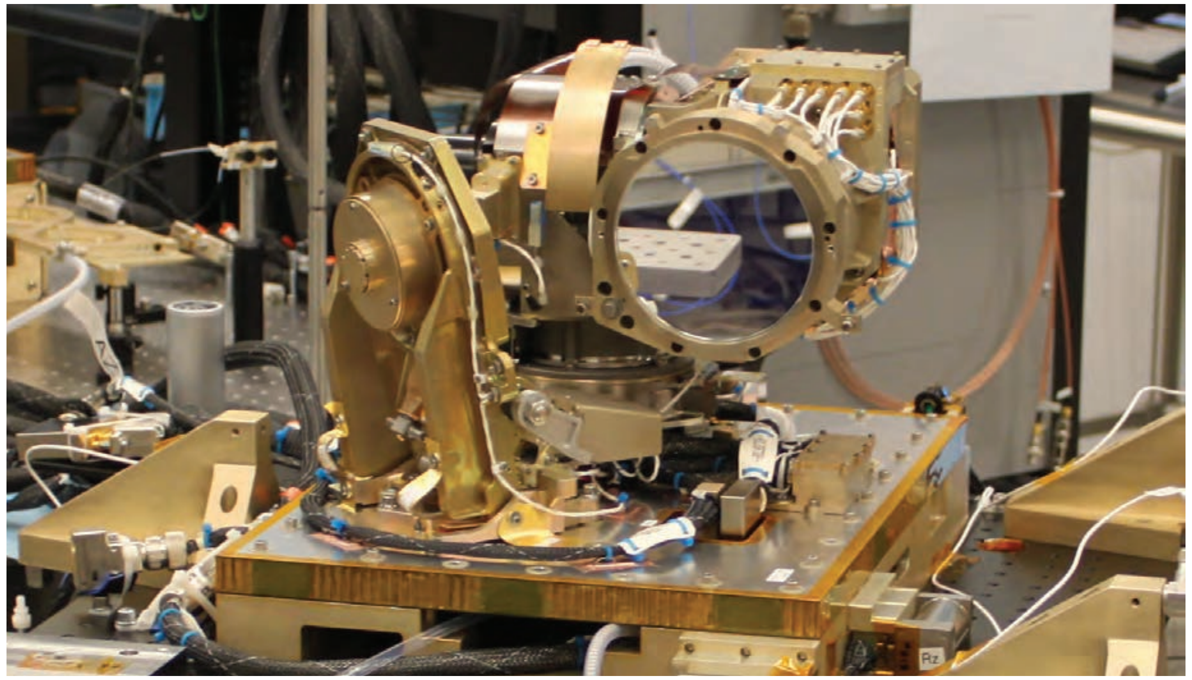

Dr. Eliahu H. Niewood


Dr. William R. Davis


Dr. Michael T. Languirand

Fundamental to the success of Lincoln Laboratory is the ability to build hardware systems incorporating advanced technology. These systems are used as platforms for testing new concepts, as prototypes for demonstrating new capabilities, and as operational systems for addressing warfighter needs. To construct the variety of systems used in programs across all mission areas, the Laboratory relies on its extensive capabilities in mechanical design and analysis, optical system design and analysis, aerodynamic analysis, mechanical fabrication, electronics design and assembly, control system development, system integration, and environmental testing. These capabilities are centered in the Laboratory's Engineering Division, which is an important contributor to many of the Laboratory's most successful efforts.

The Transiting Exoplanet Survey Satellite (TESS) system is composed of four optical sensors designed to map out the entire sky in the search for transiting exoplanets. Shown here is one of the prototype telescopes designed, built, and tested to support risk-mitigation efforts for the TESS project selected by NASA for a 2017 mission.



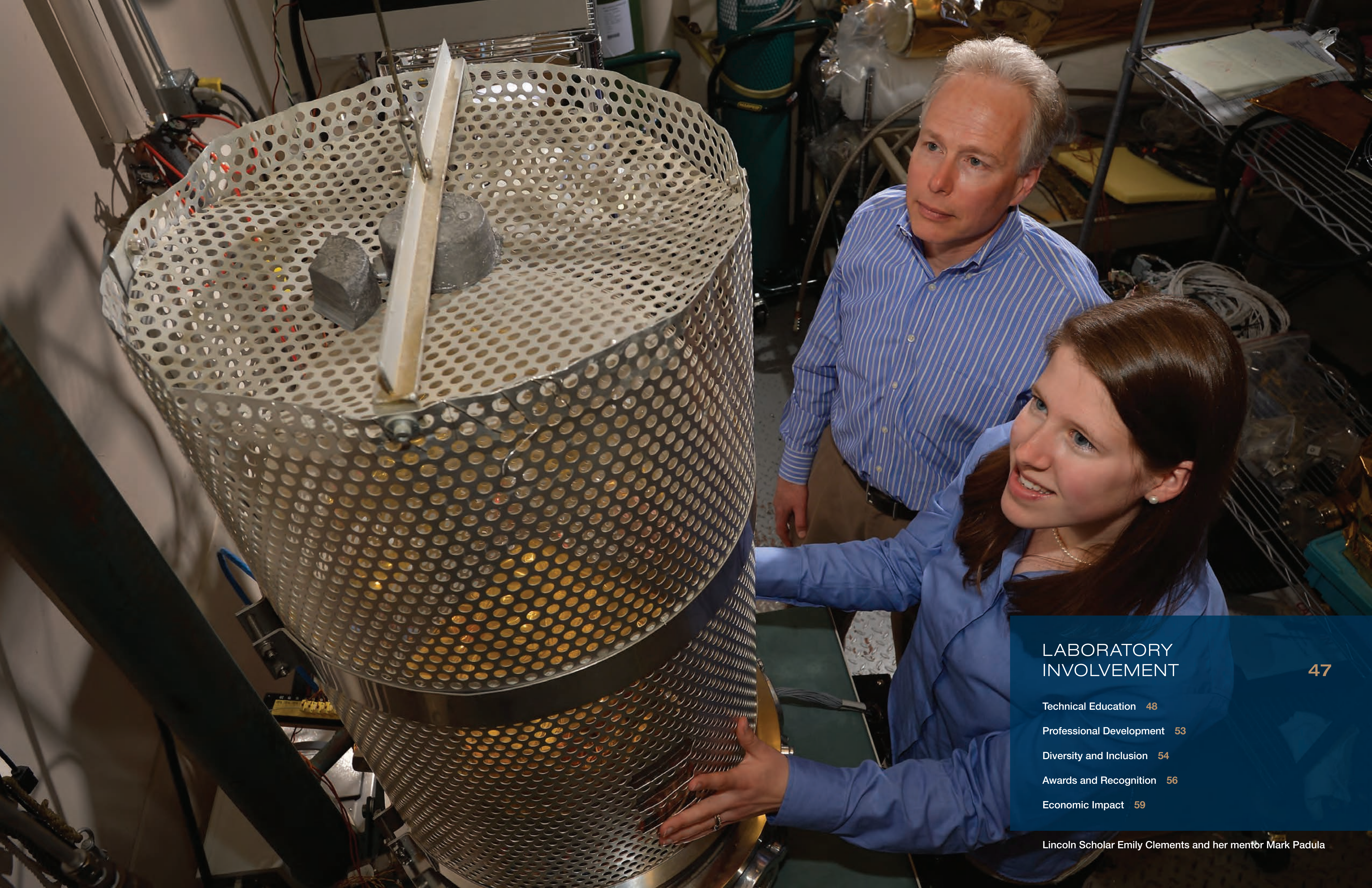
The optical module for the Lunar Laser Communication Demonstration was delivered to NASA for integration onto the spacecraft.

Principal 2013 Accomplishments

- Lincoln Laboratory's key contributions to a proposal for the Transiting Exoplanet Survey Satellite (TESS) included the design, fabrication, and testing of a prototype telescope for the satellite. Successful demonstration of the telescope design was a major risk factor for the system. The proposal presented by the MIT Kavli Institute for Astrophysics and Space Research was accepted by the National Aeronautics and Space Administration (NASA). (See page 19 for more on TESS.)
- The Laboratory continued to invest in cutting-edge fabrication and electronic assembly technologies, including sinker electrical discharge machining technology and a robotic conformal coat system for printed circuit boards.
- All three modules for the Lunar Laser Communication Demonstration completed fabrication, integration, and environment testing and were shipped to NASA Ames Research Center for integration on the Lunar Atmosphere and Dust Environment Explorer spacecraft. (See page 20 for more on this program.)
- The Laboratory continued to support efforts by the MIT Aeronautics and Astronautics Department to design, build, and test the cubesat bus for the Micro-sized Microwave Atmospheric Satellite.
- New laboratories for optical system testing and development of autonomous systems were designed and built to allow those technology areas to continue to grow within the engineering mission area.
- Modifications were completed to the hydrostatic azimuth bearing of the Haystack Ultrawideband Satellite Imaging Radar to allow the program to move forward with control system testing and initial X-band operation. Alignment of the antenna surface was successfully demonstrated at the levels needed for W-band operation.
- An engineering development unit for the Rapid Agent Aerosol Detector system was fabricated and assembled for use in a variety of validation tests that will lead to technology transfer of the system design and eventual high-rate production by industry.
- The second annual Mechanical Engineering Technology Symposium was held with sessions focusing on advanced materials, integrated engineering analysis, additive manufacturing, and thermal engineering. Laboratory presentations described work, performed under the engineering technology initiative, on topics such as shock analysis and testing, titanium fatigue strength, and solder properties.

Future Outlook

- Lincoln Laboratory is developing a strategic plan and making initial investments for its development of an ability to design and test a variety of small satellite systems, including cubesats. Efforts are ongoing to identify applicable missions and designs to meet those mission needs.
- Plans continue for a new engineering and prototyping facility. In the near future, the Laboratory will concentrate on a detailed design of the building.
- The Laboratory is making investments in technology for the in-house fabrication of several optical components in ways that will facilitate the rapid prototyping of optical systems and the development of more compact, novel designs for aircraft and other payloads. The initial focus will be on the innovative use of diamond-turning technology.



LABORATORY INVOLVEMENT

Lincoln Scholar Emily Clements and her mentor Mark Padula

Technical Education

Lincoln Laboratory invests in developing and sharing the knowledge that will drive future technological advances and inform the next generation of engineers.

EDUCATIONAL COLLABORATIONS WITH MIT

MIT Professional Education—Short Programs

Lincoln Laboratory collaborates with MIT faculty to offer courses through MIT's Professional Education Short Programs. Short Programs typically run during the summer and bring participants from industry, government, and business to the campus for intensive, week-long courses designed to expand participants' familiarity with emerging technologies.

2013 Lincoln Laboratory-Led Short Programs

- Build a Small Phased Array Radar Sensor
- Build a Small Radar System
- Build a Laser Radar: Design Principles, Technologies, and Applications
- Rapid Robotics: Autonomous Systems with Open-Source Software
- Build a Multichannel Search-and-Track Radar

MIT VI-A Master of Engineering Thesis Program

One MIT student in the VI-A Master of Engineering Thesis Program was hired in summer 2013, and four VI-A students are continuing, to work with Laboratory mentors while gaining experience in testing, design, development, research, and programming. Students in the VI-A program spend two summers as paid interns, participating in projects related to their fields. Then, the students are paid as research assistants while developing their master of engineering theses under the supervision of both Laboratory engineers and MIT faculty.

Research Assistantships

Lincoln Laboratory is currently employing 42 research assistants from MIT. Working with engineers and scientists, these assistants contribute to sponsor programs while investigating the questions that evolve into their doctoral theses. The facilities, the research thrusts, and the reputations of staff members are prime inducements behind the graduate students' decision to spend three to five years as a research assistant in a Laboratory group.

Under MIT's Undergraduate Research Opportunities Program, Colleen Rock (in foreground), a senior in the Department of Electrical Engineering and Computer Science, interned in the Active Optical Systems Group during summer 2013. She worked with technical staff members Peter Cho (in background) and Michael Yee (not pictured) on a system that organizes large imagery collections. The Image Search System enables users to explore the global structure of digital picture archives as well as drill-down into individual photos of interest.

Undergraduate Research Opportunities Program

In 2013, seven undergraduates were hired in the summer as part of the MIT Undergraduate Research Opportunities Program (UROP), which allows students to participate in every aspect of onsite research—developing research proposals, performing experiments, analyzing data, and presenting research results.

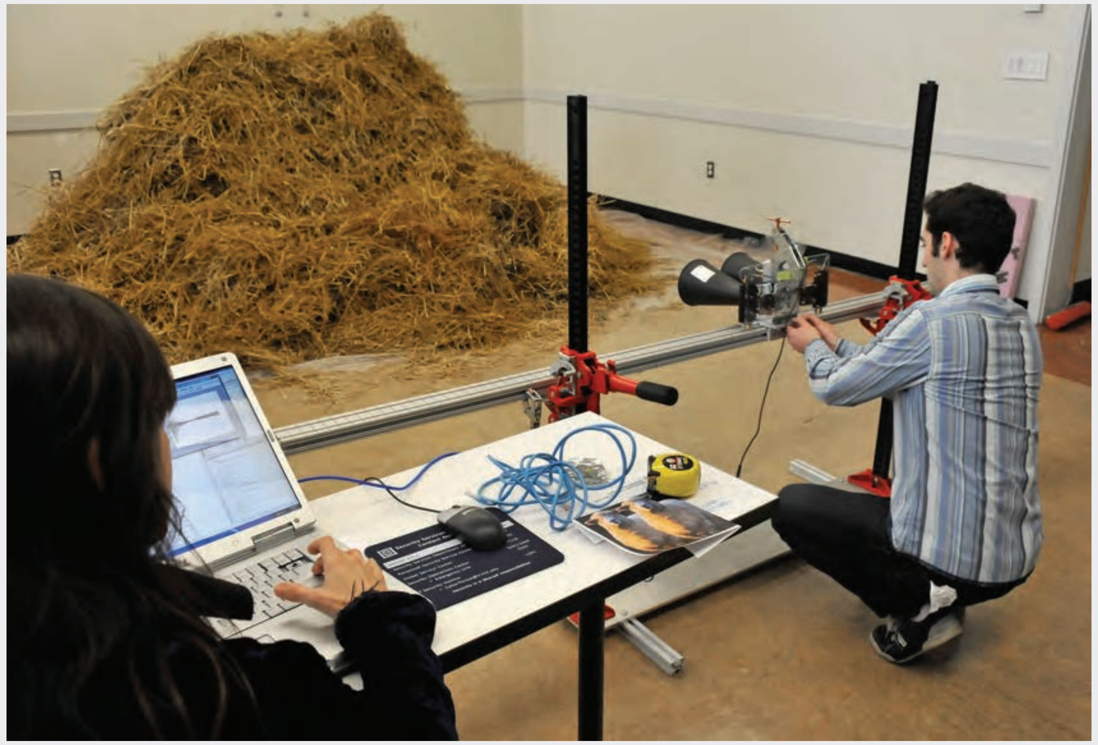
Undergraduate Practice Opportunities Program

Lincoln Laboratory participates in the Undergraduate Practice Opportunities Program (UPOP). This full-year program for MIT sophomores is an introduction to the workplace skills that students will need to thrive in their future careers. An important facet of the program is a 10- to 12-week summer internship. In summer 2013, four UPOP students worked at the Laboratory.

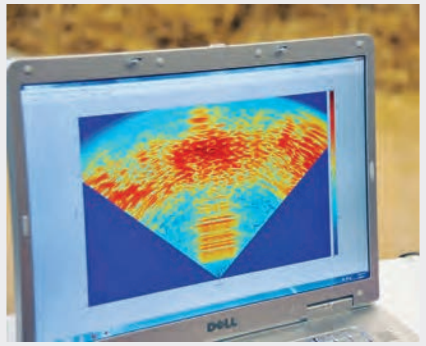
SPOTLIGHT

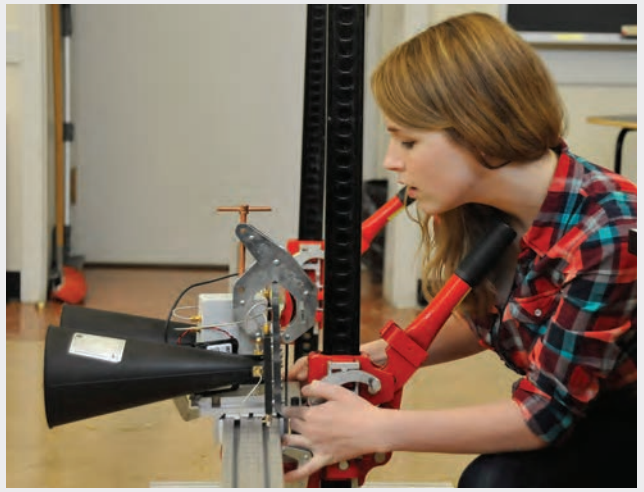
Independent Activities Period at MIT

Lincoln Laboratory technical staff again led activities offered during MIT's Independent Activity Period (IAP), a four-week term spanning the January semester break. Under the IAP program, for-credit classes are available for registered MIT students, and non-credit activities are open to all members of the MIT community. IAP offerings range from academic seminars to hands-on engineering projects to artistic pursuits. The activities are, as the IAP website states, "distinguished by their variety, innovative spirit, and fusion of fun and learning."



A new IAP course proffered a challenge: Find a Needle in a Haystack with 3D Imaging Radar. Participants set up an ultrawideband imaging radar that they used to image a haystack in which needles, skewered into Styrofoam balls, had been hidden. The onscreen image of the haystack (below) reveals the location of needles buried inside the hay. This two-day workshop built upon techniques covered in the other two radar-building IAP courses led by Lincoln Laboratory technical staff.





During the 2013 IAP, Lincoln Laboratory staff members organized and led six non-credit activities:

- *Find a Needle in a Haystack with 3D Imaging Radar* — Led by Bradley Perry, Alan Fenn, Raoul Ouedraogo, Glenn Brigham, Joseph McMichael, Daniel Rabinkin, and Gerald Benitz
- *3D Manipulation of 2D Images* — Led by Peter Cho
- *Hands-on Holography* — Led by Robert Freking, Christy Cull, and Evan Cull
- *Open Robotics Laboratory* — Led by Michael Boulet, Aaron Enes, Keith Ruenheck, Nicholas Armstrong-Crews, Kenneth Cole, Michael Carroll, and Mark Donahue
- *Build a Small Phased Array Radar System* — Led by Bradley Perry, Todd Levy, Patrick Bell, and Jeffrey Herd
- *Build a Small Radar System* — Led by Patrick Bell, Shakti Davis, Alan Fenn, and Bradley Perry

>> *Technical Education, cont.*

In August, students in the MIT Interphase Edge program spent a day at Lincoln Laboratory learning about the options and demands in engineering careers.

Interphase EDGE

In August 2013, Lincoln Laboratory welcomed 47 students from the MIT Office of Minority Education's Interphase EDGE program to a day of tours and presentations. Interphase EDGE (for Empowering Discovery/Gateway to Excellence) is a two-year program designed to help MIT students, primarily from underrepresented minorities, improve the analytical and communications skills needed for success in a rigorous academic environment. In the summer before their freshman year, EDGE students attend a seven-week session during which they take classes and become acquainted with college life.

During their day at Lincoln Laboratory, the soon-to-be freshmen were briefed on some of the Laboratory's current projects; visited unique labs, such as the Technology Office Innovation Laboratory; and discussed engineering careers with technical staff members.

"Cyber defenders" tackle the 2012 challenge at the MIT and Lincoln Laboratory Cyber Capture the Flag competition.

Capture the Flag

In November 2012, MIT and Lincoln Laboratory hosted the Cyber Capture the Flag (CTF) competition. The event launched with seminars focused on attacks and defenses in the web environment, and culminated in a weekend-long competition. During the exercise, teams squared off to prove who had the most successful offensive and defensive computer security skills. Held on MIT campus, the competition drew 62 participants from six area universities and colleges. The Cyber Systems and Technology and Cyber System Assessments Groups organized the event in collaboration with MIT Professor Nickolai Zeldovich and Northeastern University Professors Engin Kirda and Wil Robertson.

Many popular cyber security CTF exercises are held each year at universities and security conferences. The CTF format may range from linear puzzle-like challenges to team-based offensive and defensive "hacking" competitions. The MIT and Lincoln Laboratory CTF challenge was to maintain a "company's" network functionality while recovering from a cyber attack.

EDUCATIONAL PROGRAMS WITH UNIVERSITIES

Students from the U.S. military academies often participate in the Laboratory's Summer Research Program. In summer 2013, Midshipmen Michael Segalla (back left) and Zachary Blanchard (right) of the U.S. Naval Academy, and Cadet Ed Galloway of the U.S. Air Force Academy are working in the Optical Systems Engineering Group fabricating microsatellites.

Summer Research Program

Lincoln Laboratory hires undergraduate and graduate students from top universities for summer internships in technical groups. Students gain hands-on experience in a leading-edge research environment while contributing to projects that complement their courses of study. At the end of their internships, the students present the results of their research at an open forum. In 2013, 87 undergraduates and 87 graduate students from 72 different schools worked at the Laboratory.

University Cooperative Education Students

Technical groups at Lincoln Laboratory employ students from area colleges as co-ops working full time with mentors during the summer or work/study semesters and part time during academic terms. Highly qualified students selected as co-ops become significant contributors to technical project teams. During the spring semester of 2013, 46 co-ops worked in divisions and departments at the Laboratory.

Worcester Polytechnic Institute Major Qualifying Project Program

In 2013, 11 students were accepted as Laboratory interns under the Worcester Polytechnic Institute's Major Qualifying Project Program, which requires students to complete an undergraduate project equivalent to a senior thesis. The program allows students to demonstrate the application of skills, methods, and knowledge to problems typical of those encountered in industry.

Graduate Fellowship Program

In 2012–2013, three students were awarded grants through this program that offers graduate fellowships to science and engineering students pursuing MS or PhD degrees at partner universities. Funds support a Fellow's stipend, supplement an assistantship, or subsidize other direct research expenses.

In March, 19 cadets from the U.S. Military Academy at West Point visited Lincoln Laboratory. The group of engineering and computer science majors was briefed on the role of a federally funded lab and the scope of work the Laboratory undertakes. Here, Stephen McGarry of the Airborne Networks Group explains operations of the Laboratory's airborne test bed.

>> *Technical Education, cont.*

MILITARY FELLOWSHIP PROGRAM

Lincoln Laboratory awards fellowships to support the educational pursuits of active-duty military officers who are fulfilling requirements for the U.S. military's Senior Service Schools or for the Army's Training with Industry program, or who are working toward advanced degrees. This program, formalized two years ago, helps the Laboratory establish cooperative relationships with military officers. Currently, 22 officers drawn from all the Services are working under fellowships.

Officers enrolled in a Senior Service School work in research programs at the Laboratory and take national security management courses at the MIT campus. Senior officers participating in the Training with Industry program are assigned full time to a Laboratory technical group. For the military, the goal of both programs is to acquaint senior personnel with the process of developing technologies that directly impact national security. The Laboratory gains constructive insight from the frontline experiences of the officers.

Fellows pursuing graduate degrees, usually at MIT, work on sponsored programs that complement their thesis research. During their first three academic semesters, these officers typically spend two days a week at the Laboratory and are assigned an advisor from among the technical staff to supervise their work. During summers and their final semester, the fellows contribute full time to a Laboratory program.

Edward Wack, leader of the Bioengineering Systems and Technologies Group in which COL David Pendall is working (see sidebar), captured the benefit of the Fellows program to the Laboratory: "COL Pendall's operational experience in Iraq and Afghanistan brings to MIT and Lincoln Laboratory an invaluable 'real-world' perspective. COL Pendall keeps us grounded in assessing both whether our systems will likely work, but more importantly, what technologies will be operationally useful."

SPOTLIGHT: *Colonel David Pendall, U.S. Army*

Colonel David Pendall, U.S. Army, is an Army War College Fellow participating in the MIT Security Studies Program and working with various technical groups at Lincoln Laboratory. His background in military intelligence provides the user perspective on systems the Laboratory is developing for persistent surveillance, and his experience with biometrics during his tour in Afghanistan informs collaborations with researchers in the bioengineering and biodefense areas.

COL David Pendall (second from right) has been working with the Bioengineering Systems and Technologies Group. He is seen here with colleagues (left to right) Paula Pomianowski Collins, Edward Wack, and James Harper.

COL Pendall sees his fellowship at the Laboratory as providing a valuable synergy. "Lincoln Lab is about building for the future, so having my view as an operator early on can help with developing technology that will be used. Meanwhile, I am gaining more perspective on the technologies developed here and the art of the possible. I feel I will come out of this process as a much more capable military officer."

While most senior officers in the Fellows program spend one year at the Laboratory, COL Pendall is spending an extra year here to continue supporting programs that are addressing warfighter requirements. As an Army officer, he offers insight into the needs of military personnel on the ground. "The Army's battlespace is one that more directly involves human interaction," he explains.

COL Pendall has found his time at the Laboratory personally rewarding. "I have the satisfaction of learning and I enjoy working with the people here. Each group has been helpful, thoughtful, and insightful."

COL Pendall (left) accompanied Lincoln Laboratory staff on a visit to the U.S. Army Natick Soldier Systems Center to learn more about the center's recent developments in equipment for the military, including new designs for protective gear.

Chris Sataline, an assistant technical staff member in the Active Optical Systems Group and a Lincoln Scholar, is completing work on a master's degree in electrical engineering at Boston University. He recently defended his thesis project on an approach to making magnetic field measurements from a distance.

PROFESSIONAL DEVELOPMENT

Lincoln Laboratory's extensive research and development achievements are enabled by the strength of its staff. The variety of educational opportunities and technical training available to staff help ensure continuing excellence.

Lincoln Scholars Program

Currently, 24 staff members are enrolled in the Lincoln Scholars Program, a competitive program for which staff are eligible to apply and under which participants are funded by the Laboratory for full-time pursuit of an advanced degree at MIT or another local university. Lincoln Scholars contribute to the Laboratory under terms arranged with the Graduate Education Committee and work at the Laboratory during summer breaks. In 2013, five staff members earned degrees through the program.

Distance Learning

Distance learning programs coordinated by the Graduate Education Committee allow technical staff to earn master's degrees while continuing to work full time at the Laboratory. Carnegie Mellon University offers degrees in information technology and information assurance, while Pennsylvania State University offers a master's program in information sciences. Currently, three people are enrolled at each of those universities. In September 2012, one staff member was awarded a master's degree from Penn State.

Onsite Courses

A range of courses in both technical areas and management techniques are taught by either Laboratory technical experts or outside instructors.

2012–2013 Multisession Courses

- Optical Systems Overview
- Theory and Methods for Modern Graph Analysis
- Adaptive Antennas and Phased Arrays
- Data Converter Course
- Signal Processing on Databases
- Patterns and Anti-Patterns for Service-Oriented Architecture
- Decision Making Under Uncertainty
- Signals and Systems
- Electronic Warfare
- Semiconductor Course

2012–2013 Technical Short Courses

- NVIDIA CUDA Training Course
- Accumulo
- Computational Fourier Optics
- Software Architecture: Principles and Practices
- Software Architecture: Design and Analysis
- Cyber Warfare

Technical Programming Courses

- A wide range of programming courses in areas such as C++, HTML, Linux, PHP, Perl, Python, UML, UNIX and XML
- A complete MATLAB curriculum with courses in signal processing, MATLAB programming techniques, interfacing MATLAB with C code, and statistical methods for MATLAB
- Certified Information Systems Security Professional and VMware certification courses

Diversity and Inclusion

A commitment to fostering an inclusive workplace helps ensure that Lincoln Laboratory maintains an excellent, diverse staff, thereby strengthening its ability to develop innovative solutions to problems.

Lincoln Laboratory staff members led a panel discussion at the Diversity Summit: (left to right) Dr. Christ Richmond, Gary Brendel, Ngaire Underhill, Dr. Jeffrey Palmer, Dr. Nestor Lopez, and Paula Ward.

2013 Lincoln Laboratory Diversity Summit

MIT Lincoln Laboratory's second Diversity Summit addressed the challenges in fostering an environment of inclusion. Held on 22 February in the Laboratory's main auditorium, the event featured a talk by Dr. Kristin Lane, assistant professor of psychology at Bard College, whose research on bias highlights how people's conscious beliefs about their biases are often at odds with implicit attitudes they unconsciously hold. These implicit biases present a hurdle to creating a truly inclusive workplace.

Approximately 250 people attended the summit, participating in sample surveys that Prof. Lane used to demonstrate how beliefs people are unaware of can influence their behaviors. She also shared findings from research undertaken by Project Implicit at Harvard University's Implicit Social Cognition Laboratory, where she conducted doctoral and postdoctoral research on unconscious biases.

The second half of the summit was a panel discussion led by six members of the Laboratory technical staff: Gary Brendel, Dr. Nestor Lopez, Dr. Jeffrey Palmer, Dr. Christ Richmond, Ngaire Underhill, and Paula Ward. Through the perspectives of these six individuals from diverse backgrounds, the audience gained an overview of both the Laboratory's success at creating a workplace that welcomes diversity and its still unresolved issues. During the question and answer period, the audience and the panel explored ideas for improving inclusion.

2013 MIT Diversity Summit

Members of Lincoln Laboratory's leadership and staff attended MIT's third annual Diversity Summit held on 30 January at the Kresge Auditorium on campus. The summit focused on the complexities of maintaining diversity in a meritocracy. A panel discussion on this theme was held during the morning session. Midday, keynote speaker Dr. Valerie Young spoke about her research on "the Impostor Syndrome," which breeds a lack of confidence in one's abilities. Throughout the day, a variety of workshops addressed topics ranging from preventing harassment, to creating employee resource groups, to defining the role of religious diversity.

Diversity Presentations for 2013

May
"The Bamboo Ceiling." Dr. Chris Yu, division leader of the Embedded Navigation and Sensor Systems Division, Draper Laboratory, spoke on cultural and organizational factors that prohibit Asian Americans from attaining executive positions.

June
"Lesbian, Gay, Bisexual, and Transgendered (LGBT) Issues." Tom Bourdon, director of the Lesbian, Gay, Bisexual, and Transgender Center and chair of the Social Justice Leadership Initiative, Tufts University, discussed challenges that LGBT employees face.

September
"The Imposter Syndrome." Dr. Valerie Young, author of *The Secret Thoughts of Successful Women*, explained what she calls "the imposter syndrome," a psychological mindset that prevents people from believing in their own abilities.

Employee Resource Groups

Lincoln Laboratory's resource groups provide support to staff members during the transitions they make as they advance in their careers. From helping new staff acclimate to the Laboratory's work environment, to encouraging professional development, to facilitating involvement in community outreach activities, the groups below help promote the retention and achievement of employees:

- New Employees Network
- Technical Women's Network
- Veterans Network
- Hispanic and Latino Network
- Out Professionals and Employees Network
- Lincoln Employees' African American Network

At the Veterans' Day luncheon held in November 2013, General Mark A. Welsh III, U.S. Air Force, delivered the keynote address. This annual event for armed forces veterans who work at the Laboratory is organized by the Lincoln Laboratory Veterans Network (LLVETS) to celebrate the contributions veterans have made to the nation.

In 2013, Lincoln Laboratory offered GEM fellowships to nine graduate students, some of whom worked as summer interns in Laboratory technical groups. During their internships, the GEM students took time to tour Laboratory facilities. Above, students visit the autonomous systems lab to learn about prototyping efforts in robotics.

GEM National Consortium

In 2012, MIT Lincoln Laboratory Director Eric Evans was named to a two-year term as president of the National Graduate Degrees for Minorities in Engineering and Science (GEM) Consortium. Through partnerships with universities and industry, GEM provides support to students from underrepresented groups who are seeking advanced degrees in science and engineering fields. In February 2013, the executive committee of the consortium held its planning meeting at Lincoln Laboratory. In August, Dr. Evans and William Kindred, manager of the Laboratory's diversity program, attended the 2013 GEM Annual Board Meeting and Conference, which engaged GEM officers and partnering organizations in discussions on strategies for transforming how the United States prepares engineers and scientists.

Mentorship Programs

Recognizing that strong mentorships enhance an inclusive workplace, Lincoln Laboratory conducts four formal mentoring programs:

- The New Employee Guides acquaint newly hired staff members with their groups, divisions, or departments.
- Early Career Mentoring is a six-month, one-on-one mentorship that helps technical and administrative professionals with early career development.
- Circle Mentoring small discussion groups, led by experienced employees, address diverse topics relevant to career growth.
- The New Assistant Group Leader Mentoring partners a newly promoted assistant leader with an experienced group leader to help with the transition into new responsibilities.

Awards and Recognition

The commitment to excellence that characterizes our staff has enabled the Laboratory's 62 years of achievements and its sustained reputation for innovation.

2013 American Institute of Aeronautics and Astronautics Fellow

Dr. Hsiao-hua K. Burke, for her "outstanding leadership in the development of missile defense systems, hyperspectral imaging technology and algorithms, and satellite systems for military and civilian applications."

2013 Optical Society of America Fellow

Dr. Paul W. Juodawlkis, for "significant contributions to optically sampled analog-to-digital conversion and the development of the slab-coupled optical waveguide amplifier."

2012 Jamieson Award

Dr. John A. Tabaczynski, for his "outstanding contributions to Ballistic Missile Defense programs." The award is presented by the Military Sensing Symposium on Missile Defense Sensors, Environments, and Algorithms.

2012 Superior Security Rating

To Lincoln Laboratory's collateral security program from the U.S. Air Force 66th Air Base Wing Information Protection Office.

2012 MIT Lincoln Laboratory Technical Excellence Awards

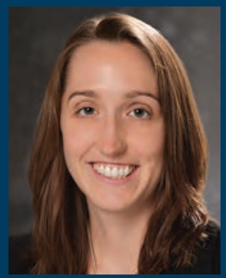
Dr. Clifford J. Weinstein, for his nationally recognized technical achievements and leadership in human language technology and its applications, and specifically for his contributions in speech recognition, machine translation, automated social network analysis, speech communications in packet networks, and digital signal processing.

Dr. Helen H. Kim, for her creativity in developing innovative radio-frequency (RF) integrated circuit capabilities that have solved difficult RF system challenges in a wide range of applications, and for her leadership in helping revitalize RF technology work at MIT Lincoln Laboratory.

2013 Dwight D. Eisenhower Award for Excellence

Presented by the U.S. Small Business Administration to MIT Lincoln Laboratory for exceptional utilization of small businesses in its 2012 subcontracting activities.

2012 Early Career Technical Achievement Awards



Laura A. Kennedy, a technical staff member in the Space Control Systems Group, was recognized for her substantial contributions in a wide range of technical areas. She has been a key contributor to the development of algorithms that are integral to systems such as the Optical Processing Architecture at Lincoln. She often serves as the technical lead on a project, working directly with sponsors and users. Her deep understanding of the systems that Lincoln Laboratory develops and her analysis work have directly improved signal processing capabilities for operational systems.

Dr. Jason R. Thornton, a technical staff member in the Informatics and Decision Support Group, was recognized for his substantial contributions in transforming the Laboratory's ground-based video analytics capabilities through the development of novel methods for rapid video content analysis by security professionals. His research has produced video processing system performance superior to recent commercial and academic approaches. His work also includes research related to sensor fusion, threat assessment, decision support, and image and video processing.

2012 MIT Lincoln Laboratory Best Paper Award

Dr. Peter L. Cho and Prof. Noah Snavely (of Cornell University), for "Enhancing Large Urban Photo Collections with 3D Ladar and GIS Data," accepted for publication in the *International Journal of Remote Sensing Applications*.

2012 MIT Lincoln Laboratory Best Invention Award

Dr. Roger I. Khazan, **Dr. Joshua I. Kramer**, **Dan Utin**, **Dr. M. Michael Vai**, and **Dr. David J. Whelihan**, for "SHAMROCK: Self-contained High Assurance MicRO Crypto and Key-management processor."

2012 C4ISR Top 5 Winner from the Big 25

The Imaging System for Immersive Surveillance (ISIS), developed by Lincoln Laboratory in partnership with Pacific Northwest National Laboratory under sponsorship of the Department of Homeland Security, Science & Technology Directorate, was named a Top 5 Winner from *C4ISR Journal*'s 2012 "Big 25" technologies. The Big 25 are new technologies and efforts that significantly impact the fields of networking and intelligence, surveillance, and reconnaissance (ISR).

2012 National Defense Industrial Association Contractor Tester of the Year

David P. Conrad, for leadership and contributions to test and evaluation as the Missile Defense Agency mission director for the Flight Test Integrated-01.

Air Vehicle Survivability Evaluation Lifetime Achievement Award

William P. Delaney, for his pivotal role in establishing the Air Vehicle Survivability Evaluation program and for "extraordinary achievements in defense of the nation."

Chief of Naval Research (CNR) Commendation

The Lincoln Laboratory team that developed the Gimbaled Airborne Test Radar was among the recipients of a CNR commendation for "outstanding support for science and technology" for their work on a high-interest data collection event in January 2013.

Clemson University College of Engineering and Science Outstanding Young Alumni Award

Dr. Thomas G. Macdonald, in recognition of his excellence in research and his contributions to the engineering field and the professional community.

Penn State Alumni Fellow

Dr. Antonio F. Pensa, for outstanding professional accomplishments; this award is the highest one conferred by the Penn State Alumni Association.

2013 MIT Excellence Awards

Unsung Hero Awards

Jessica E. Holland, **Gregory S. Rowe**, and **Dennis C. Weikle, Sr.**

Serving the Client Award

The "Superdrivers" team: **Robert M. Clegg**, **Scott P. Leach**, and **Leonard E. Nunes**.

Presidential Meeting with 2012 Kavli Prize Recipients

President Barack Obama met in the Oval Office on 29 March 2013 with the six U.S. recipients of the 2012 Kavli Prizes. Among these laureates was **Dr. Jane Luu**, a technical staff member in the Active Optical Systems Group, who shared the Kavli Prize for Astrophysics with David Jewitt of the University of California–Los Angeles and Michael Brown of Caltech.

2013 MassCommute Bicycle Challenge Awards

MIT Lincoln Laboratory's bicyclists took two first-place awards in the 2013 MassCommute Bicycle Challenge: for number of participants in the Bike Week challenge from a business of 3,000 to 4,999 employees and for total mileage ridden by Lincoln Laboratory participants in the challenge.

2013 Dick Aubin Distinguished Paper Award

Michael L. Stern and **Eli A. Cohen**, for their paper on the development of a 3D-printed, extendable-wing unmanned aerial vehicle. The award, presented by the Society of Manufacturing Engineers at its annual RAPID Conference, recognizes a paper that has had a significant impact on rapid prototyping or additive manufacturing.

Honorable Mention: Visual Analytics Science and Technology (VAST) Mini-challenge

A visual display for a cyber situational awareness scenario created by a multidivisional team for a VAST 2013 Mini-challenge was selected by the Visual Analytics Community for an honorable mention. The team was composed of members from four groups: Cyber Systems and Operations, Informatics and Decision Support, Wideband Tactical Networking, and Intelligence and Decision Technologies.

2013 Molecular Beam Epitaxy Innovator Award

Dr. George W. Turner, for "pioneering and sustained contributions in antimonide materials research and mid-wavelength infrared laser development," presented by the North American Molecular Beam Epitaxy organization and Veeco Instruments, Inc.

Associate Fellow of the American Institute of Aeronautics and Astronautics

Dr. William R. Davis, for "contributions to the arts, sciences, or technology of aeronautics or astronautics."

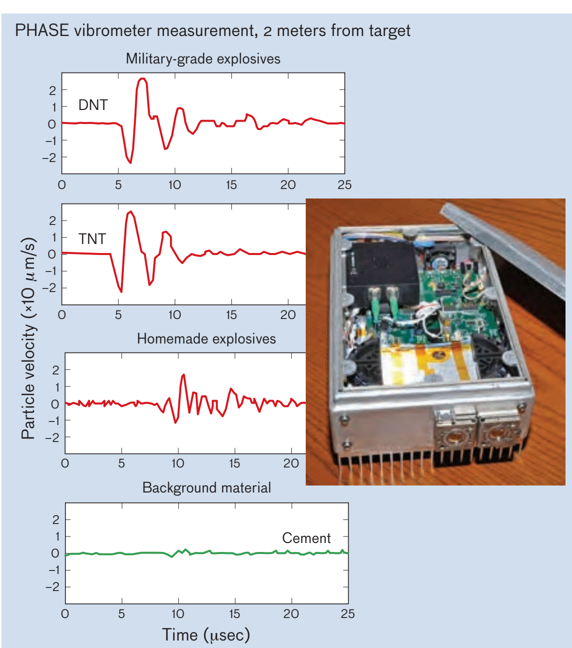
R&D 100 Awards

Two technologies developed at MIT Lincoln Laboratory were named 2013 recipients of R&D 100 Awards. Given annually by *R&D Magazine*, a publication for research scientists and engineers, these international awards recognize the 100 most technologically significant innovations introduced during the prior year. Recipients of R&D 100 Awards are chosen from hundreds of nominations by a panel of independent evaluators and editors of *R&D Magazine*. The winning innovations represent a broad range of technologies developed in industry, government laboratories, and university research facilities worldwide.

At the R&D 100 Awards banquet in Orlando, Florida, on 8 November, members of the teams that won 2013 awards accepted commemorative plaques. Pictured here with Associate Director Marc Bernstein (at right) are, left to right, Dr. Gary Condon, Francesca Lettang, Robert Haupt, Delsey Sherrill, and Dr. Charles Wynn.

Photoacoustic Sensing of Explosives

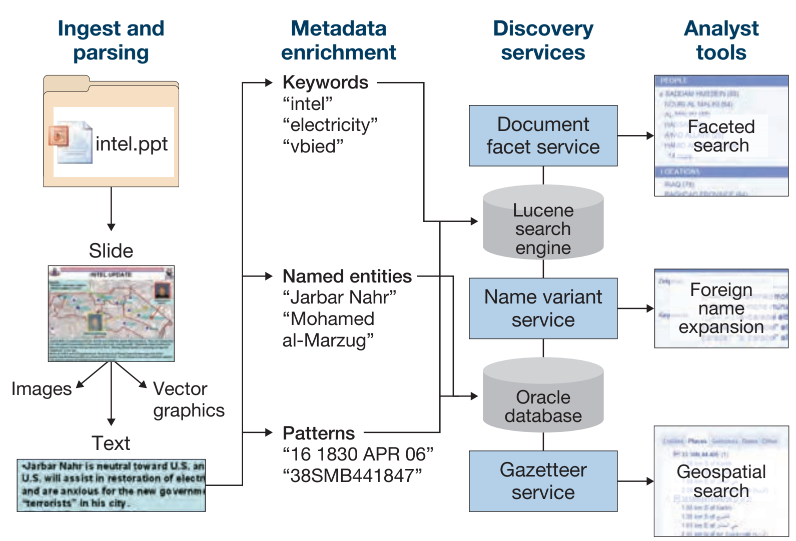
A system that exploits acoustic emissions to detect trace levels of explosives' residue deposited on common surfaces.



Team: Robert Haupt, Dr. Charles Wynn, Dr. Leaf Jiang, Francesca Lettang, Dr. Napoleon Thantu, Stephen Palmacci, Gregory Rowe, Charles Cobbett, Rosalie Bucci, Dr. Jae Kyung, Dr. Roderick Kunz, and Dr. Sumanth Kaushik

Structured Knowledge Space

A software system that combines open-source technologies, custom-built software, and domain knowledge about entities in intelligence reporting to facilitate search over a collection of intelligence documents that had previously been largely unsearchable.



Team: Dr. Gary Condon, Benjamin Landon, Delsey Sherrill, Dr. Michael Yee, Richard Delanoy, Jonathan Kurz, Jason Hepp, Jeffrey Allen, Yican Cao, Brian Corwin, Andrea Coyle, Nils Edstrom, Mark Ford, Neal Hartmann, Davis King, Chi Lam, Donald Leger, Mel Martinez, Jeremy Mineweaser, Justin O'Brien, Ritesh Patel, Harry Phan, Bob Piotti, Travis Riley, Steven Schoeffler, Michael Snyder, Ven Tadipatri, Gordon Vidaver, George Wilk, Chris Wyse, Erik Brinkman, Aaron Daubman, Jason Duncan, T.J. Hazen, Ari Kobren, and Ramesh Ramachandran

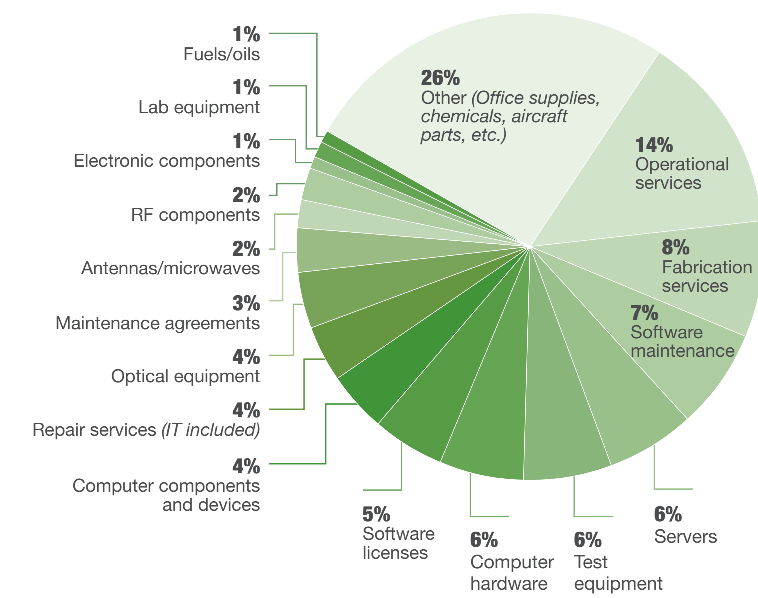
Economic Impact

Lincoln Laboratory serves as an economic engine for the region and the nation through its procurement of equipment and technical services.

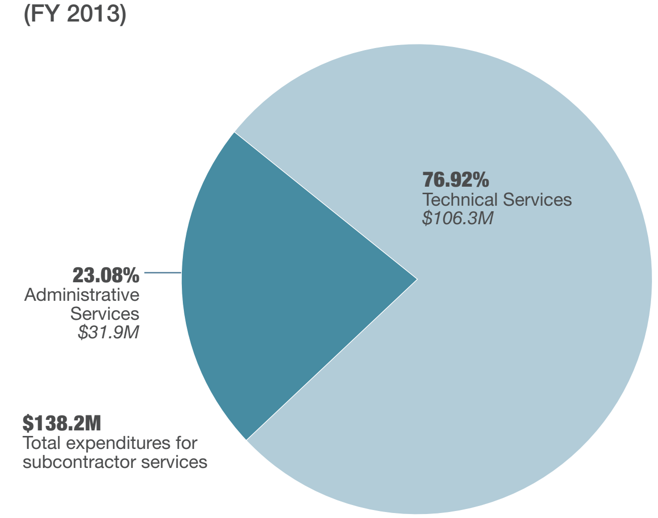
During fiscal year 2013, the Laboratory issued subcontracts with a value that exceeded $401 million. The Laboratory, which typically awards subcontracts to businesses in all 50 states, purchased more than $237 million in goods and services from New England companies in 2013, with Massachusetts businesses receiving approximately $203 million. States as distant as California and Texas also realized significant benefits to their economies.

Small businesses—which supply construction, maintenance, fabrication, and professional technical services in addition to commercial equipment and material—are primary beneficiaries of the Laboratory's outside procurement program. In 2013, 53% of subcontracts were awarded to small businesses of all types (as reported to the Defense Contract Management Agency). The Laboratory's Small Business Office is committed to an aggressive program designed to afford small business concerns the maximum opportunity to compete for purchase orders. In addition, the Laboratory contracts with universities outside of MIT for basic and applied research. These research subcontracts include expert consulting, analysis, and technical support.

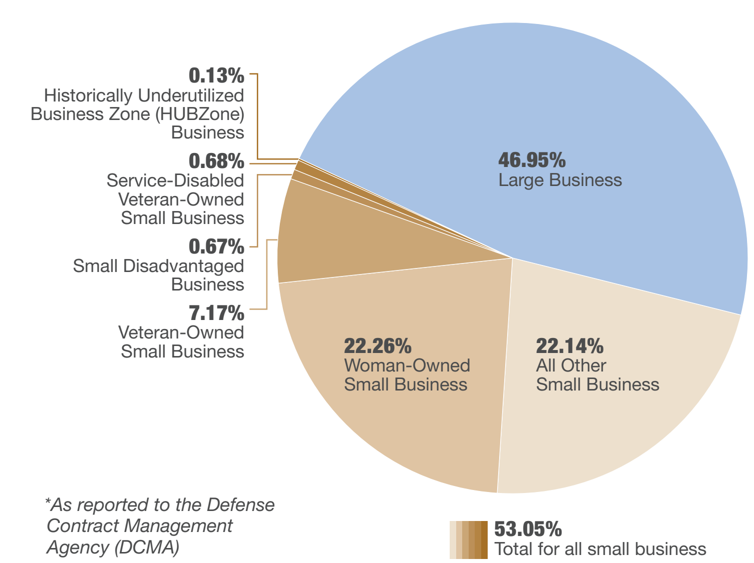
Commercial hardware and materials contracted to businesses (FY 2013)



Subcontractor services (FY 2013)



Contract awards by category of businesses (FY 2013)*



*As reported to the Defense Contract Management Agency (DCMA)

EDUCATIONAL AND COMMUNITY OUTREACH 61

US FIRST Lego League robotics

Educational Outreach

Community outreach programs are an important component of the Laboratory's mission. Our outreach initiatives are inspired by employee desires to help people in need and to motivate student interest in science, technology, engineering, and math (STEM). New efforts in 2013 included developing an MIT Museum display and creating a new merit badge for the Boy Scouts of America.

Lincoln Laboratory Community Outreach

Lexington's 300th Anniversary

The planning committee for the 300th anniversary of the town of Lexington, Massachusetts, graciously invited Lincoln Laboratory to participate in the town's celebration. On 16 March 2013, Robert Atkins, head of the Advanced Technology Division, provided a historical overview of Lincoln Laboratory in the panel discussion "Military History of the Lexington Area." Todd Rider, formerly of the Bioengineering Systems and Technologies Group, offered hands-on displays in science, biology, and engineering. Grant Stokes, head of the Aerospace Division, served as a panel member for a symposium on the history of technology in Lexington during the last 70 years, speaking about the Laboratory's major achievements and impacts on national security and the non-defense domain.

MIT Museum Exhibit

In December 2012, the MIT Museum unveiled its newest addition to the "Sampling MIT" exhibition, a display of Lincoln Laboratory's Air Traffic Control (ATC) programs. The exhibition's six rotating displays feature current MIT research that addresses big questions facing the world today. On view throughout 2013, the ATC display highlights the Laboratory's technological contributions to flight safety, including the Traffic Alert and Collision Avoidance System, Runway Status Lights, and Corridor Integrated Weather System.

The Laboratory personnel assisting with the concept, research, and design for the ATC display were Mel Stone, Ann Drumm, Jim Eggert, Jessica Holland, and Ted Londner of the Surveillance Systems Group; Richard DeLaura, Elizabeth Ducot, and Richard Ferris of the Air Traffic Control Systems Group; and Chester Beals, Technical Communications. Deborah Douglas, MIT Curator of Science and Technology and designer of the exhibition, remarked, "Working on this exhibition project gave me a much deeper appreciation of the Laboratory's unique research environment, most notably an exceptional dedication to teamwork. Researchers at Lincoln Laboratory do extraordinary things because of this."

AAAS Family Science Days

Evan Cull, Optical Systems Technology Group, explains the infrared spectrum to visitors at the American Association for the Advancement of Science (AAAS) Family Science Days exhibition in February.

Endowed Funds

Lincoln Laboratory's outreach activities are funded in part through the endowments listed on the plaque above. Donations to these funds provide ongoing support to educational programs.

Students of the 2013 LLRISE program at Lincoln Laboratory prepare for two weeks of college courses prior to building their own radar. LLRISE teachers are shown on the left and right.

SPOTLIGHT: *Lincoln Laboratory Radar Introduction for Student Engineers*

Lincoln Laboratory's summer engineering workshop for high-school students, Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE), was expanded in July. The two-week residential, project-based enrichment program enrolled 18 outstanding students from across the nation who had completed their junior year in high school. The program debuted in 2012, at which time it was offered only locally to 12 students.

The radar technology program is based on a very popular three-week class offered by Laboratory technical staff to MIT undergraduates during the January intersession between academic semesters. The college course was modified to suit high-school students, yet provide the same depth of material and hands-on activities. While designed to provide an understanding of radar systems, the program is intended to foster a realization that engineering is about problem solving and applying knowledge in innovative ways. Participants were challenged to build a Doppler and range radar by using creative problem-solving strategies while working in a state-of-the-art laboratory with highly talented scientists and engineers.

LLRISE
LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS

Chiamaka Agbasi-Porter of the Communications and Community Outreach Office coordinated the program and was supported by 10 technical staff members: Mabel Ramirez, Nestor Lopez, Raoul Ouedraogo, Wingyan Beverly Lykins, Alexis Prasov, Joseph McMichael, James McIntire, John Meklenburg, Bradley Perry, and Alan Fenn.

LLRISE students demonstrate their self-built radar to visitors at the MIT Museum.

During the two-week period, the students attended college-level classes on physics, electromagnetics, mechanics of Doppler radar, modular radio-frequency design circuitry, Matlab, pulse compression, signal processing, and antennas. In addition to a presentation about career exploration, the students were given an overview of Lincoln Laboratory and a tour of its facilities, including the Flight Facility, the Antenna Test Range, and the Haystack Observatory in Westford, Massachusetts.

During the workshop, students experienced dorm life at MIT campus. In between instructional lectures and homework, the students toured MIT campus and the MIT Museum, and visited MIT's Financial Aid Office to learn about the college application process. The participants also learned how to stage an experiment and how to present a project, preparing them for their final technology demonstrations. Social activities, such as a Museum of Science visit and a festival on Boston Common, provided breaks from the rigorous workload.

>> *Educational Outreach, cont.*

Science On Saturday

The free Science on Saturday demonstrations continued to fill the Auditorium. This year, 1600 children enjoyed the robotics demonstration hosted by Robotics Outreach at Lincoln Laboratory (ROLL) and the asteroids demonstration, particularly pertinent in light of the Russian meteorite and the DA14 asteroid in February. Other shows during the school year included demonstrations on radar and chemistry.

Science Fair Volunteers

Lincoln Laboratory supports the community by offering volunteer judges for local and state science fairs. The Laboratory typically sends more than 10 volunteers to the Lexington High Science Fair and to the Massachusetts State Science and Engineering Fair. Volunteers from the Robotics Outreach group manned a booth at the Cambridge Science Festival. In May, David Kong, a technical staff member in the Bioengineering Systems and Technologies Group, volunteered as a guest expert/guest juror for the Boston ArtScience Prize, a year-long after-school competition through which high-school students develop innovative art and design ideas informed by concepts at the frontiers of modern science, culminating in a prize being awarded in May. The theme for the 2012–2013 ArtScience Prize was synthetic biology.

Attendees at the Science on Saturday presentation on radars (above) found out how radar works. Attendees of the asteroids presentation (left) were able to see “space rocks” up close.

Classroom Presentations

Each year, Lincoln Laboratory technical staff members give free classroom presentations and lead hands-on activities to approximately 7000 students. More than 40 presentations are available in both general and specific scientific fields, and can be adapted for different grade levels. Early this year, Laboratory scientists traveled to Estabrook Elementary School in Lexington to share “How to Do a Science Fair Project” and to McCarthy-Towne Elementary School in Acton to present a demonstration on Egyptian archaeology.

CyberPatriot

In March, the Lincoln Laboratory CyberPatriot team, Donut Hack Us, traveled to Maryland to compete in the national high-school cyber-defense finals. Mentored by Joseph Werther of the Cyber System Assessments Group and Robert Cunningham of the Cyber Systems and Technology Group, and coached by Chiamaka Agbasi-Porter of the Communications and Community Outreach Office, the six-member team was named Open Division National Finalists. Assisting in preparing the team for competition were James Astle of the Cyber System Assessments Group and Kevin Bauer, Kyle Ingols, and Sophia Yakoubov, all of the Cyber Systems and Technology Group.

The Air Force Association’s annual CyberPatriot competition aims to inspire high-school students to train for careers in cyber security as well as science, technology, engineering, and mathematics. This year’s event included a Network Security Competition, designed to test the skills of the national finalist teams in an exercise against a red team of “attackers,” and a Cisco networking competition.

Lincoln Laboratory’s CyberPatriot team, Donut Hack Us, was one of the 12 out of 419 teams advancing to the national finals competition. The team placed eighth overall in the nation.

Reading Outreach

Lincoln Laboratory’s Outreach Volunteer Group offers opportunities to assist with different outreach events once a month with no further commitment. Their motto is “sign up, show up, and help out.” Volunteers help with monthly story times for children in grades K–4 at the Dudley Branch of the Boston Public Library in an effort to inspire children’s passion for reading. Volunteerism will expand to other libraries and public schools in the future. This group also contributes on a weekly basis at Loaves and Fishes in Cambridge. Their website lists many ways to help a variety of causes and guides personnel to appropriate points of contact for other outreach efforts at the Laboratory.

Boy Scouts of America

The Boy Scouts of America (BSA) launched a new Game Design Merit Badge in March. Frank Schimmoller (Director’s Office), David Radue (Mechanical Engineering Group), and Curtis Heisey (Surveillance Systems Group) played a vital role in the development of the badge by providing facilities, resources, and personnel for a set of crucial requirement

TECHNICAL SCHOOL STUDENT INTERNSHIPS

Each year, two students from Minuteman High School in Lexington, Massachusetts, and one student from Shawsheen Valley Technical High School in Billerica, Massachusetts, are provided with internships at Lincoln Laboratory, giving them hands-on experience in a real-world setting.

Anthony Carreon, an intern from Minuteman High School, worked at the Laboratory’s Flight Facility.

>> Educational Outreach, cont.

tests in August. Local scouts were invited to the Laboratory to plan their own games, design a product, and have it tested with the assistance of experts in the game design industry.

The Laboratory BSA outreach team also participated in SOAR, Scouting Adventures On the River, which offered hands-on science demonstrations to Boy Scouts of all ages. The Laboratory's "whisper dish" was on display to help scouts understand how a parabolic reflector works. Richard Williamson performed his ever-popular Liquid Nitrogen Show, and David Radue showed the finer points of game design in preparation for the unveiling of the Game Design merit badge, while John Kuconis explained the engineering concepts of tension and compression by building a weight-bearing gumdrop bridge.

Team America Rocketry Challenge

The Laboratory sponsored two teams this year in the 2013 Team America Rocketry Challenge (TARC), a national aerospace challenge to foster interest in science and engineering. TARC is an extracurricular hands-on project-based learning program; its objective is the successful launch and recovery of one large egg ("the astronaut") that must lie horizontally inside the rocket. Other requirements include a target altitude of 750 feet, a payload aloft duration between 48 and 50 seconds, a 15-inch-diameter parachute, and limitations on rocket weight, size, and motor impulse. Both middle-school and high-school teams completed two official flights for the challenge.

Frank Schimmoller (far right) looks on as local Scouts test a game design that uses the requirements set forth in the new Game Design Merit Badge.

Although the competitors were just shy of placing on the national level, mentors Francesca Lettang, Active Optical Systems Group, and Curtis Heisey, Surveillance Systems Group, expressed their pride in the teams' accomplishments. "I found it exciting to see the teams assess their flights and apply engineering principles to make improvements in real time," Heisey said. Lettang added, "They impressed me many times by figuring out for themselves what engineering trade was needed in order to get closer to their goal."

Team America Rocketry Challenge participants braved the winter weather to flight-test their design.

Robotics Outreach

Robotics Outreach at Lincoln Laboratory (ROLL) volunteers serve as coaches and mentors for 15 teams, totaling 125 students, sponsored by Lincoln Laboratory. The teams compete in local, state, and national robotic competitions designed by FIRST (For Inspiration and Recognition of Science and Technology), whose reach extends to more than 300,000 students worldwide.

The FTC (FIRST Technical Challenge) game for grades 7–12 in the 2012–2013 school year was Ring It Up. The object of Ring It Up is to score more points than an opponent's alliance by placing plastic rings onto pegs on the center rack. Teams were challenged to detect special "weighted" rings to earn a special multiplier bonus.

This year's FRC (FIRST Robotics Competition) challenge for grades 9–12 was Ultimate Ascent. The game is played by two competing alliances. Each alliance of three robots competes to score discs into its goals. The match begins with robots operating independently of driver inputs. Then, drivers controlling robots try to score as many goals as possible. The match ends with robots attempting to climb pyramids.

The FLL (FIRST Lego League) challenge for grades 4–8 this year was Senior Solutions. During this challenge, teams build, test, and program an autonomous robot to solve a set of missions on a themed playing field. Teams also present reports on solving a real-world problem related to the challenge topic.

LINCOLN LABORATORY TEAMS

FTC Level Teams

In the challenge for high-school students, the MightyBots team, mentored by Alexander Divinsky of the ISR Systems and Architectures Group and Scott Griffith of the Tactical Defense Systems Group, won the Think Award and the Innovate Award in separate regional tournaments, and won the Promote Award at the Massachusetts Championship Tournament. FTC Team Ingenium, mentored by Joel Walker of the Tactical Defense Systems Group, received the Inspire Award at the Vermont State Championship and qualified to compete in the national championship in St. Louis, Missouri.

FLL Level Teams

Lincoln Laboratory was represented by 11 FLL teams with a total of 90 children. The three FLL teams that qualified to compete in the state competition in December 2012 were Piece of Cake, LLAMAS, and A Robot Walks Into A Bar. The Lincoln Laboratory FLL teams that competed at the regional level included Flaming Phoenix, Get Off My Bricks, Lightning Legos, Nyan Cat, Razor Pickles, RoboWolves, Lego Einsteins, and The Matrix.

The MightyBots robotics team won the Think Award and the Promote Award at regional tournaments.

This year, two Jr. FLL teams, made up of six- to nine-year-old children of Laboratory employees, attempted the 2013 challenge, Super Seniors, helping senior citizens stay independent and connected. Jr. FLL is designed to direct children's curiosity toward ideas for improving the world.

Sister Teams

ROLL has a continuing collaboration with teams from Roxbury, Waltham, Lexington, Weston, and Shrewsbury, Massachusetts, as well as Hanscom Air Force Base. ROLL ensures that these teams have adequate supplies, funds, and mentorship to design, build, and program their robots. The Laboratory teams assist their sister teams by staging scrimmages and sharing design concepts and programming tips.

Notably, Lexington's FTC Team, Battery-Powered Pickle Jar Heads, won the Inspire Award at two tournaments and at the Massachusetts Championship, which they won. They competed in the national championship with Lincoln Laboratory's support. FRC Team Athena's Warriors, made up of 20 students from three high schools, began as an all-girls team and is now dedicated to creating a diverse STEM workforce. FRC Team Beantown Botz from the John D. O'Bryant School of Math and Science in Roxbury, participated in regional tournaments.

Massachusetts FTC

All of the Lincoln Laboratory teams and sister teams belong to the MassFTC league, led by Loretta Bessette of the ISR Systems and Architectures Group. This group promotes the opening of the challenges and facilitates teams working cooperatively. MassFTC and ROLL work together to provide volunteers, referees, and judges for each regional qualifier.

Community Giving

MIT Lincoln Laboratory's Heart Walk team invited supporters to wear red on February 1.

American Heart Association

Lincoln Laboratory's supporters of the American Heart Association (AHA) gathered in February for AHA's National Wear Red Day. Each year, the first Friday of February is a day to call attention to heart disease. Efforts of the six-member team, MIT Lincoln Laboratory for the Heart Walk, are spearheaded by Sandra McLellan of the Advanced Sensor Systems and Test Beds Group and Susan Curry of the Advanced SATCOM Systems and Operations Group. In preparation for the Boston Heart Walk in September, the team hosted a bake sale in February, Heart Awareness month. A total of $4117 was raised toward their fundraising goal.

Lowell General Hospital

A Lincoln Laboratory team helmed by Julie Arloro-Mehta of the Optical Systems Technology Group participated in Lowell General Hospital's TeamWalk for CancerCare for the fourth year. This year, the team raised $5450 to support the Cancer Center. TeamWalk funds make a difference in the lives of cancer patients by paying for medications, nutritional supplements, wigs and prostheses, support groups, nursing visits, transportation, and supportive services to patients of all cancer types.

Veterans Network

Laboratory personnel joined over 100 supporters to show their admiration for our nation's heroes on Valentine's Day during the 2013 National Salute to Hospitalized Veterans at the Edith Nourse Rogers Memorial Veterans Hospital, in Bedford, Massachusetts. "When participating in an event like this, one hopes to make at least some small difference in the lives of these sick and aging veteran patients. Their long-ago service and sacrifices paid the bill for our freedom today. As we went from ward to ward armed with children's valentines and red balloons, the smiles erupting on the faces of patients and dedicated staff members gave back to us much more than we had given by our visit," said Daniel O'Shea, Infrastructure and Operations, organizer of the Laboratory's volunteer group. The Veterans Network also participates annually in the Veterans' Day 5K Fun Run sponsored by the Edith Nourse Rogers Memorial Veterans Hospital.

Tori Orr, Elena Zorn, Bill Kindred, Richard Coveno, and Daniel O'Shea shared their appreciation with local veterans at the Edith Nourse Rogers Memorial Veterans Hospital.

Troop Support

Lincoln Laboratory's Troop Support volunteers were busy the end of last year raising funds for care packages to be sent overseas to our soldiers. Through a bake and crafts sale in the fall, enough funds were raised to send special holiday packages, each containing supplies and seasonal surprises to share. Troop Support also hosted a card-signing event to provide holiday cards to soldiers who do not regularly receive mail. Troop Support organized the Laboratory-wide collection of Halloween candies to be shipped to soldiers serving in the Middle East. This shipment, limited to a short time of year during which chocolates can be safely shipped without melting, is eagerly anticipated. Troop Support also hosted a donation drive and packing party in the summer, resulting in 150 boxes ready to send overseas.

Multiple Sclerosis Society

Team MIT Lincoln Laboratory supported the Multiple Sclerosis Society by hiking and biking in the Berkshires in September. Co-captains David Granchelli (Communications and Community Outreach Office) and John Kuconis (Director's Office) led the 13-member team in raising $7528 to help people in the community who are affected by multiple sclerosis and help advance research and treatments. The Hike and Bike team included Laboratory staff members Christine Cambrils, Alan Gee, Robert Seidel, Paul Smith, David Tyo, and Leslie Watkins.

AIDS Walk and 5K Run

Lincoln Laboratory's first year of participation in Boston's AIDS Walk and 5K Run was coordinated by Thomas Zugibe of the Airborne Radar Systems and Techniques Group. Members of the Hispanic/Latino Network and OPEN, Out Professionals and Employees Network, raised $755.

AIDS Action Committee

New to Lincoln Laboratory's outreach roster in 2013 is the Harbor to the Bay Bike Ride for AIDS. Team Lincoln participated in this one-day bike ride from Boston to Provincetown in September. The three-member team, led by R. Jordan Crouser (Computing and Analytics Group) and Ariel Hamlin (Cyber Systems and Technology Group), raised $2272 to support the AIDS Action Committee of Massachusetts, the state's leading provider of prevention and wellness services for people vulnerable to HIV infection.

Alzheimer's Association

The 52 Lincoln Laboratory team members, led by Kit Holland, Wideband Tactical Networking Group, raised $30,954, beating their $25,000 goal and ranking as the region's top fundraiser in the 2013 Greater Boston Walk to End Alzheimer's.

The MIT Lincoln Laboratory Alzheimer's Awareness and Outreach Team held a silent auction of autographed Bruins items to support the 2013 Greater Boston Walk to End Alzheimer's. In July, a team of Laboratory bicyclists participated in the Ride to End Alzheimer's. The ride featured three distances departing and finishing at Devens, Massachusetts. Bruce Bray and Bob Schulein completed 100 miles; Kim Hebert rode 62 miles, while Carolyn Hutchinson, Ken Cole, Xiao Wang, and John Kaufmann rode the 30-mile route. Out of more than 80 teams participating, the all-volunteer Lincoln Laboratory team ranked fourth in dollars raised, contributing more than $10,000 to Alzheimer's research.

GOVERNANCE AND ORGANIZATION

Laboratory Governance and Organization

MIT
Dr. L. Rafael Reif
President

Dr. Chris A. Kaiser
Provost

Dr. Claude R. Canizares
Vice President

DoD Joint Advisory Committee
Annually reviews the Laboratory's proposal for programs to be undertaken in the subsequent fiscal year and five-year plan.

Mr. Alan R. Shaffer, Chairman
Principal Deputy, Assistant Secretary of Defense for Research and Engineering

Ms. Betty J. Sapp
Director, National Reconnaissance Office

Dr. Arati Prabhakar
Director, Defense Advanced Research Projects Agency

Vice Admiral James D. Syring
Director, Missile Defense Agency

Ms. Heidi Shyu
Assistant Secretary of the Army for Acquisition, Logistics and Technology

Mr. Sean J. Stackley
Assistant Secretary of the Navy for Research, Development and Acquisition

Lt Gen Charles R. Davis
Military Deputy, Office of the Assistant Secretary of the Air Force for Acquisition

Maj Gen William N. McCasland
Commander, Air Force Research Laboratory, Joint Advisory Committee Executive Group—Chair

Lincoln Laboratory
Eric D. Evans, *Director*
Marc D. Bernstein, *Associate Director*
C. Scott Anderson, *Assistant Director – Operations*

Office of the Director
Steven R. Bussolari, *Strategic Initiatives*
Bernadette Johnson, *Chief Technology Officer*
David R. Granchelli, *Communications and Community Outreach Office*
John E. Kuconis, *Executive Officer*
Deborah A. Valley, *Safety, Mission Assurance, and Program Support Office*
J. Michael Menadue, *Capital Projects Office*
David A. Suski, *Counsel*

Service Departments
Contracting Services: Paul F. Conroy
Financial Services: Patricia O'Riordan
Information Services: Charles W. Maxson
Facility Services: Donald N. Holmes
Human Resources: Brian S. Donahue
Security Services: Shawn S. Daley, *Chief Security Officer*

Air and Missile Defense Technology
Hsiao-hua K. Burke, *Head*
Andrew D. Gerber, *Associate Head*
Gerald C. Augeri, *Assistant Head*
Dennis J. Keane, *Assistant Head*

Cyber Security and Information Sciences
Stephen B. Rejto, *Head*
David R. Martinez, *Associate Head*
Marc A. Zissman, *Associate Head*

Engineering
Eliahu H. Niewood, *Head*
William R. Davis, Jr., *Assistant Head*
Michael T. Languirand, *Assistant Head*

Advanced Technology
Robert G. Atkins, *Head*
Craig L. Keast, *Associate Head*
Simon Verghese, *Assistant Head*

Intelligence, Surveillance, and Reconnaissance and Tactical Systems
Robert T-I. Shin, *Head*
Robert A. Bond, *Assistant Head*
Justin J. Brooke, *Assistant Head*
Melissa G. Choi, *Assistant Head*

Homeland Protection and Air Traffic Control
Israel Soibelman, *Head*
James M. Flavin, *Assistant Head*
Mark E. Weber, *Assistant Head*

Communication Systems
J. Scott Stadler, *Head*
Roy S. Bondurant, *Associate Head*
James Ward, *Assistant Head*

Aerospace
Grant H. Stokes, *Head*
Lawrence M. Candell, *Assistant Head*
William J. Donnelly III, *Assistant Head*
Craig E. Perini, *Assistant Head*

MIT Lincoln Laboratory Advisory Board
The Advisory Board is appointed by the MIT President and reports to the Provost. The board meets twice a year to review the direction of Laboratory programs.

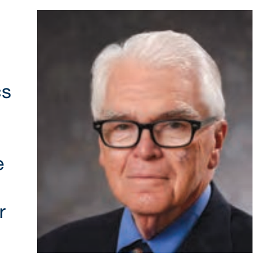

Mr. Kent Kresa, Chairman
Former Chairman and CEO of Northrop Grumman

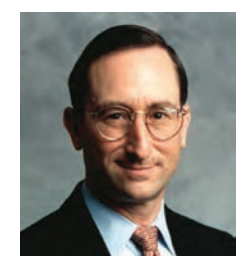

ADM Edmund P. Giambastiani Jr., USN (Ret)
Former Vice-Chairman of the Joint Chiefs of Staff


Gen Lester L. Lyles, USAF (Ret)
Board of Directors, General Dynamics Corporation; Former Vice Chief of Staff of the Air Force; Former Commander, Air Force Materiel Command


Prof. Angela M. Belcher
W.M. Keck Professor of Energy, Massachusetts Institute of Technology


Prof. Daniel E. Hastings
Green Education Professor of Aeronautics and Astronautics and Engineering Systems, Massachusetts Institute of Technology; Former Chief Scientist of the Air Force


Prof. Hans Mark
The University of Texas at Austin; Former Secretary of the Air Force; Former Deputy Administrator of NASA


Mr. Denis A. Bovin
Co-chairman and Co-CEO, Stone Key Partners; Life member, MIT Corporation; Former member, President's Foreign Intelligence Advisory Board

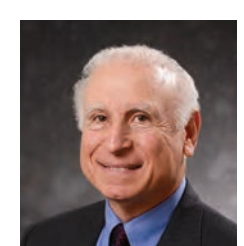

Dr. Miriam John
Vice President Emeritus of Sandia National Laboratories


Prof. Jeffrey H. Shapiro
Julius A. Stratton Professor of Electrical Engineering, Massachusetts Institute of Technology

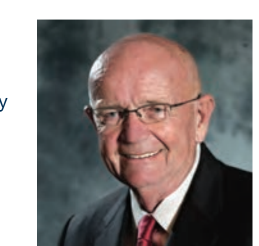

VADM David E. Frost, USN (Ret)
President, Frost & Associates, Inc.; Former Deputy Commander, U.S. Space Command


Dr. Paul G. Kaminski
Chairman and CEO of Technovation, Inc.; Former Under Secretary of Defense for Acquisition and Technology


Mr. John P. Stenbit
Former Assistant Secretary of Defense (C3I); Former Executive Vice President, TRW


Dr. Arthur Gelb
President, Four Sigma Corporation; Former Chairman and CEO of The Analytic Sciences Corporation


Dr. Donald M. Kerr
Board of Trustees, MITRE Corporation; Former Principal Deputy Director of National Intelligence; Former Director of the National Reconnaissance Office

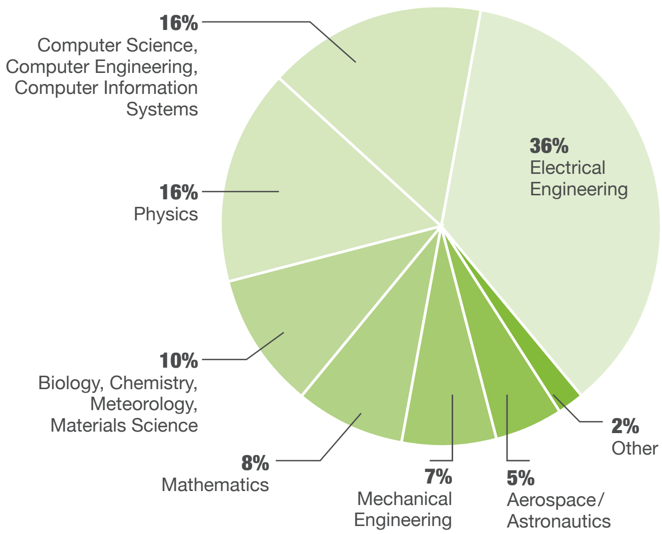

GEN Gordon R. Sullivan, USA (Ret)
President of the Association of the U.S. Army; Former Chief of Staff of the U.S. Army

Staff and Laboratory Programs

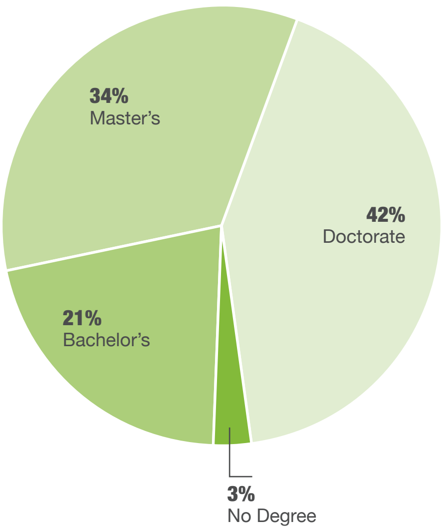
1,738	Professional Technical Staff
1,101	Support Personnel
418	Technical Support
525	Subcontractors
3,782	**Total Employees**

Composition of Professional Technical Staff

Academic Discipline

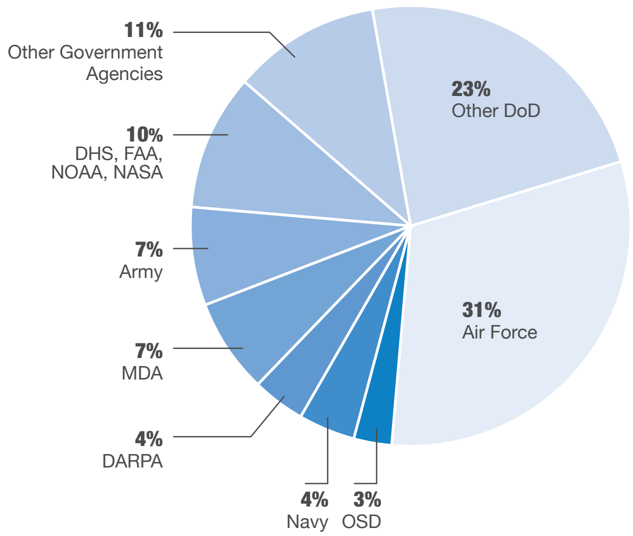


Academic Degree

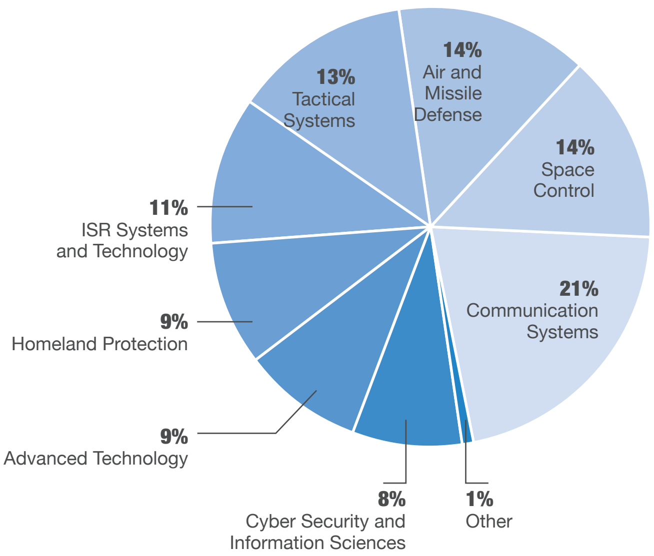


Breakdown of Laboratory Program Funding

Sponsor

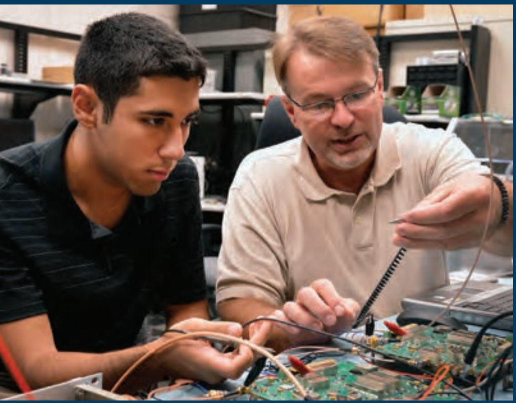


Mission Area



Lincoln Space Surveillance Complex, Westford, Massachusetts

Reagan Test Site, Kwajalein Atoll, Marshall Islands



LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
244 Wood Street, Lexington, MA 02420-9108

www.ll.mit.edu
Communications and Community Outreach Office: 781.981.4204

Approved for public release; distribution is unlimited.
This work is sponsored by the Department of the Air Force under Air Force Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Government.

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

Follow MIT Lincoln Laboratory online.

Facebook: MIT Lincoln Laboratory (Official)

LinkedIn: http://www.linkedin.com/company/mit-lincoln-laboratory

Twitter: @MITLL