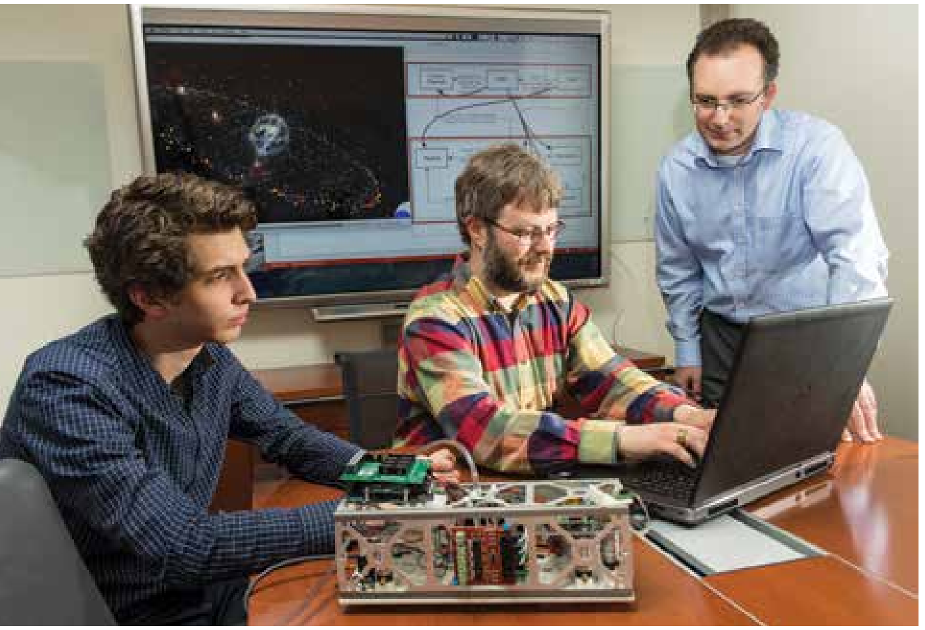
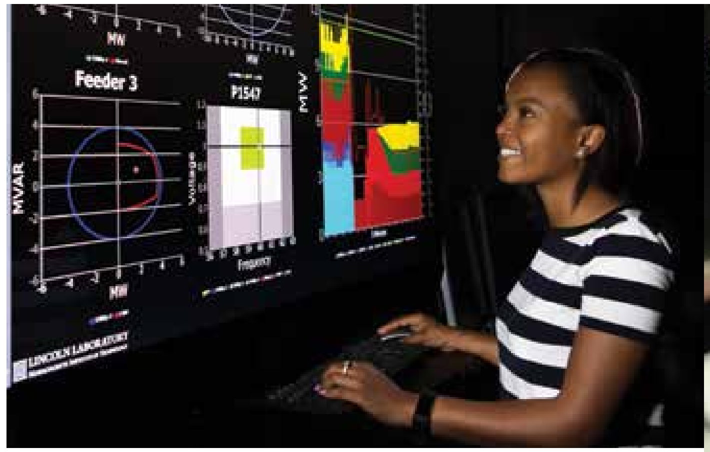
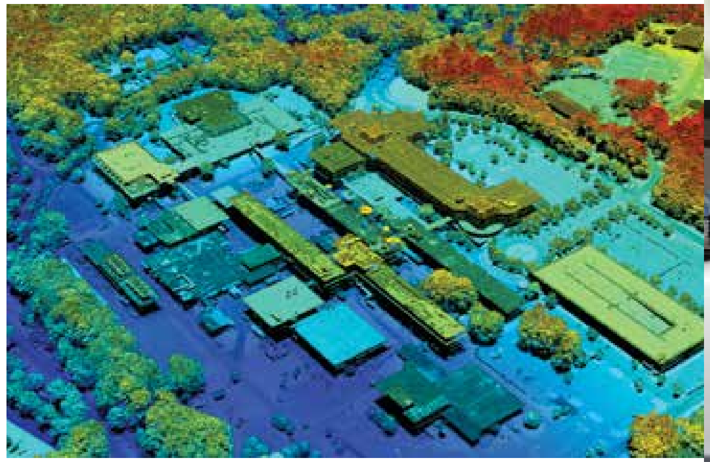
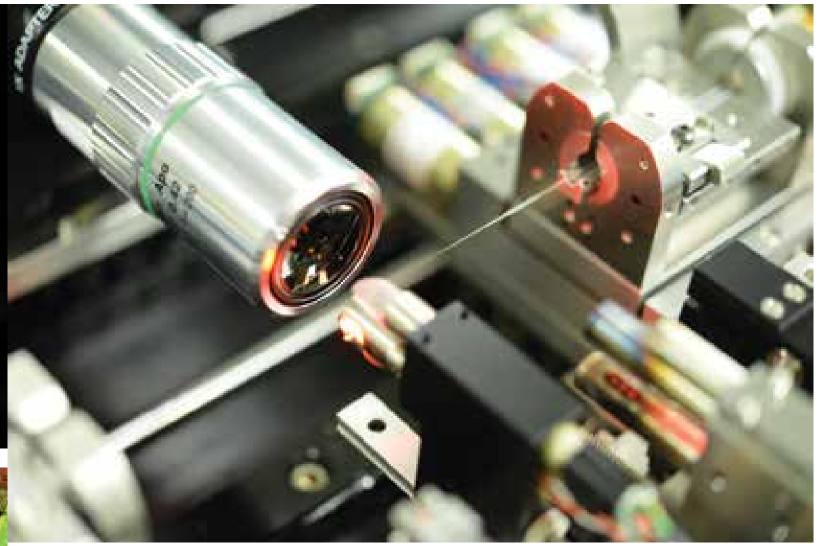
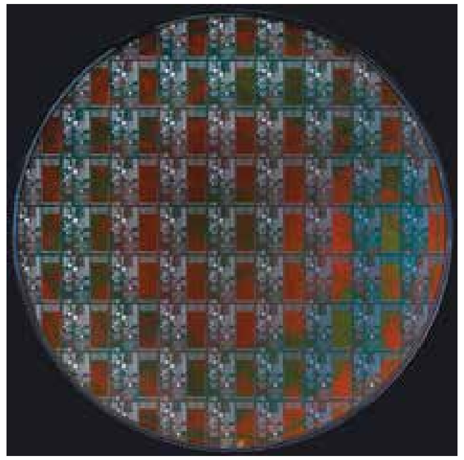










Follow MIT Lincoln Laboratory online.

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
244 Wood Street ▪ Lexington, Massachusetts 02421-6426

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

Approved for public release: distribution unlimited. This material is based upon work supported by the Department of the Air Force under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the U.S. Air Force.

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

MIT LINCOLN LABORATORY

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

2017 ANNUAL REPORT

Massachusetts Institute of Technology

Lincoln Space Surveillance Complex, Westford, Massachusetts

MIT Lincoln Laboratory

Reagan Test Site, Kwajalein Atoll, Marshall Islands

MIT LINCOLN LABORATORY 2017

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 66 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. Martin A. Schmidt (left)
Provost

Dr. Maria T. Zuber (right)
Vice President for Research

MIT Lincoln Laboratory

Dr. Eric D. Evans
Director

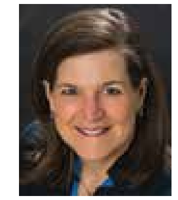
Dr. Marc D. Bernstein (left)
Associate Director

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

ORGANIZATIONAL CHANGES

Deborah J. Campbell

Associate Technology Officer



Dr. Deborah J. Campbell was appointed an Associate Technology Officer within the MIT Lincoln Laboratory Technology Office (TO). Her responsibilities include supporting the strategic development of the Laboratory's internal R&D investments, developing and executing innovation initiatives such as the TO Challenges, and aiding in the general coordination of the Laboratory's technology development strategy. She also helps facilitate research collaborations with MIT campus and other academic institutions. Prior to this appointment, she was a technical staff member in the Chemical and Biological Defense Systems Group, where she led a significant portfolio of programs focused on developing, testing, and fielding technologies and techniques to support the attribution of illicit activities to groups or individuals.

Alexander M. Stolyarov

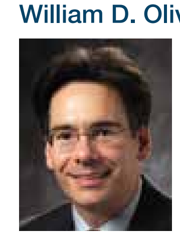
Project Lead, Defense Fabric Discovery Center

Dr. Alexander M. Stolyarov, a technical staff member in the Chemical, Microsystem, and Nanoscale Technologies Group, is the project lead for the new initiative to develop advanced fibers and fabrics for clothing or equipment used by the military. He will be leading R&D at the Defense Fabric Discovery Center, an end-to-end prototyping facility equipped to design and produce fabrics that can change color, store energy, emit and detect light, monitor health, or facilitate communication. This center was established through a collaboration among Lincoln Laboratory, the U.S. Army Natick Soldier Systems Center, the Commonwealth of Massachusetts, and the Advanced Functional Fabrics of America.

MIT Lincoln Laboratory Fellow

The Fellow position recognizes the Laboratory's strongest technical talent for their sustained outstanding contributions to both Laboratory and national-level programs.

William D. Oliver



Dr. William D. Oliver is recognized for his exceptional technical achievements in quantum information science (QIS), superconducting electronics, and complementary metal-oxide semiconductor (CMOS) technology operated at cryogenic temperatures. He established much of Lincoln Laboratory's early QIS research portfolio. In the area of superconducting quantum computing, he has advanced the state of the art for the design, fabrication, and measurement of quantum bits (qubits) in experiments performed at millikelvin temperatures.

Dr. Oliver was responsible for launching cryogenic electronics program areas important for future QIS demonstrations and for other Department of Defense advanced computing and imager applications. As part of this work, he laid the foundation for the Laboratory to develop the world's most advanced fabrication process for superconducting circuits.

Dr. Oliver has also been appointed the associate director of the MIT Research Laboratory of Electronics (RLE), where he will lead a broad range of QIS research and development activities and serve as the liaison for joint ventures between RLE and Lincoln Laboratory. He has served as a Professor of the Practice in the MIT Physics Department since 2015 and has led collaborations between MIT and the Laboratory to advance the scientific understanding of superconducting qubits through widely recognized seminal experiments.

Letter from the Director

For Lincoln Laboratory, 2017 has seen successful research and development of advanced technology across all mission areas. Our researchers, often working in cross-divisional teams, have produced many prototype systems with expanded capabilities. It has also been a year of exciting new projects. Throughout the Laboratory, our scientists and engineers are proposing new, interesting ways to apply our expertise in sensors, computing, and electronics.

We were proud to have contributed to disaster preparation and response efforts for hurricanes Harvey, Irma, and Maria. Researchers used prototype decision support technology to help agencies plan for the hurricanes' landfall. Several staff members deployed to Texas to fly an airborne optical system that collected imagery data of ground conditions in the Houston area; analysts back at the Laboratory processed the data to provide the Federal Emergency Management Agency with maps depicting significant debris locations and road trafficability. On Puerto Rico, staff helped build a water purification system that is bringing clean water to a small village.

During the past year, we reached significant milestones in several areas.

- SensorSat, a small satellite developed by the Laboratory, was launched in August and is in orbit helping to help provide the Air Force with increased space situational awareness.
- The flight payload for the Transiting Exoplanet Survey Satellite (TESS) was delivered to the spacecraft vendor. TESS, jointly developed by the MIT Kavli Institute for Space Research and Lincoln Laboratory under funding from NASA, is scheduled to launch in 2018 on its mission to discover exoplanets orbiting stars other than the Sun.
- We established the Defense Fabric Discovery Center, a facility for the development of advanced fabrics that can be integrated with microelectronics to provide clothing equipped with sensing capabilities.
- Our advanced signal processing techniques can significantly improve the direction-finding performance of undersea electronic surveillance systems.
- A graph processor designed to handle large, complex datasets has shown computational performance similar to that of supercomputers while consuming 100 times less power.
- The increased computational power provided by the petascale computer of the Lincoln Laboratory Supercomputing Center is allowing researchers to model complex simulations and manage big data. This supercomputer is also capable of supporting the continuing work of our bioengineers who have developed the world's fastest computational methods for searching DNA databases.
- We developed an advanced high-power laser that is being evaluated for use in the Laser Interferometer Gravitational-wave Observatory.
- Our promising new process for building germanium charge-coupled devices (CCDs) could expand imaging into the shortwave and X-ray bands. We built the world's first functional 32 × 32–pixel germanium CCD.
- Work is continuing on the 76-panel Multifunction Phased Array Radar, whose dual-use capabilities may make it the future replacement for the nation's various aging weather and air traffic surveillance radars.
- We developed and demonstrated the world's first distributed low-power coherent radio system for antijam communications.

The above summary presents just a fraction of the important work that we have done this year. We encourage you to read this report to find out more about the many accomplishments that continue to build our reputation for applying technical excellence and integrity to the development of technology for national security.

Sincerely,

Eric D. Evans
Director

MIT Lincoln Laboratory

MISSION: TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

VISION

To be the nation's premier laboratory that develops advanced technology and system prototypes for national security problems

- To work in the most relevant and difficult technical areas
- To strive for highly effective program execution in all phases

VALUES

- **Technical Excellence:** The Laboratory is committed to technical excellence through the people it hires and through its system and technology development, prototyping, and transition.
- **Integrity:** The Laboratory strives to develop and present correct and complete technical results and recommendations, without real or perceived conflicts of interest.
- **Meritocracy:** The Laboratory bases career advancement on an individual's ability and achievements. A diverse and inclusive culture is critically important for a well-functioning meritocracy.
- **Service:** The Laboratory is committed to service to the nation, to the local community, and to its employees.

STRATEGIC DIRECTIONS

- Continue evolving mission areas and programs
- Strengthen core technology programs
- Increase MIT campus/Lincoln Laboratory collaboration
- Strengthen technology transfer to acquisition, user, and commercial communities
- Find greater efficiencies and reduce overhead process
- Improve leverage through external relationships
- Improve Laboratory diversity and inclusion
- Enhance Laboratory facilities
- Enhance Laboratory community outreach and education

Distinguished Visitors

Senior military leaders and government representatives visit Lincoln Laboratory to learn about innovative research and technology development that can advance their missions, provide solutions to national defense problems, or contribute to the nation's industrial base.

Below are some of this year's guests who discussed current technology thrusts with Laboratory leadership, toured the Laboratory's unique facilities, and attended demonstrations of new systems.

U.S. Representative Donald J. Bacon (R-Neb.)

Lieutenant Governor Karyn Polito (R-Mass.)

Dr. Michael M. Watkins
Director, NASA Jet Propulsion Laboratory

Department of Defense

General Mark A. Milley
Chief of Staff of the U.S. Army

General Ellen M. Pawlikowski
Commander, Air Force Materiel Command, Wright-Patterson Air Force Base

Vice Admiral Thomas S. Rowden
Commander, Naval Surface Forces, U.S. Pacific Fleet

Lieutenant General VeraLinn Jamieson
U.S. Air Force, Deputy Chief of Staff for Intelligence, Surveillance and Reconnaissance, Headquarters, U.S. Air Force

Lieutenant General Jeffrey G. Lofgren
U.S. Air Force, Deputy Chief of Staff for Capability Development, Headquarters, Allied Command Transformation

Lieutenant General Michael H. Shields
U.S. Army, Director, Joint Improvised-Threat Defeat Agency

Major General Stephen T. Denker
U.S. Air Force, Deputy Director, National Reconnaissance Office

Major General Michael A. Fantini
Director, Global Power Programs, Office of the Assistant Secretary of the Air Force for Acquisition

Major General James V. Young Jr.
U.S. Army, Commander, 75th Training Command, Houston, Texas

Major General Thomas J. Masiello
U.S. Air Force (Ret.), Director, Adaptive Execution Office, Defense Advanced Research Projects Agency

Brigadier General John E. Shaw
U.S. Air Force, Director, Strategic Plans, Programs, Requirements, and Analysis, Headquarters, Air Force Space Command

Senatorial Visit

In August, Senators Elizabeth A. Warren (D-Mass.) and John F. "Jack" Reed (R-R.I.) visited Lincoln Laboratory. The senators were briefed on some of the new technologies being developed here and the economic impact the Laboratory has on the region.

Above, during a tour of the Laboratory, from left to right, Colonel Roman Hund, Commander, 66th Air Base Group, Hanscom Air Force Base; Maria Zuber, Vice President for Research, MIT; Sen. Jack Reed, R-R.I.; Sen. Elizabeth Warren, D-Mass.: Eric Evans, Director, Lincoln Laboratory; and General Dwyer Dennis, Program Executive Officer for C3I and Networks, Hanscom Air Force Base, paused for a photograph.
Left, in the Laboratory's Rapid Prototyping Facility, Sen Warren, who gets a closeup view of the miniature unmanned aerial vehicle (UAV), and General Dennis heard about the development of this mini-UAV that is capable of autonomous navigation.

Keynote Speakers

Major General Sarah Zabel, Vice Director of the Defense Information Systems Agency, delivered a keynote address at the 2017 Communications Workshop.

Annually, 10 to 12 technical conferences are held at Lincoln Laboratory. Covering a range of topics core to the Laboratory's work, the conferences foster a continuing dialogue among members of the defense community, research institutes, and industry. Typically, leaders from the military or academia give keynote addresses.

In 2017, the keynote speakers included several senior military and government leaders:

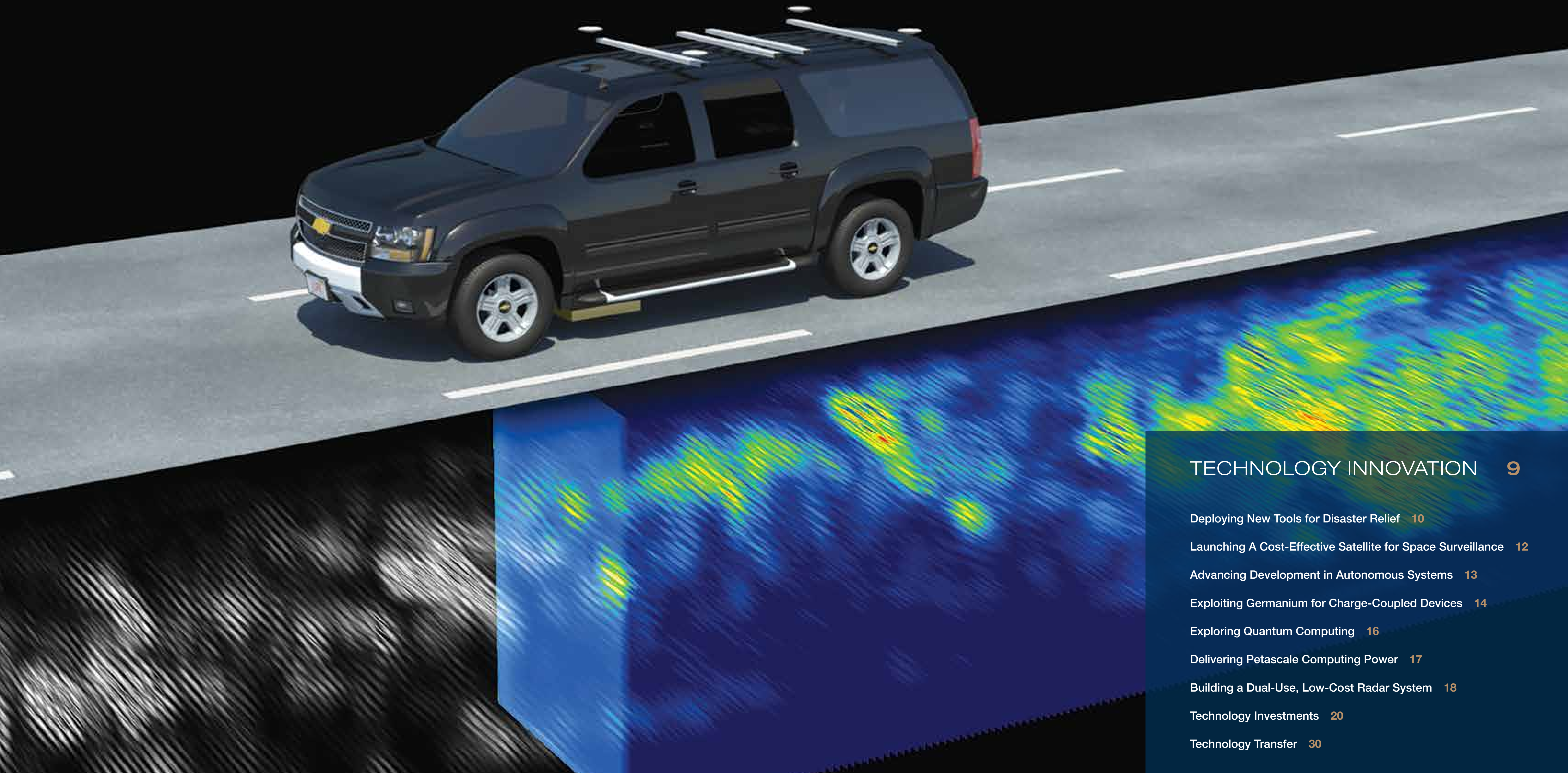
- **Major General David W. Allvin**, Director, Strategy and Policy, U.S. European Command
- **James H. Baker**, Director of the Office of Net Assessment, Office of the Secretary of Defense
- **Vice Admiral Richard P. Breckenridge**, Deputy Commander, U.S. Fleet Forces Command
- **Colin F. Jackson**, Professor of Strategy and Policy, Advanced Naval Strategy Program, Naval War College
- **General David G. Perkins**, Commanding General, U.S. Army Training and Doctrine Command

Special Seminar

The Cybersecurity, Exploitation, and Operations Workshop held in June at Lincoln Laboratory hosted a talk by Paul Reed Smith, far right, manager and original technology developer at Digital Harmonic, a company that provides new technologies for image and signal analysis. Smith is also the founder of PRS Guitars, which provides electric and acoustic guitars to some of the most respected guitarists in the country. He is seen here with, from left, Curt Davis, Principal Staff in the ISR and Tactical Systems Division; John Wilkinson, Leader of the Cyber System Assessments Group; and Dinara Doyle, an information technology specialist in the Secure Resilient Systems and Technology Group.

U.S. Air Force

During his visit to the Laboratory, General Herbert Carlisle, Commander, Air Combat Command, Langley Air Force Base, addressed an audience in the auditorium and fielded questions on Air Force future needs.

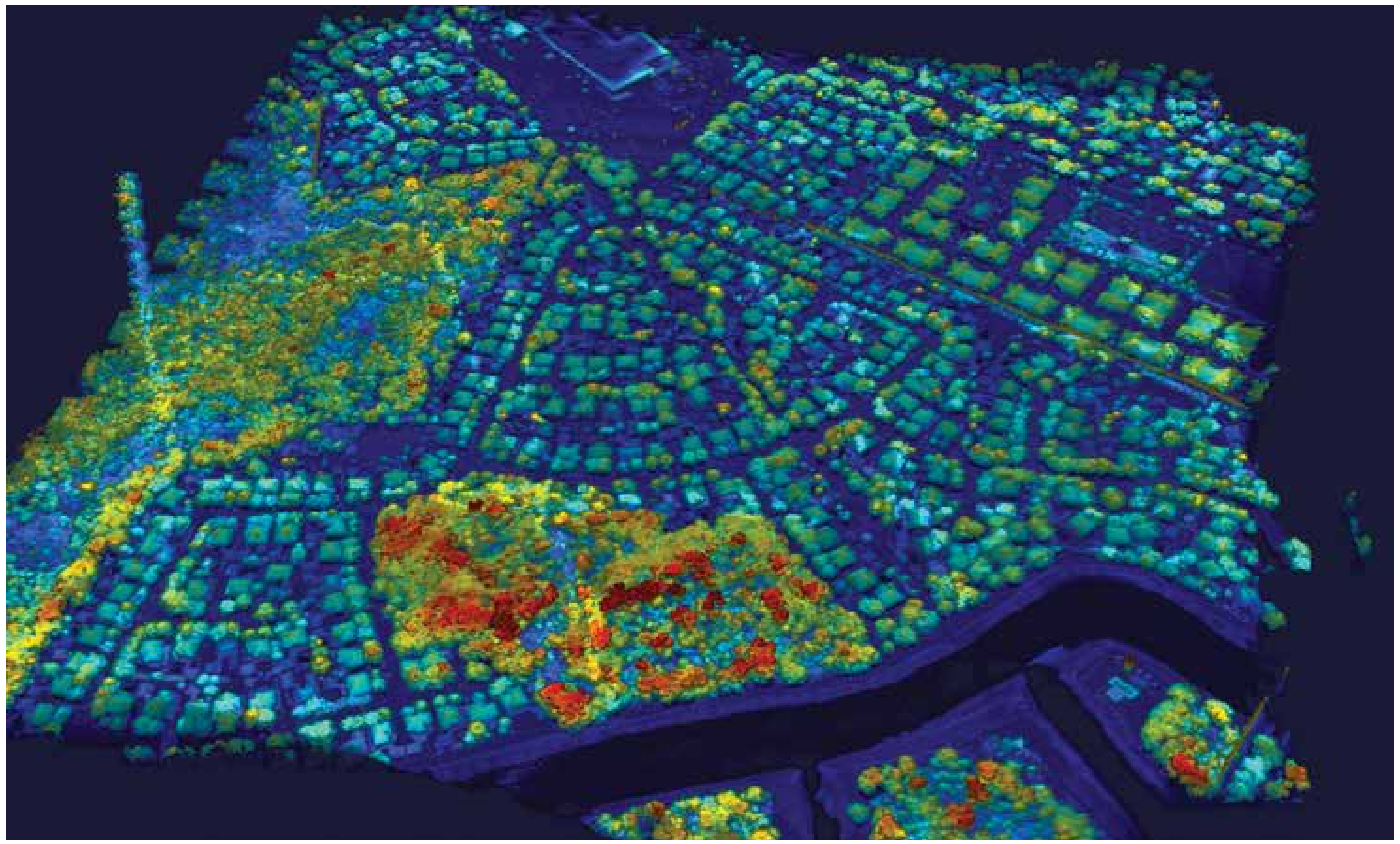


TECHNOLOGY INNOVATION 9

The car is autonomously navigated within its lane by the Localizing Ground-Penetrating Radar mounted beneath the vehicle. The radar orients the car by “reading” a map of geological features below the road surface (the colored RF reflections).

Deploying New Tools for Disaster Relief

In the days leading up to Hurricane Harvey's landfall in Texas in August 2017, the Federal Emergency Management Agency (FEMA) asked Lincoln Laboratory to assist with planning and response efforts. Staff from the Humanitarian Assistance and Disaster Relief Systems Group joined FEMA at the National Response Coordination Center (NRCC) in Washington, D.C., where they shared knowledge of Laboratory capabilities. FEMA would soon call upon those capabilities to address the crises of hurricanes Harvey, Irma, and Maria.



Above, a wide-area 3D ladar image of a Houston suburb. The colors denote elevation, with red indicating the highest heights (treetops) and indigo indicating ground level. By processing out the data denoting the higher elevations, analysts can then locate debris piles that are blocking roads. Below, a researcher zooms in on the power outage map of Puerto Rico in Irma's immediate aftermath. Power outage maps are just one tool that the Laboratory integrated into the HV-X interface to enable timely and accurate monitoring of hurricane impacts.

Assessing Road Trafficability

Among the many responsibilities FEMA faces after a disaster is clearing debris that blocks roads and buildings. Locating debris piles and estimating their size usually require the U.S. Army Corps of Engineers (USACE) to physically survey streets. A Laboratory ladar platform known as the Airborne Optical Systems Test Bed (AOSTB), integrated onto a Twin Otter aircraft, proved that it can replace this task by generating wide-area debris maps and volume estimations based on data collected from an altitude of 11,000 feet.

Laboratory staff conducted daily flight missions for two weeks over impacted areas near Houston. The ladar data were collected in two modes. First, the system scanned in wide-area mode, which allowed for quickly imaging large areas but at a low resolution. Within those areas, the team also scanned smaller swaths in targeted mode, which provided clean data more suited for estimating debris. The data were then sent to the processing team at the Laboratory, where the collection of data was filtered and enhanced to remove all elements except debris piles. Debris volumes deduced from the ladar images were consistent with those made by USACE.

Improving Hurricane Situational Awareness

Since 2014, Lincoln Laboratory has been funded by the Department of Homeland Security Science and Technology Directorate (DHS S&T) to analyze and enhance FEMA's National Hurricane Program suite of hurricane planning and evacuation tools. As a result, Lincoln Laboratory has prototyped a new platform, called HURREVAC-eXtended (HV-X). This web-based platform provides decision support tools that enable emergency managers to make timely, accurate evacuation-related decisions. HV-X is the first platform to include evacuation zone–based impact assessments and unique tools for visualizing potential storm surge levels. In a simple user interface, the system incorporates into these tools hurricane forecasts, current weather conditions, and embedded data analytics. Although slated for operation in 2018, HV-X successfully debuted its capabilities to FEMA staff who requested its use at the NRCC. In addition, the S&T investment enabled the visualization of data analytics that provided situational awareness on hazards such as power outages, business open/close status, and off-shore precipitation.

Monitoring Power Outages

It can take days to understand the extent of power outages in large-scale disasters. Using a new cyber-sensing system, Lincoln Laboratory produced accurate, real-time power outage maps that were delivered to FEMA hourly. The system uses network data to infer the status of power infrastructure by scanning IP addresses in a targeted region and comparing their response rates before, during, and after the storm. Using those results, Laboratory researchers calculate an average percentage of normal network activity per town. These percentages are mapped on a color-scale, ranging from dark red for zero network activity to dark blue for networks operating as usual. This system was used to create power outage maps for the coastal areas of Texas and the entirety of Florida, Georgia, Puerto Rico, U.S. Virgin Islands, and other Caribbean islands during each relevant hurricane.

Providing Clean Water

Depleted water resources paired with power outages and fuel shortages can translate into a humanitarian crisis. In Puerto Rico, Laboratory staff and GeoInnovation, an energy company based out of Arizona, deployed a photovoltaic system to power a water purifier and eliminate its need for a generator and a corresponding fuel supply. The solar-powered system is lightweight and doesn't require power from the electrical grid or batteries. The water purifier provides clean water for 1000 people per day and was developed by Infinitum Humanitarian Systems and the Roddenberry Foundation. A follow-on to this effort will be the joint development of a water system and renewable power source that can support 4000 people per day in a disaster area.

Photo courtesy of Lorenzo Moscia

Erik Limpaecher of the Laboratory's Energy Systems Group and Mabel Ramirez of the Advanced Concepts and Technologies Group worked with a team from Infinitum Humanitarian Systems and the Roddenberry Foundation to install a solar-powered water filtration system at the Boys and Girls Club in Residencial Las Margaritas in Santurce, San Juan, Puerto Rico, as part of the island's continued Hurricane Maria recovery effort. The team also installed this system at the Boys and Girls Club in Loiza, Puerto Rico. Each water filtration system will be able to provide clean and safe water to 1000 people a day.

Launching A Cost-Effective Satellite for Space Surveillance

On 26 August 2017, the sky over Cape Canaveral, Florida, lit up with the bright plume of a Minotaur rocket lifting off from its launch pad. Aboard the rocket, a satellite developed by Lincoln Laboratory for the U.S. Air Force's Space Rapid Capabilities Office, formerly Operationally Responsive Space (ORS), awaited its deployment into low Earth orbit. The ORS-5 SensorSat spacecraft is on a 3-year mission to continually scan the geosynchronous belt, which at about 36,000 kilometers above Earth is home to satellites indispensable to the national economy and security. Data collected by SensorSat will help the United States keep a protective eye on the movements of satellites and space debris in the belt.

The 226-pound SensorSat is small compared to current U.S. satellites that monitor activity in the geosynchronous belt. SensorSat's size and its optical system design that uses a smaller aperture make it a lower-cost, more rapidly built option for space surveillance missions than the large systems designed for missions of 10 years or more. Unlike satellites that use optical systems mounted on gimbals that must be rotated to view sections of the sky, SensorSat's fixed optical system surveys the portion of the belt it "sees" as the satellite orbits Earth. SensorSat makes approximately 14 passes around Earth each day, providing up-to-date views of activity in the geosynchronous belt.

The SensorSat engineering effort involved the design, fabrication, and testing of the satellite structure and cover mechanism, lens optomechanics, telescope baffle, charge-coupled device packaging, electrical cabling, and thermal control. The shock, vibration, attitude control system, and thermal-vacuum testing performed in the Laboratory's cleanroom facilities were critical in validating SensorSat against the expected launch and space conditions it would need to endure.

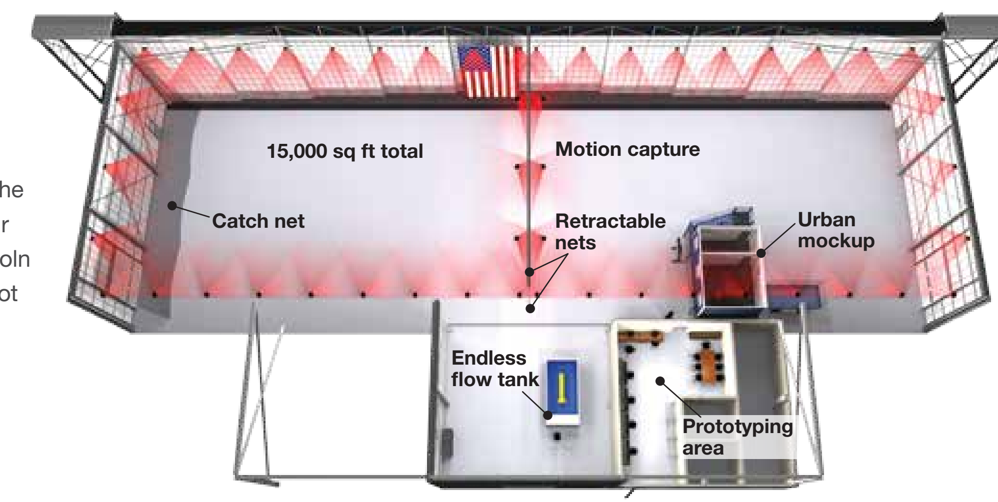
Since launch, SensorSat has undergone a complete checkout process, opened the cover of its optical system, collected the first imagery of objects in the geosynchronous belt, and is collecting data to fulfill its space surveillance mission.

Above, engineers inspect SensorSat prior to thermal-vacuum testing that emulates the conditions the satellite will be exposed to on orbit. Below, in Florida, researchers integrate SensorSat with the Minotaur IV rocket from which it will be deployed into orbit.

Above, an autonomous aerial vehicle is navigating through a set of obstacles set up in the Autonomous Systems Development Facility. Below, the illustration shows the layout of the Autonomous Systems Development Facility.

Advancing Development in Autonomous Systems

The Autonomous Systems Development Facility (ASDF) is a new state-of-the-art Laboratory-wide resource that enables the development and testing of cutting-edge autonomy algorithms and capabilities and that facilitates early risk-reduction efforts. The ASDF is housed in a hangar on Hanscom Air Force Base about a mile from the main Lincoln Laboratory complex. This 17,000-square-foot indoor test facility with its 200-foot length, 34-foot-high ceiling, and continuous-flow water tank accommodates the prototyping and testing of unmanned ground-based, aerial, and undersea autonomous systems.



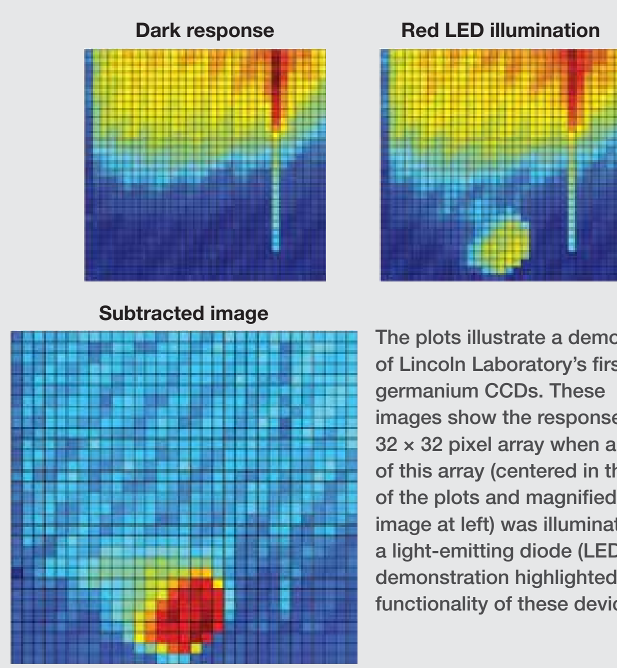
The space is outfitted with vertically retractable nets that act as safety barriers capable of withstanding high-force impacts and that can section off areas for simultaneous use of the space by multiple programs. Mounted around the perimeter of the hangar are infrared sensors that function as part of an integrated motion-capture system to localize passive reflective tags on vehicles. This system provides highly accurate information about the position and orientation of those vehicles in real time. The motion-capture system is planned to be part of a future novel indoor positioning system that generates GPS signals while a GPS-equipped vehicle is in motion.

Staff from more than a dozen groups and six divisions are using this new facility for testing and dry runing systems before major outdoor field tests. Some of the innovations being explored in the ASDF are advanced autonomy algorithms that coordinate the interaction of a group of drones, a new type of propeller that has a low acoustic signature, and a system for countering unmanned aircraft in an urban environment.

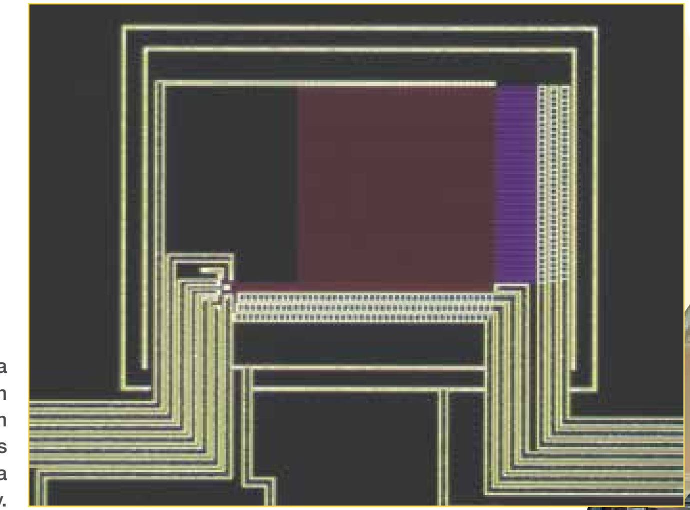
The equipment in the state-of-the-art Microelectronics Laboratory allows researchers to develop world-class imaging devices in a facility that provides an unparalleled combination of advanced capabilities and the flexibility to introduce new materials and processes.

Exploiting Germanium for Charge-Coupled Devices

Lincoln Laboratory is developing germanium charge-coupled devices (CCDs) for new applications in advanced imaging. Charge-coupled devices fabricated on bulk germanium realize all of the advantages of traditional silicon CCDs—excellent uniformity, low noise, and specialized capabilities such as orthogonal transfer for motion compensation and time-delay integration to track faint moving objects—but cover an even broader spectral range. In particular, germanium CCDs have sensitivity extending into both the short-wave infrared (SWIR) and hard X-ray bands while maintaining sensitivity to all of the wavebands covered by silicon. In addition, because germanium substrates are commercially available in diameters up to 200 mm, germanium CCDs can be processed with advanced fabrication tools already used in silicon wafer fabrication, enabling the same wide field of view and narrow pixel pitch of silicon devices.



The plots illustrate a demonstration of Lincoln Laboratory's first germanium CCDs. These images show the response of a 32 × 32 pixel array when a section of this array (centered in the bottom of the plots and magnified in the image at left) was illuminated by a light-emitting diode (LED). This demonstration highlighted the functionality of these devices.



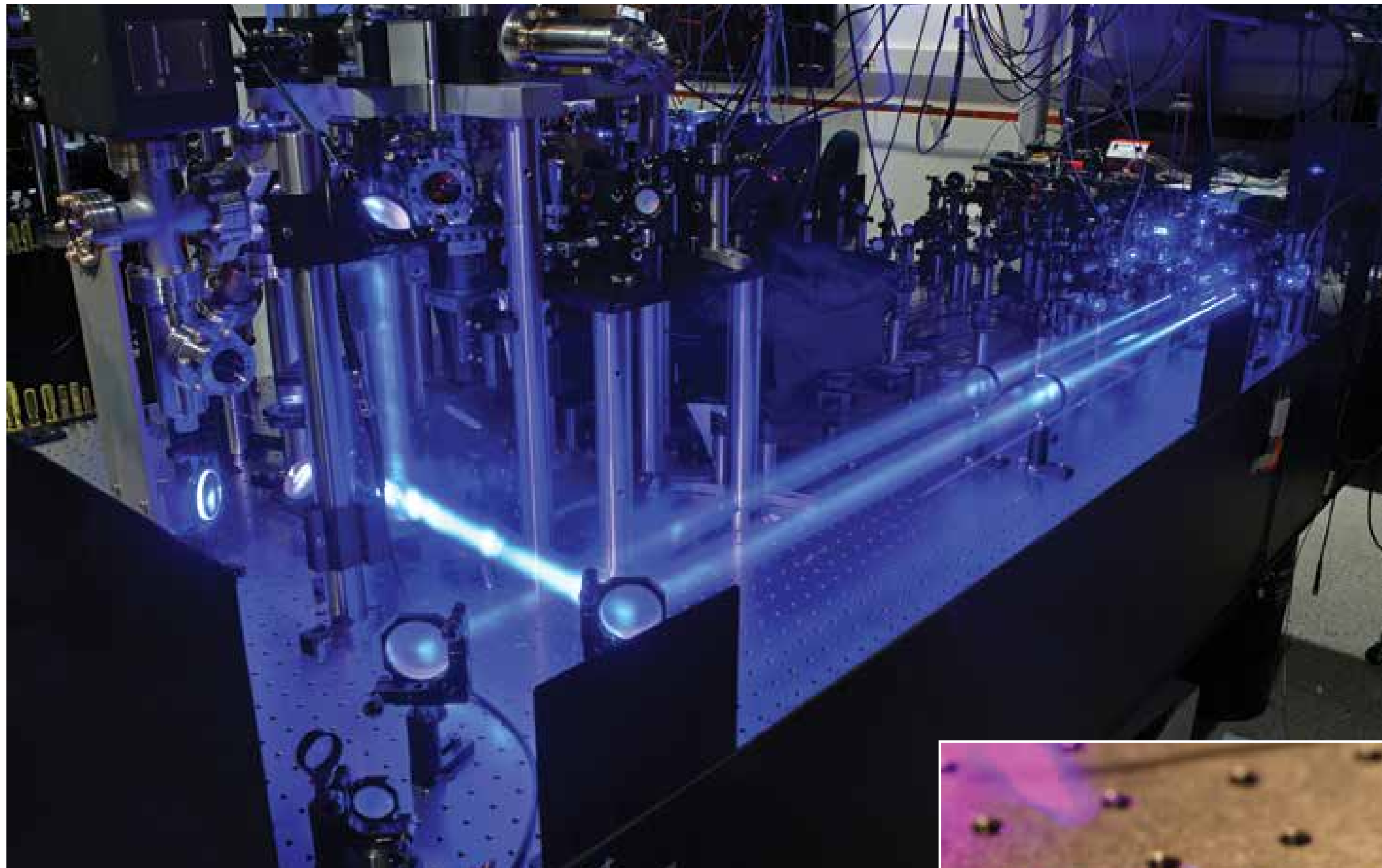
In this image of a processed 200 mm diameter germanium wafer, the callout shows a micrograph of a 32 × 32 pixel array.

Germanium CCDs have the potential to significantly improve imager performance for night-vision applications. The SWIR band, which is critical for night vision, is enabled by a phenomenon known as airglow. Airglow occurs primarily from the de-excitation of atoms and molecules in the upper atmosphere that have been ionized by ultraviolet solar radiation during the day. The light emitted from this process occurs predominantly in the SWIR band. While airglow provides a substantial source of nighttime illumination, nearly all of its intensity lies outside the detection range of silicon CCDs. In contrast, germanium CCDs can detect the vast majority of airglow, providing an extremely sensitive, large-field-of-view night-vision capability.

Germanium CCDs also have important applications in astronomy. Black holes, active galactic nuclei, and other energetic objects in deep space emit X-rays. A germanium CCD can image over the entire X-ray band, enabling observations of objects throughout the universe that were previously beyond the capabilities of other imagers. Imagery gathered from the X-ray band could provide valuable insights about the evolution of these objects across time and space; for example, images of deep-space bodies could help to resolve questions around galaxy formation.

Finally, the broad sensitivity of germanium across multiple wavebands may also enable new applications in imaging. As an example, one sensor equipped with germanium CCDs could image in both the visible and SWIR bands, enabling persistent day–night surveillance.

Researchers working in Lincoln Laboratory's unique semiconductor fabrication facility were able to introduce germanium wafers and develop the requisite processes used to build high-quality germanium CCDs in the same state-of-the-art tool set used to build silicon imagers. In early 2017, they demonstrated a germanium CCD in a 32 × 32 pixel array that represents an important proof of concept for this technology. In the coming years, the Laboratory plans to scale these devices to larger arrays, eventually making Mpixel-class, and beyond, devices for applications in national defense and basic science.



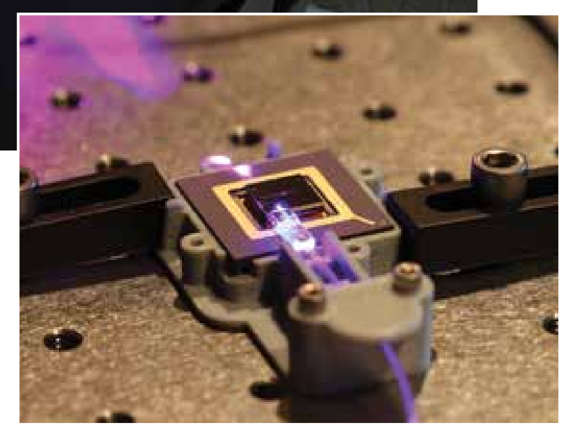
Exploring Quantum Computing

Quantum computing could solve problems that are beyond the capabilities of the world's most powerful classical supercomputers. To realize this potential, researchers are exploring how quantum physics can be applied to storing and manipulating data in a way fundamentally different from that of classical physics. The quantum bits, or qubits, used in a quantum computer can be made from a number of physical systems, two of which Lincoln Laboratory is investigating: single trapped atomic ions and Josephson junction–based superconducting circuits.

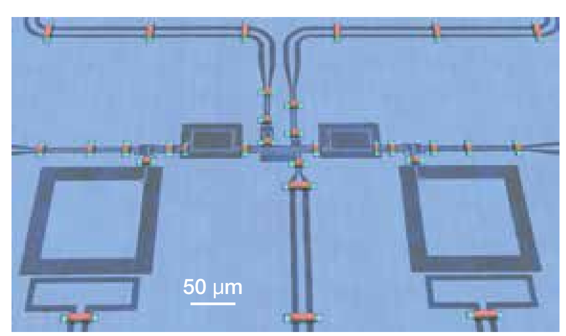
Lincoln Laboratory researchers are working on quantum systems in a well-equipped set of facilities that make up the Quantum Computing Laboratory. The trapped-ion facility contains several cryogenically cooled ultrahigh vacuum systems used to house microfabricated chips that trap individual strontium and calcium ions above their surface. The trapped ions are manipulated through the use of lasers and other electromagnetic fields to perform quantum processing operations.

The superconducting quantum computing facility contains nine cryogenic dilution refrigerators as well as microwave test and measurement equipment for controlling and measuring superconducting qubits at temperatures of 20 mK and below.

Ongoing work in both facilities is focused on scaling up systems of qubits to a size large enough to address real computational problems, such as decrypting data and performing faster molecular analysis to design better drug treatments.



Top, lasers and optics are used to control single-atomic ions. Above, light is sent into an ion trap chip to be routed to the trapped-ion qubit via integrated optics.



This image of a coupled superconducting qubit device was produced by a confocal microscope. Two qubits interact through a tunable coupler. This device is fabricated from patterned aluminum (light blue) on a high-resistivity silicon substrate (dark blue). The orange lines indicate the aluminum air-bridge crossover connections.

Delivering Petascale Computing Power

The Lincoln Laboratory Supercomputing Center is an interactive, on-demand parallel computing system that uses large computing clusters to enable Laboratory researchers to augment the power of desktop systems to process large sets of sensor data, create high-fidelity simulations, and develop entirely new algorithms.

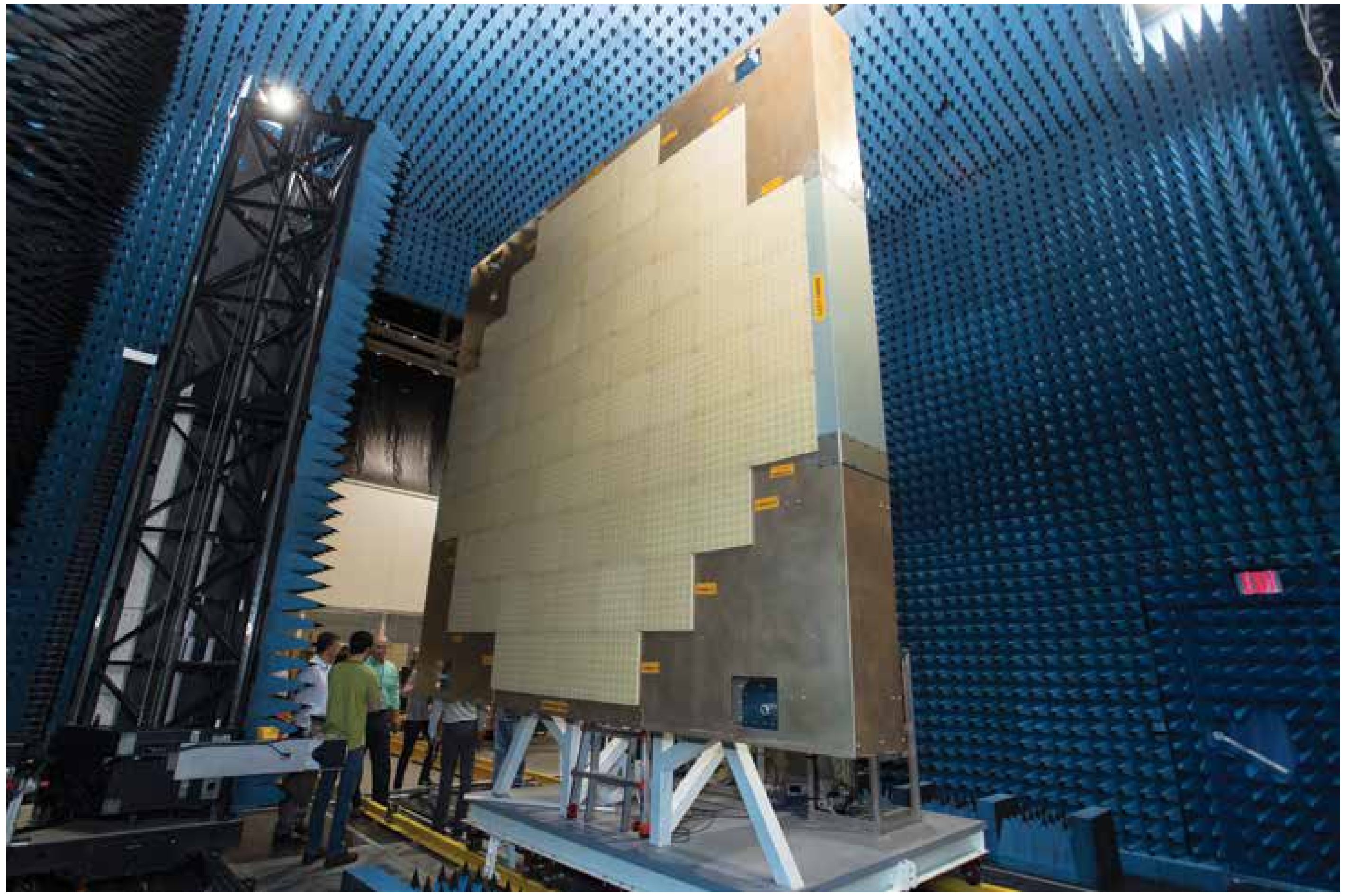
The most recent upgrade to the center is a petaflop-scale computing system that is providing researchers with 6 times more processing power and 20 times more bandwidth than the previous system. The new system contains 41,472 processor cores that can compute 10^{15} operations per second. This system is the most powerful supercomputer in New England and the third most powerful one used by a U.S. university.

The Supercomputing Center connects to a data center situated 90 miles away in Holyoke, a Massachusetts city on the Connecticut River. This data center, the Massachusetts Green High Performance Computing Center, is a computing infrastructure available to researchers from a consortium of technologies industries and Massachusetts schools, including MIT, Harvard University, the University of Massachusetts, Boston University, and Northeastern University. The center is powered by a combination of hydroelectric, wind, solar, and nuclear sources, allowing the Laboratory's computers to run 93% carbon-free.

Established in early 2016, the Supercomputing Center is used by more than 1000 researchers across the Laboratory. With the addition of the petascale system, the center is enabling new research in machine learning, advanced physical devices, cyber security, bioinformatics, and autonomous systems.

Above, a researcher is checking the petascale interactive supercomputer. Below, the Lincoln Laboratory supercomputing facility in Holyoke, Massachusetts, is an energy-efficient EcoPod.

Access to many compute nodes, each with substantial memory and a streamlined job submission process, has shortened the run time for simulations from a week to a few hours.



The 76-panel array, inside the large near-field chamber at the Flight Test Facility, is ready for testing.

Building a Dual-Use, Low-Cost Radar System

Lincoln Laboratory is developing a Multifunction Phased Array Radar (MPAR) Advanced Technology Demonstrator (ATD) that will be 4 meters in diameter, encompass 76 phased array panels, contain 5000 elements, have full polarimetric capability, and achieve a peak radiated power of 60 kW.

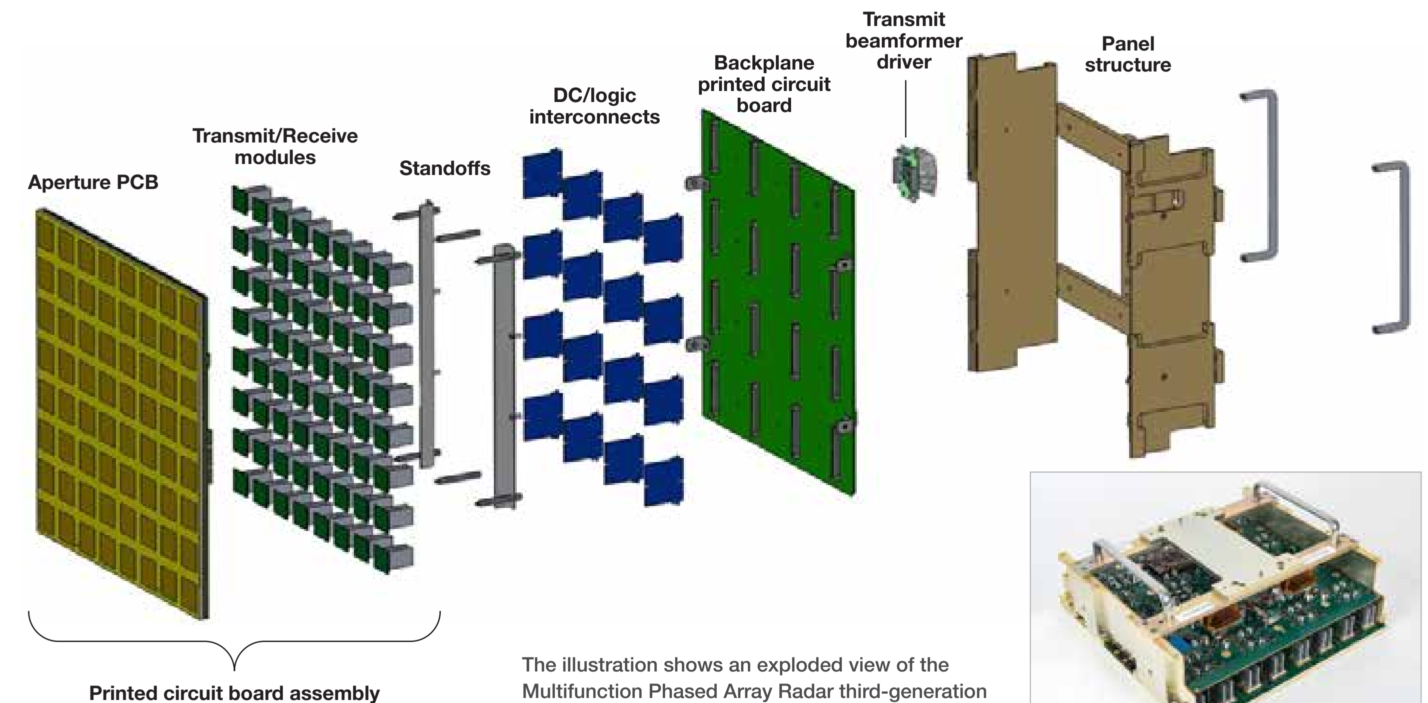
This large demonstration unit is made up of third-generation MPAR panels. Since 2007, the Laboratory has been developing an advanced, scalable phased array system based on low-cost panel technology. R&D into the MPAR was initiated to investigate replacement systems for the nation's aging air surveillance and weather radars. Currently within the United States and its territories, the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Air Force field more than 600 radars to conduct border and aircraft surveillance and weather forecasting. These radars are based on nine unique system designs that all employ mechanically rotated apertures and have an operational age of between 10 and 40 years. With some systems nearing their end of life, the costs and difficulty to maintain them are increasing because of the age of the systems and the obsolescence of parts.

The MPAR development, sponsored by the FAA, NOAA, and Air Force, is focused on the transition of phased arrays from predominantly Department of Defense missions to FAA and NOAA uses. This transition requires a nearly 20-fold decrease in cost from currently fielded military phased array apertures. The MPAR concept envisions a single scalable radar that could perform both aircraft surveillance and weather observations and could coalesce the operating bands of the nine existing radar systems of L, S, and C bands to S band only. Phased array attributes of adaptive scanning, higher sample rates, and variable waveforms directly enable this concept, while S-band-only operation frees up portions of the microwave spectrum traditionally dedicated to government use.

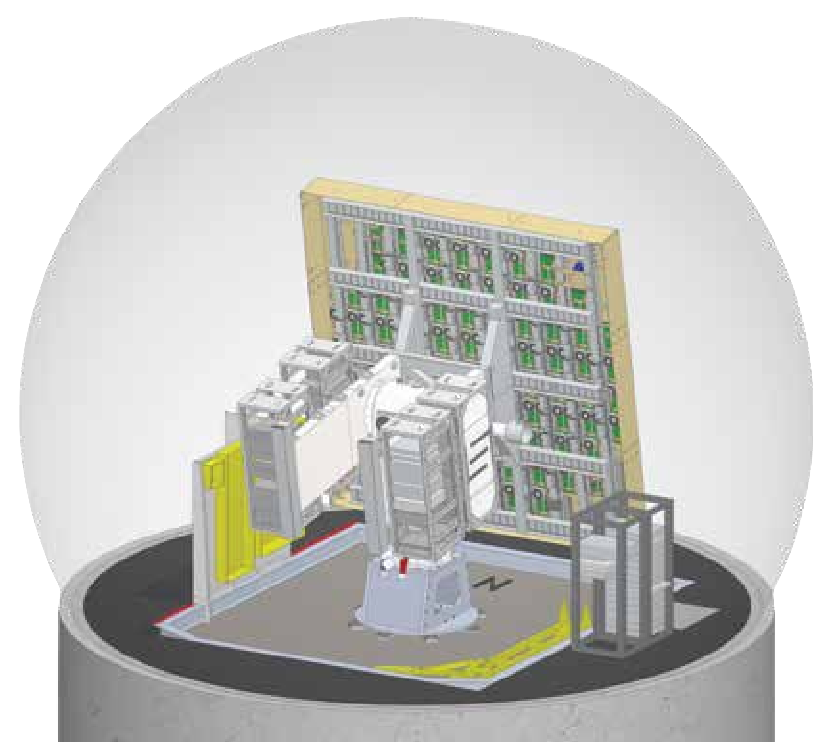
For the first-generation MPAR, Lincoln Laboratory teamed with the semiconductor company MACOM to develop the required microwave functions, beamformers, radiators, transmit and receive (T/R) modules, and monolithic microwave integrated circuits. Second-generation efforts focused on making the panels "tileable," that is, they could be arrayed in two dimensions. This objective required the development of a transmit driver, mechanical infrastructure, a thermal management scheme, and a backplane for voltage rail generation, power conditioning, and T/R module state control. These efforts culminated in the design, assembly, integration, and test of a mobile 10-panel demonstrator that was delivered in May 2015 to NOAA's National Severe Storms Laboratory in Norman, Oklahoma, where scientists have been using it to retire risk associated with the calibration of a dual-polarization (polarimetric) phased array.

A 5 m × 5 m near-field chamber newly built at Lincoln Laboratory's Flight Test Facility was used to evaluate the current ATD as an antenna and radar in the latter half of 2017. The MPAR ATD after shipment to Norman will take up residence at the National Weather Radar Testbed. Over the next decade, the ATD will be the National Severe Storms Laboratory's primary asset for R&D in the use of phased arrays for polarimetric radar.

The MPAR program has created technology transfer opportunities: the Laboratory's panel hardware was licensed to MACOM for sale to interested parties; a software licensing agreement for the real-time control of the panel state will be available soon; and the low-cost panel architecture is being adopted by other cost-sensitive phased array applications that target higher power and operating frequency, lighter weight, or element-level digital variants.



The illustration shows an exploded view of the Multifunction Phased Array Radar third-generation panel. At the bottom right is a photograph of an assembled panel.



This illustration shows the back view of the Multifunction Phased Array Radar Advanced Technology Demonstrator (ATD) as it sits atop the tower of the National Weather Radar Testbed facility in Norman, Oklahoma. The ATD is shown as encased by a transparent representation of its radome.

Technology Investments

The Technology Office manages Lincoln Laboratory's strategic technology investments and helps to establish and grow technical relationships outside the Laboratory. The office is responsible for overseeing investments in both mission-critical technology and potentially impactful emerging technology. To maintain an awareness of emerging national security problems and applicable technologies, the office interacts regularly with the Assistant Secretary of Defense for Research and Engineering and other government agencies. The office collaborates with and supports university researchers, and aids in the transfer of technology to industry. The Technology Office also works to enhance inventiveness and innovation at the Laboratory through various activities that effectively promote a culture of creative problem solving and innovative thinking.

LEADERSHIP
Mr. Robert A. Bond, Chief Technology Officer
Dr. Deborah J. Campbell, Associate Technology Officer (left)
Dr. Peter A. Schulz, Associate Technology Officer (right)

TECHNOLOGY HIGHLIGHT

Maritime Laser Communications

Optical communication signals are absorbed and scattered in the ocean, thereby limiting the link range and the data rate of the communication system. Lincoln Laboratory recently improved the link range and data rate in an undersea optical communications demonstration. The improvements resulted from the use of a collimated rather than a diverging beam. A collimated transmit beam was precisely pointed to the receive terminal during an in-ocean test at the Naval Undersea Warfare Center, located in Newport, Rhode Island, on Narragansett Bay.

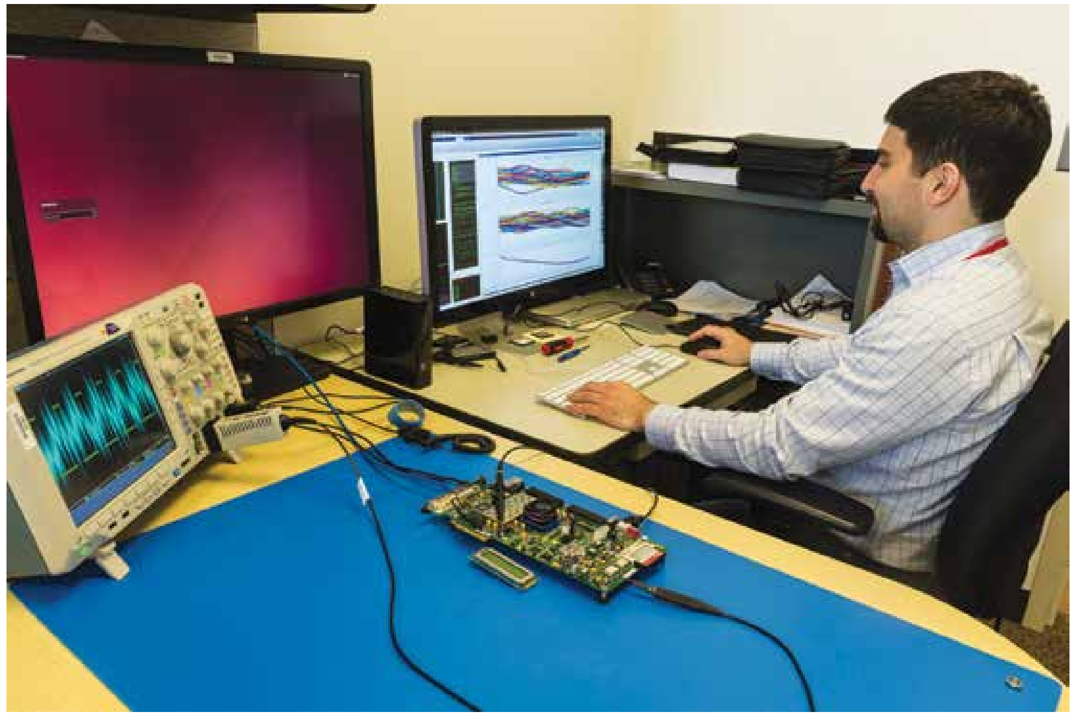
Precision pointing was accomplished by bidirectional search and track loops on each terminal, a methodology similar to that used in space laser communication systems. The high-rate communications and accurate pointing provide a flexible underwater system "information backplane" that enhances the utility of sensor packages integrated onto undersea platforms and provides an advancement that could fundamentally change undersea communications.

In 2017, optical communication terminals were integrated onto Blue Robotics' remotely operated underwater vehicle, the BlueROV2 platform, above, for in-ocean demonstrations.

INVESTMENTS IN MISSION-CRITICAL TECHNOLOGY

Enabling development of technologies that address long-term challenges and emerging issues within core mission areas

Cyber Security



An engineer is testing a cyber threat integrated into the hardware on the table.

The Laboratory's applied cyber research is focused on improving cyber security for the Department of Defense (DoD) and U.S. government agencies, and on developing a cyber security infrastructure for the future. Project highlights in 2017 include

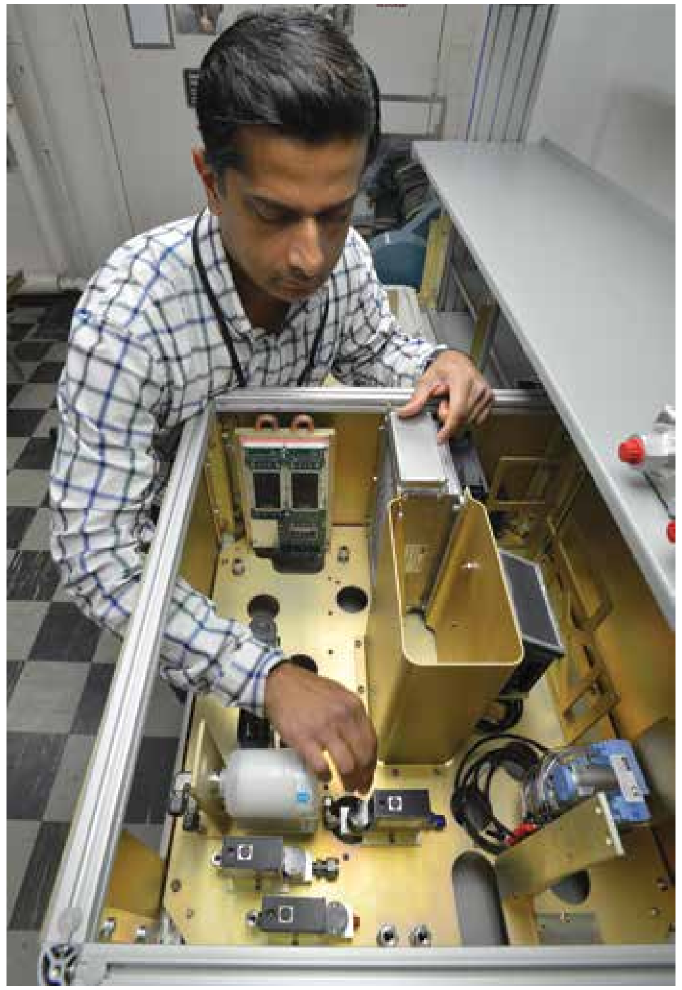
- Advancement in the ability for the warfighter to use industry-developed Internet of Things technologies and their capabilities, while allowing these technologies to remain resilient to cyber attack
- Creation of cyber security design guidelines and recommendations to secure U.S. small satellites against the growing threat of cyber attack
- Automation of the creation of a large library of cyber vulnerabilities to aid in the development of approaches for the detection and mitigation of cyber threats
- Use of data mining and machine learning techniques to develop new capabilities for detecting insider threats

Information, Computation, and Exploitation

Applied research in data processing, computation, exploitation, and visualization is required to address challenges posed by the increasing growth in the volume and variety of data used for national security and intelligence operations. Novel projects undertaken in 2017 are the development of

- New analytic methods that use in-house expertise in machine learning, computer vision, graph analytics, high-performance computing, and human-computer interaction
- The next-generation human language and network analytics to uncover and understand activities on the dark network
- Data analytics to allow an analyst workforce to exploit larger amounts of data without increasing the number of personnel

>> Investments in Mission-Critical Technology, cont.



This researcher is constructing a long-wave infrared hyperspectral coherent laser radar that may be useful for remote detection of trace compounds.

Optical Systems Technology

In this applied research area, scientists and engineers conduct R&D to fill critical gaps in technology that addresses emerging DoD threats, such as anti-access/area denial, weapons of mass destruction, and asymmetric warfare.

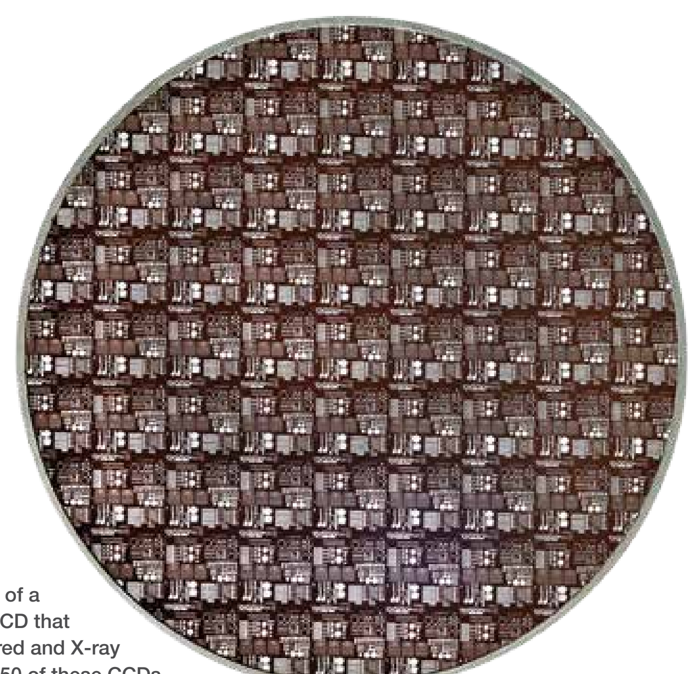
Some of the research is into new technologies that can change the paradigm in DoD mission areas, such as directed energy, space control, ballistic missile defense, and intelligence, surveillance, and reconnaissance (ISR). In 2017, efforts are ongoing to

- Scale infrared digital focal plane arrays to megapixel sizes through die fabrication on 8-inch wafers; the design allows for no gaps in the array after die assembly
- Develop a panelized optical phased array laser transmitter by using modular designs with surface-emitting semiconductor emitters
- Develop a novel photothermal modulation of a Mie scattering method for concurrent spatial and spectral discrimination of individual micron-sized particles

Advanced Devices

Work in advanced devices focuses on developing novel components and modalities to enable new system-level solutions to national security problems. Project highlights in 2017 include

- Development of a prototype large-format, visible image sensor that integrates a charge-coupled device (CCD) with circuitry that can perform per-pixel digital processing
- Demonstration of a novel microhydraulic actuator, with the strength of human muscle, that combines design concepts from biology and stepping motors



Researchers performed first-light testing of a 1024-pixel (32 × 32) germanium-based CCD that will be used for imaging in the near-infrared and X-ray bands. Shown is a wafer with more than 50 of these CCDs.

Integrated Systems

Technical staff in the integrated systems area conduct applied research into disruptive systems for national security; these systems are based on advanced technologies developed at both Lincoln Laboratory and elsewhere. Systems being developed in 2017 include

- A novel space-based three-dimensional (3D) ladar co-designed with a low-Earth-orbit small satellite
- Tactical cloud computing co-designed with a resilient communication architecture
- A laser-based communication system for undersea vehicles

Radio-Frequency Systems

Research and development in radio-frequency (RF) systems is exploring innovative technologies and concepts in radar, signals intelligence, communications, and electronic warfare. Among the significant projects in 2017 are

- Demonstration of a simultaneous transmit and receive subarray with 140 dB isolation, a capability that will enable many new RF applications, such as simultaneous communications and radar
- Development of a space-based lightweight active electronically scanned array concept to enable the cost-effective deployment of a space radar system

TECHNOLOGY HIGHLIGHT

Graph Processor for High-Performance Databases

Discovering relationships between entities in large, complex time-varying environments is a driving factor in the development of big data analytics. For example, analyzing open-source Internet databases and data feeds can provide timely information about the propagation and impact of both news and misinformation. Today's volumes of data, which can easily exceed 1 trillion entities, pose data storage, access, and computational challenges that are difficult to meet with current data processing technologies.

By viewing databases as large graphs, with the nodes representing the entities and the edges between nodes capturing relationships between entities, database operations can be reformulated as graph operations. Lincoln Laboratory has developed a novel graph processor that has demonstrated nearly 100 times the power efficiency on graph computations as attained by state-of-the-art supercomputers. A small prototype system installed into the Lincoln Laboratory Supercomputing Center has achieved world-record performance for database entity insertions. A full-scale graph processor promises to revolutionize this increasingly important area of big data analytics.

Shown above is a 64-node version of the graph processor. This system has similar processing performance to today's best supercomputers but consumes only 1/100th of the power.

INVESTMENTS IN EMERGING TECHNOLOGY

Promoting research into technologies of growing importance to national security and development of novel engineering solutions for projects in the mission areas

Engineering Research

This photograph of a prototype of zero thermal expansion metal manufactured with ultrasonic consolidation and electric discharge machining shows the titanium hexagonal cells and the aluminum re-entrant or "bow tie" cells. This sample measures about 1 inch square.

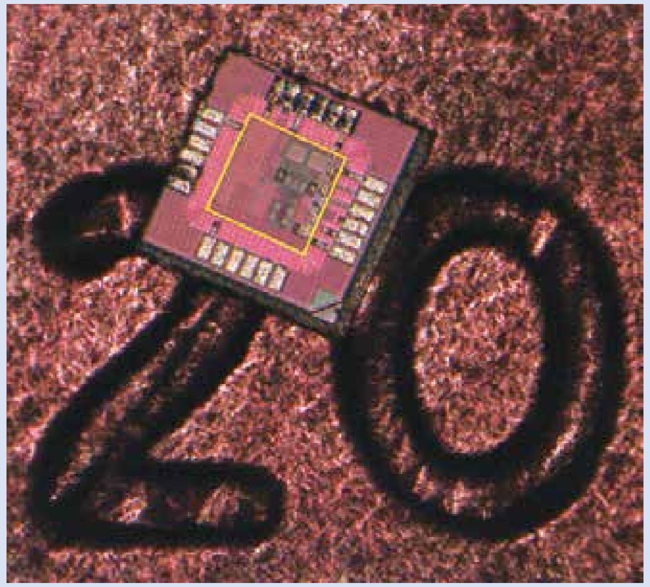
The Laboratory depends on state-of-the-art engineering capabilities to facilitate the development of prototype systems. Advancing these capabilities is achieved through investments in five areas of engineering research: advanced materials, mechanical and thermal technologies, optical technology, software for control systems, and propulsion systems. Highlights from this diverse portfolio include materials with zero thermal expansion and optimized specific stiffness, and a highly efficient cross-flow vortex droplet heat exchanger.

Novel and Engineered Materials

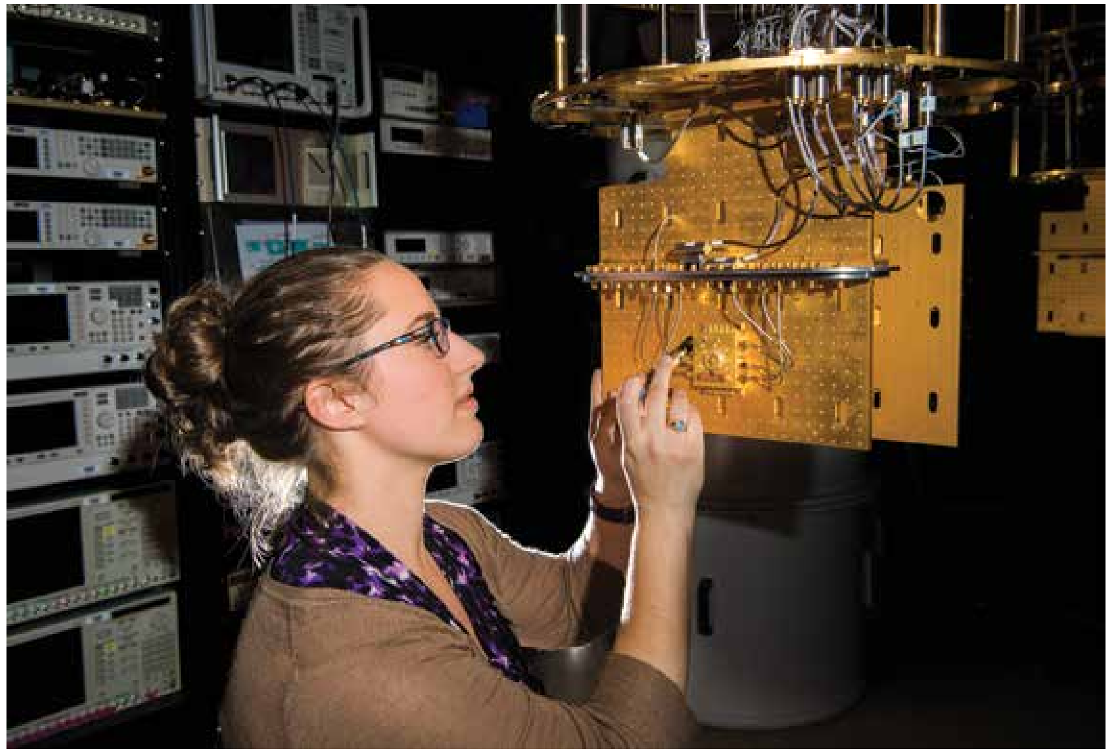
Developing advanced materials with novel properties and devising new processes to revolutionize multimaterial manufacturing are the goals in this area. While history suggests that advances in this field occur mainly through trial and error, the funded projects take advantage of recent progress in supercomputing to combine high-fidelity theoretical models with experiments to shorten development time. Areas of study include new materials and metamaterials for advanced computing and imaging, textile fibers with electronic functionality, and three-dimensional printing of materials previously inaccessible by additive techniques, including composites with high strength-to-weight ratio, dielectrics, conductors, and semiconductors.

Biomedical Sciences

Under the biomedical sciences initiative, Lincoln Laboratory is investigating advanced technologies and systems to address warfighters' healthcare needs and enhance warfighters' performance. In 2017, researchers are developing a small, low-cost, room-temperature magnetometer for brain disorder study and treatment. Work on sensorimotor tracking of neurological disorders is aimed at discovering subtle changes in behavior that may lead to improved detection of mild traumatic brain injury. Research on an artificial gut platform attempts to help elucidate the relationship between the gut and the brain, and to ultimately inform improvements in warfighter health and resilience. A noncontact ultrasound imaging system for enhancing physicians' ability to diagnose and visualize injury and disease has been approved for testing on human subjects. Researchers are also developing tools for high-throughput brain mapping to advance the understanding of brain circuits and to identify new ways to treat and prevent brain disorders.



The goal of the Microelectronics Interfacing Neural Devices (MIND) project is to build the world's smallest (perhaps injectable) wireless neural measurement and reporting device. If successful, MIND holds the promise of providing greater spatiotemporal understanding of human nerve activity than has been realized before. The image shows the latest version of the device with the MIND chip (outlined by the yellow box), along with its outer input/output ring and pads, placed on the date on the surface of a penny. The chip is ~250 µm per side, shown compared to the numbers of the penny's date, which are ~1000 µm in height.



Quantum Systems Science

Quantum systems are the basis for new paradigms in computing, networking, and sensing. Research in quantum computers is reducing the size of infrastructure and applying microelectronic manufacturing techniques. Also, a quantum network is being tested over a 40 km link between MIT and Lincoln Laboratory.

A researcher is using three-dimensional integration to connect signals for logical qubits.

Energy

Funding in this area supports DoD energy needs and the sustainability and reliability of the national power grid. A primary consideration for DoD energy needs is the size and weight of batteries. Recent research has demonstrated a metal-air nanobattery that can be used for microscopic electronics and tiny robots.

Homeland Protection and Air Traffic Control

Investments in these two areas support advances in transportation safety, land-border and maritime security, critical infrastructure protection, chemical and biological defense, and disaster response. For example, researchers have created and are using a test bed in which small unmanned aircraft systems act as surrogates for larger platforms. The 2017 projects also include prototyping novel network topology and traffic analysis methods to rapidly geolocate power outages, and adapting the interactive flight-management test bed to include a rapid-turnaround system that enables the exploration of alternative decisions with data-based results.

Autonomous Systems

Work in this area is focused on developing foundational technologies for unmanned systems in air, ground, space, and maritime domains. For example, researchers are prototyping a sensor system that enables an unmanned aerial vehicle (UAV) to navigate at high speed near the ground in complex environments.

In 2017, project teams are also developing and testing unique electro-aerodynamic propulsion for small UAVs, a verification and validation platform to ensure that these systems are safe and secure, a sparse sensing system to enable real-time onboard sense and avoid for micro-UAVs, approaches for coordinating the actions of swarms of autonomous systems, and a biomimetic sonar system for an unmanned undersea vehicle to improve target detection and recognition.

>> *Investments in Emerging Technology, cont.*

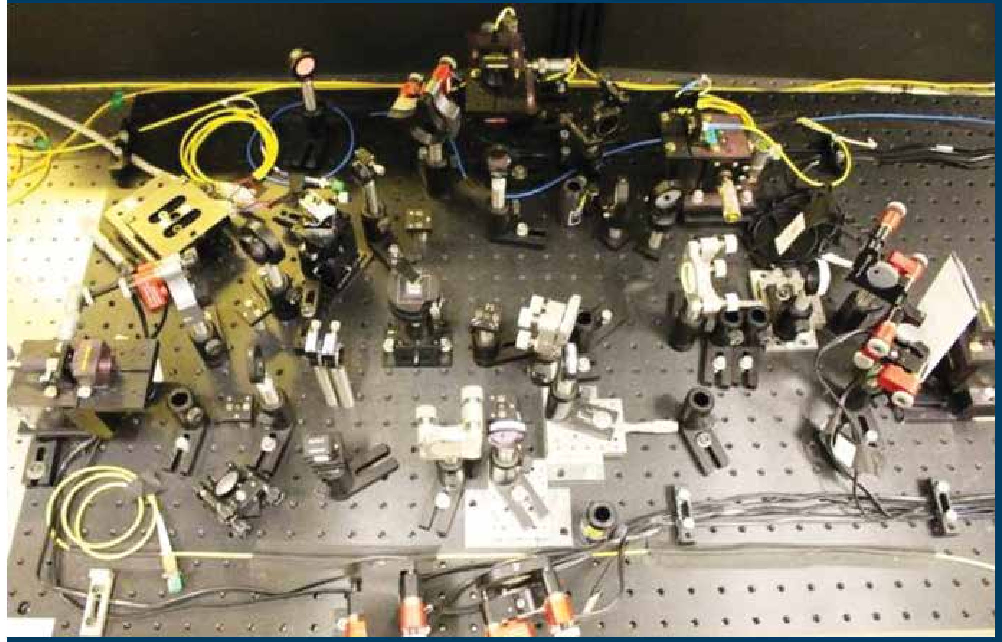
TECHNOLOGY HIGHLIGHT

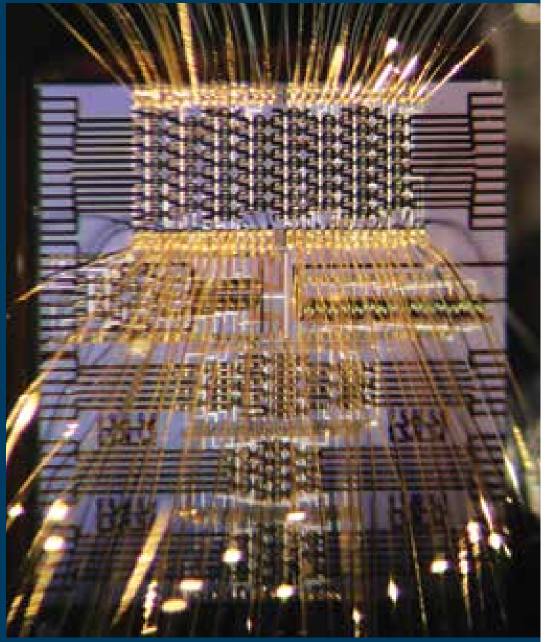
Quantum Network Test Bed Development

The strange features of nature described by quantum mechanics have the potential to enable powerful advances in technology. Quantum entanglement is a particularly strange phenomenon in which two quantum systems cannot be accurately described individually but must instead be described in reference to each other.

When distributed across a network, these entangled states can act as a shared quantum reference between users, enabling a range of applications. They can be used to generate secure encryption keys, to optimally link distributed sensor arrays, and to serve as interconnects between quantum processor units. However, because these quantum states are at the single particle regime and are inherently delicate, high-rate generation capabilities and high-fidelity processing capabilities are required to overcome real-world system limitations.

Lincoln Laboratory is developing a quantum network test bed to demonstrate the distribution of quantum states at high rates with scalable connectivity. In collaboration with several groups at MIT, Laboratory researchers are pursuing a phased development approach by which state-of-the-art quantum technologies are systematically incorporated into a test bed that will be used to investigate quantum networking system applications. The initial test bed channel consists of two 43 km optical fibers connected to MIT and will allow improved technology and advanced applications to be characterized and tested in a real-world environment.





High-rate entangled photon source, at left, and high-fidelity integrated photonics quantum state processor, at right, technologies are under development for integration into a 43 km optical fiber quantum network test bed connecting Lincoln Laboratory and MIT.

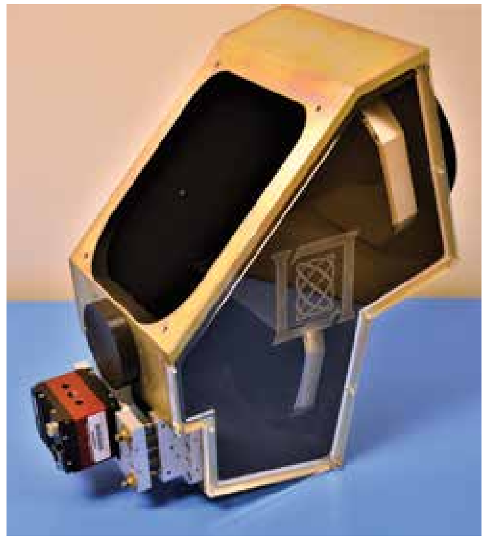
INVESTMENTS IN BASIC AND APPLIED RESEARCH

Providing support for R&D into foundational concepts and their application in new systems

Freeform Optics

Optics traditionally uses spherical surfaces for generating images, but the images can incur significant aberrations, i.e., imperfections caused by a lens not focusing all light rays to one point in the image plane. Aberrations can be reduced with the use of multiple lenses in an optical system. Consequently, high-quality, fast optical systems with several lenses have traditionally been large and heavy. Starting in the 1980s, the use of high-quality aspheric lenses with polynomial deviation from spherical surfaces enabled high-quality imaging systems that used fewer lenses.

Recent advances in optical manufacturing technology have made possible the accurate fabrication of surfaces with complex freeform shapes. In principle, the use of such surfaces can reduce the number of optical elements that are currently used in aspheric systems. The problem is how to design high-quality, fast optical systems that use a very small number of freeform surfaces. Groundbreaking work at Lincoln Laboratory has led to the development of software that allows the design of optical systems with performance far beyond what was previously possible.



This freeform, optical, very wide field-of-view telescope is ready for testing. The design code of this Lincoln Laboratory–developed optical system optimizes the three mirror surfaces. The mirror surfaces are manufactured with diamond-turning technology and polished to match exactly the design shapes. Assembled and aligned at the Laboratory, the telescope has demonstrated a six-fold improvement in field of view over a design that uses conventional mirrors.

Balloon-Enabled Atmospheric Convection Observation Network

The Balloon-Enabled Atmospheric Convection Observation Network (BEACON) is being developed to generate high-resolution maps of the distribution of electrical charge within a cloud. The BEACON concept is to launch into a potential storm cloud a constellation of weather balloons, each carrying a novel instrument designed to measure the electric field (E-field) in the cloud. The cumulative data on the E-fields around the instruments will be used to create time-recorded maps of the electrical activity throughout the cloud. Accurate maps could provide important input to the modeling and understanding of thunderstorm dynamics. In addition, if the maps could be correlated to radar measurements on the precipitation in clouds, data from weather radars could be used to predict the likelihood of lightning forming. The ultimate goal of the BEACON project is to allow air traffic controllers to use information from weather radars to decide if aircraft can safely be directed to fly through clouds that may produce lightning strikes.

An early BEACON prototype made accurate measurements at Lincoln Laboratory and at the Boston Museum of Science's Theater of Electricity. In October 2017, Laboratory researchers launched a prototype sensor into a late-season Oklahoma thunderstorm. During this test, performed in collaboration with a team from NOAA's National Severe Storms Laboratory, the BEACON instrument was flown along with an older instrument for measuring atmospheric electricity. The data collected by both the legacy instrument and the BEACON probe are still being analyzed but have provided preliminary validation of the BEACON instrument.

The prototype BEACON instrument takes a near strike from the Van de Graaff generator at the Boston Museum of Science. Testing in the museum's Theater of Electricity allowed the BEACON team to simulate some of the extreme electrical environments that the instrument may experience while mapping the charge structure of a cloud.

TECHNOLOGY OFFICE CHALLENGES

Each year, the Technology Office invites staff to participate in challenges that explore problems with rising impact on the nation or our mission areas. Two challenges involving machine learning were issued in 2017.

"Fake News" Hackathon

Laboratory staff developed algorithms that use text, images, and html metadata to determine the reliability of news articles.

Since the 2016 presidential election, awareness of fake news has grown. Detecting and preventing the spread of unreliable media content is a difficult problem, especially given the rate at which news can spread online. With its power to erode the public's ability to make informed decisions, fake news poses a serious threat to our national security. To combat this problem, the Technology Office designed its first-ever hackathon, challenging the Laboratory community to build automatic detectors of unreliable media.

Forty-five participants from across the Laboratory signed up for the challenge. During the month before the hackathon, teams prepared using example data—images, text, and html metadata drawn from 1600 truth-marked articles—and baseline algorithms to begin developing their systems. The core task of the challenge was to train systems to extract features from the data, classify the features, and fuse those classifications into a binary decision: reliable or unreliable.

Teams created a variety of tools to find features in the data that could help determine if the content was fake. Tools included stance classification to determine whether a headline agreed with the article body, text processing to analyze the author's writing style, and image forensics to detect Photoshop use. Algorithms to extract even relatively simple data features, like image size, readability level, and the ratio of reactions versus shares on Facebook, proved useful in determining article reliability.

At the "Breaking News or Broken News?" hackathon, nine teams used machine learning techniques to classify real-world multimedia data as either reliable or unreliable.

TECHNOLOGY OFFICE CHALLENGE WINNERS

Members of the winning team, Tor News Network, accept trophies presented by Robert Bond, Chief Technology Officer (right).

At the hackathon, the systems were put to the test against the challenge dataset, which was collected from 12,000 truth-marked news articles. The organizers scored each team's submission based on its rate of true detection versus false detection. All teams delivered impressive results, with the top three scoring systems performing close to perfect.

While mitigating the spread of fake news remains a challenge, the hackathon opened up doors to joint research into the identification of misinformation. "From professors on MIT campus to industry leaders, we have been receiving a lot of requests to access our data and collaborate on different aspects of the problem," hackathon co-organizer Elizabeth Godoy said.

Autonomous UAV Race

Laboratory staff programmed unpiloted aerial vehicles to autonomously fly through an obstacle course as quickly as possible.

Today, because of their low cost, widespread availability, and growing capabilities, unpiloted aerial vehicles (UAVs) increasingly impact both commercial businesses and national security. In order for UAVs to accomplish tasks, especially in denied, inaccessible, or hostile environments, they will need to navigate autonomously and employ machine learning to make sense of what needs to be done. This challenge was a small step in the exploration of UAV autonomy with machine learning; no human interaction with the UAV was allowed during the race.

The challenge required staff to develop Robot Operating System software that allowed commercial UAVs to map the area, learn the locations of gates in the course, and figure out the fastest path through the course. Thirty-five staff members on six teams participated in the challenge, honing their skills for six months as they experimented with the intricacies of code. The day of the challenge, each team had three time trials to compete for the fastest time.

TECHNOLOGY OFFICE CHALLENGE WINNERS

Members of the winning team, Penguin, celebrated their UAV's victorious 57-second run.

The winning team got their UAV to complete the course in less than a minute. They used the first trial to allow the UAV to map the course, gathering information about the height and orientation of each gate it would have to pass through. The drone made it through all the gates in just under 7 minutes. In the second trial, the drone used an algorithm for path planning, confirming its newly acquired information about the gate openings as it flew through the course in 81 seconds. In the last run, the drone did not hesitate and completed the race in 57 seconds for the fastest run of the day.

"Artificial intelligence (AI) is becoming increasingly important in many national security areas. The challenge was a great way to encourage staff to develop expertise in various aspects of AI, including machine learning."

Peter Schulz,
Associate Technology Officer

Laboratory staff look on as their UAV learns to maneuver through a gate on the race course.

Technology Transfer

Air, Missile, and Maritime Defense Technology

Lincoln Laboratory transitioned electronic protection technology to the prime contractor for the Airborne Warning and Control System (AWACS) Modernization Program.

The Laboratory successfully completed the technology transfer of mature and previously flight-tested countermeasure designs to a selected industry partner for the development and delivery of flight units for an upcoming Ballistic Missile Defense System test in 2018.

Air Traffic Control

The Laboratory completed the development of a ground-based sense-and-avoid system in partnership with the Department of Defense and is transitioning the system to U.S. Army and U.S. Air Force sites. This transition will enable the first general-purpose sense-and-avoid system for unmanned aircraft in the National Airspace System. To date, four systems are operating in the National Airspace System, and at least two more systems will follow.

Cyber Security and Information Sciences

Speaker and language recognition technology components developed by Lincoln Laboratory were transferred into key sponsor systems. These components enabled systems that demonstrated exceptional performance at international speaker and language recognition evaluations conducted by the National Institute of Standards and Technology to measure the state of the art in human language technology and to identify the most promising algorithmic approaches to speaker and language recognition.

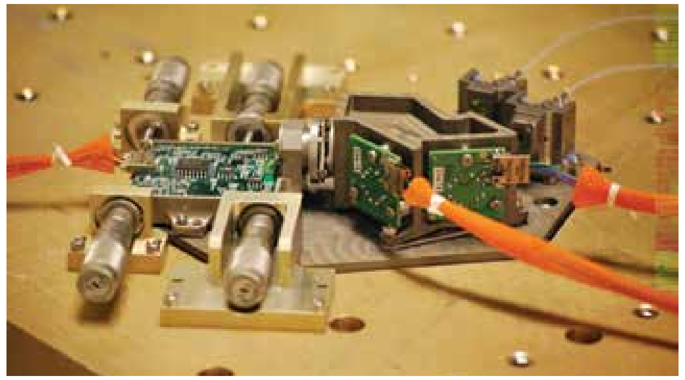
Working with colleagues from MIT, Lincoln Laboratory researchers released an open-source polystore database, BigDAWG, that can be used for managing complex and heterogeneous data. BigDAWG is available at the BigDAWG Polystore on MIT's website. More about this data management system is on page 64 of this report.

Communication Systems

Lincoln Laboratory released the Group Centric Networking codebase and the Dynamic Link Exchange Protocol (DLEP) implementation as open-source software.

The fifth-generation Advanced Training Waveform, which supports the U.S. Air Force's Live, Virtual, and Constructive training environments, was transferred to government and industry.

The Laboratory transitioned designs for the Next-Generation Laser Communications (lasercom) terminals to industry partners. The industry-fabricated telescope, gimbal, and latch subassemblies were integrated into a prototype terminal.



The small optics assembly for the Next-Generation Laser Communications terminal is pictured in the alignment fixture.

Modem and optical terminal technology has been transferred to NASA to support the development of the lasercom terminal for the Laser Communications Relay Demonstration. The Laboratory worked with multiple industry vendors to validate the subsystems that NASA will use for the terminal.

Technology was transferred to NASA for the ground terminal designed for optical communication with NASA's Laser Communications Relay Demonstration spacecraft.

Homeland Protection

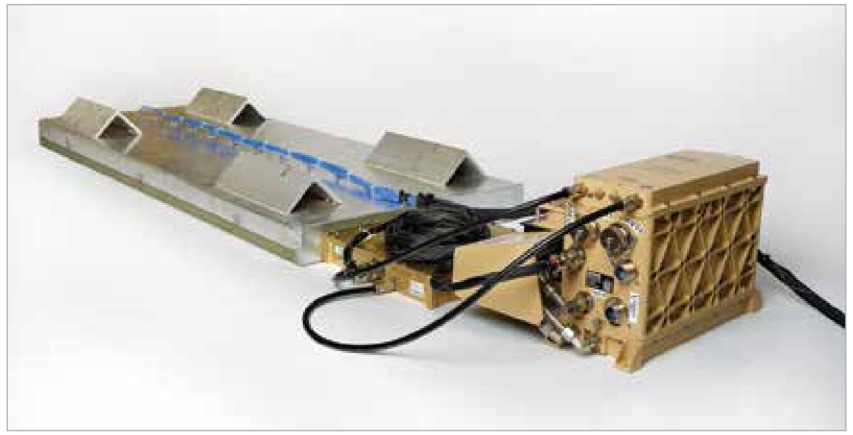
Scott Anderson, Assistant Director for Operations, far left, presented the MIT Lincoln Laboratory Small Business of the Year Award to the principals of Odic Inc., who are seen here with the U.S. Army sponsor Reed Hoyt, far right, and Lincoln Laboratory members who worked with them to transfer the wearable monitoring system to industry production.

Through a partnership with the U.S. Army Medical Research and Materiel Command to develop integrated wearable sensors for improved monitoring of warfighter health and performance, a tactically acceptable, ultralow-power wearable physiological monitoring system was transitioned to industry partner Odic Inc. for initial production. This successful transition led to Odic's being recognized by the U.S. Small Business Administration as the 2017 Small Business Association Subcontractor of the Year for the New England Region.

Lincoln Laboratory transitioned the HURREVAC-eXtended (HV-X), a modernized decision-making platform, to the Federal Emergency Management Agency. Funded by the Department of Homeland Security Science and Technology Directorate, HV-X has been used in recent events, such as Hurricane Mathew, to plan evacuation routes and other responses to major storms.

Engineering

The Localizing Ground-Penetrating Radar (LGPR) developed by Lincoln Laboratory has been licensed to Geophysical Survey Systems, Inc. (GSSI). GSSI will build and sell the prototype LGPR systems that enable autonomous vehicles to navigate over roads by using maps of subterranean geological features such as rock formations and soil layers. Because the LGPR uses subsurface maps, it can localize a vehicle when weather conditions like snow or heavy rain obscure the lane markings or signs and landmarks that optical systems use to orient a self-driving vehicle.



The Localizing Ground-Penetrating Radar system consists of an antenna array (left-hand silver component) and the electronics and processing unit (right-hand section). The system is 1.5 m wide, 7.6 cm tall, and 0.6 m long.

>> *Technology Transfer, cont.*

Selected Patents 25 October 2016–3 October 2017

Methods and Apparatus for Recording Impulsive Sounds
Joseph J. Lacirignola, Trina R. Vian, David F. Aubin Jr., Thomas F. Quatieri, Kate D. Fischl, Paula P. Collins, Christopher J. Smalt, Paul D. Gatewood, Nicolas Malyska, and David C. Maurer
Date issued: 25 October 2016
U.S. Patent no.: 9,478,229

Focal Plane Array Processing Method and Apparatus
Michael Kelly, Brian Tyrrell, Curtis Colonero, Robert Berger, Kenneth Schultz, James Wey, Daniel Mooney, and Lawrence Candell
Date issued: 8 November 2016
U.S. Patent no.: 9,491,389

Grid Arrays with Enhanced Fatigue Life
Dmitry Tolpin, James H. Kelly, and Roger M. Maurais
Date issued: 8 November 2016
U.S. Patent no.: 9,491,859

Optoelectronic Detection System
Eric D. Schwoebel, James D. Harper, Martha S. Petrovick, Frances E. Nargi, Todd H. Rider, Kristine E. Hogan, Richard H. Mathews, Joseph Lacirignola, Mark Hennessy, Trina R. Vian, Rose M. Joseph, Raymond S. Uttaro, Shaun Berry, Bernadette Johnson, and Mark A. Hollis
Date issued: 15 November 2016
U.S. Patent no.: 9,494,579

Systems and Methods for Light Amplification
John J. Zayhowski and Dale H. Martz
Date issued: 6 December 2016
U.S. Patent no.: 9,515,451

Rare Earth Spatial/Spectral Microparticle Barcodes for Labeling of Objects and Tissues
Paul Bisso, Albert Swiston, Jiseok Lee, and Patrick S. Doyle
Date issued: 27 December 2016
U.S. Patent no.: 9,528,144

Rare Earth Spatial/Spectral Barcodes for Multiplexed Biochemical Testing
Paul Bisso, Albert Swiston, Jiseok Lee, and Patrick S. Doyle
Date issued: 27 December 2016
U.S. Patent no.: 9,528,145

Processor for Large Graph Algorithm Computations and Matrix Operations
William Song
Date issued: 27 December 2016
U.S. Patent no.: 9,529,590

Joint Use of Multi-packet Reception and Network Coding for Performance Improvement
Linda M. Zeger, Jason M. Cloud, and Muriel Medard
Date issued: 10 January 2017
U.S. Patent no.: 9,544,126

Two-Dimensional Wavelength-Beam-Combining of Lasers Using First-Order Grating Stack
Bien Chann, Tso Yee Fan, and Antonio Sanchez-Rubio
Date issued: 21 February 2017
U.S. Patent no.: 9,575,325

Reagents for Oxidizer-Based Chemical Detection
Kerin E. Gregory, Roderick R. Kunz, and Michael Sworin
Date issued: 7 March 2017
U.S. Patent no.: 9,588,095

Method and Instrumentation for Determining a Physical Property of a Particle
William D. Herzog
Date issued: 14 March 2017
U.S. Patent no.: 9,594,011

Discrete Bypass Particle Concentrator
Thomas Sebastian and Timothy Stephens
Date issued: 28 March 2017
U.S. Patent no.: 9,604,169

Methods and Apparatus for True High Dynamic Range Imaging
Michael W. Kelly, Megan H. Blackwell, Curtis B. Colonero, James Wey, Christopher David, Justin Baker, and Joseph Costa
Date issued: 4 April 2017
U.S. Patent no.: 9,615,038

Continuous Wave or Ultrafast Lasers
Bien Chann, Daniel Ripin, Tso Yee Fan, and Antonio Sanchez-Rubio
Date issued: 11 April 2017
U.S. Patent no.: 9,620,928

Sleeved Coaxial Printed Circuit Board Vias
Glenn A. Brigham, Richard J. Stanley, Bradley T. Perry, and Patrick J. Bell
Date issued: 25 April 2017
U.S. Patent no.: 9,635,761

Method and Apparatus for Transmitting Phase Shift Keyed Optical Signals
David O. Caplan, Neal W. Spellmeyer, Bryan S. Robinson, Scott A. Hamilton, Don M. Boroson, Hemonth G. Rao, and Marc C. Norvig
Date issued: 9 May 2017
U.S. Patent no.: 9,647,765

Inductance-Tuned Electro-optic Modulators
Mark A. Hollis, Reuel B. Swint, Dominic Siriani, Joseph P. Donnelly, and Paul W. Juodawlkis
Date issued: 6 June 2017
U.S. Patent no.: 9,671,670

Method and Apparatus for Motion Coded Imaging
Yaron Rachlin and Sumanth Kaushik
Date issued: 13 June 2017
U.S. Patent no.: 9,681,051

Visible-Infrared Plane Grating Imaging Spectrometer
Michael P. Chrisp
Date issued: 27 June 2017
U.S. Patent no.: 9,689,744

Method and Apparatus for Rate Determination in a Radio Frequency System
Rachel E. Learned
Date issued: 27 June 2017
U.S. Patent no.: 9,693,351

Cognitive Radio Method and Apparatus for Achieving ad hoc Interference Multiple Access Wireless Communication
Rachel E. Learned and Nicholas J. Kaminski
Date issued: 27 June 2017
U.S. Patent no.: 9,693,361

Method and Apparatus for Locating a Target Using an Autonomous Unmanned Aerial Vehicle
Michael J. Park and Charles Coldwell
Date issued: 4 July 2017
U.S. Patent no.: 9,696,430

Cognitive Radio Method and Apparatus for Achieving ad hoc Interference Multiple Access Wireless Communication
Rachel E. Learned
Date issued: 4 July 2017
U.S. Patent no.: 9,699,665

Cryptography and Key Management Device and Architecture
Roger I. Khazan, Joshua Kramer, Daniil M. Utin, M. Michael Vai, and David Whelihan
Date issued: 11 July 2017
U.S. Patent no.: 9,705,854

Packet Header Randomization
Hamed Okhravi, Richard W. Skowyra, Kevin Bauer, and William W. Streilein
Date issued: 18 July 2017
U.S. Patent no.: 9,712,501

Digital Readout Method and Apparatus
Michael Kelly, Daniel Mooney, Curtis Colonero, Robert Berger, and Lawrence Candell
Date issued: 18 July 2017
U.S. Patent no.: 9,712,771

Methods for Forming Photonic Integrated Circuits Based on Quantum Cascade Structures
Anish K. Goyal, Laurent Diehl, Christian Pfluegl, Christine A. Wang, and Mark F. Witinski
Date issued: 15 August 2017
U.S. Patent no.: 9,735,549

Method and Apparatus for On-Chip per-Pixel Pseudo-Random Time Coded Exposure
Brian M. Tyrrell, Christy Fernandez Cull, and Andrew K. Bolstad
Date issued: 22 August 2017
U.S. Patent no.: 9,743,024

Imaging System for Immersive Surveillance
Daniel B. Chuang, Lawrence M. Candell, William D. Ross, Mark E. Beattie, Cindy Y. Fang, Bobby Ren, and Jonathan P. Blanchard
Date issued: 29 August 2017
U.S. Patent no.: 9,749,526

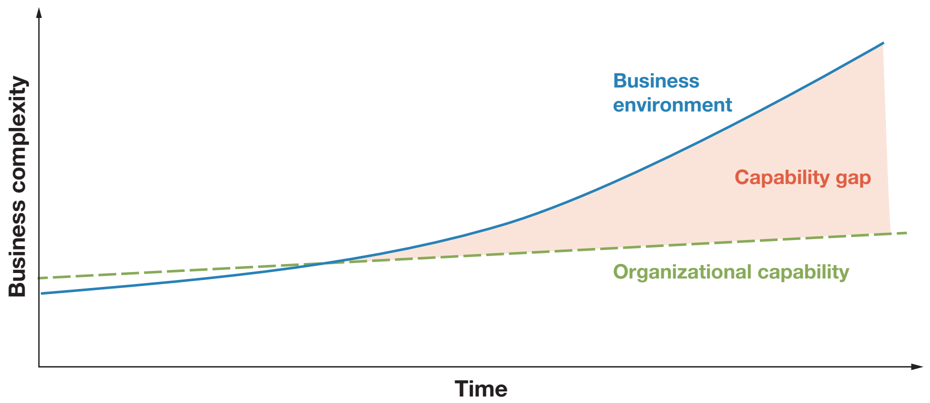
Phonologically Based Biomarkers for Major Depressive Disorder
Thomas F. Quatieri, Nicolas Malyska, and Andrea C. Trevino
Date issued: 19 September 2017
U.S. Patent no.: 9,763,617

Methods and Apparatus for Counting Pulses Representing an Analog Signal
Kenneth I. Schultz, Brian Tyrrell, Michael W. Kelly, Curtis B. Colonero, Lawrence M. Candell, and Daniel Mooney
Date issued: 19 September 2017
U.S. Patent no.: 9,768,785

Interconnect Structures for Assembly of Multi-layer Semiconductor Devices
Rabindra N. Das, Donna-Ruth Yost, Chenson Chen, Keith Warner, Steven A. Vitale, Mark A. Gouker, and Craig L. Keast
Date issued: 3 October 2017
U.S. Patent no.: 9,780,075

Efficient Operations

Rapid increases in the complexity of today's business operations are compelling organizations to reassess their traditional practices and processes. Whether those organizations are commercial companies, academic institutions, government departments and agencies, or national laboratories like Lincoln Laboratory, they are confronted with challenges presented by the fast-paced expansion of technologies and applications used in business, and by stricter government regulations that lead to increased business auditing and reporting.



As seen in the notional chart above, organizations characteristically encounter a gap between the complexity of the evolving business environment and their capability to execute business efficiently. As complexity grows, organizations that do not revitalize their practices are left with a widening gap.

Lincoln Laboratory is closing this gap. The Laboratory conducted an extensive efficiency study of operations and identified specific issues in staffing, training, business systems, and operating procedures that contribute to this capability gap. Subsequently, the Laboratory has developed a strategic plan that is organized around three primary focuses to improve efficiency: the workforce, training, and business systems and processes.

Workforce

As part of the strategic plan to improve business efficiency, Lincoln Laboratory created a professional career path for business managers, who partner with the leadership of the technical groups to satisfy requirements for financial reporting, to oversee the procurement of equipment and services to support technical programs, and to provide support to program managers, particularly in integrating work scope with schedule and budget resources (known as earned value management). Through a series of positions of increasing responsibility, the business manager track promotes the development of professionals who are highly skilled in the management of the financial and compliance requirements of R&D programs.

Training

Lincoln Laboratory has always assured that its employees have access to training for complying with government regulations, safeguarding the Laboratory's intellectual property, and protecting themselves from injury. The various types of training had been tracked by the departments or offices that had oversight of the requirements. They had used several systems that were not integrated, and enrollment in training sessions had been handled manually by multiple people.

To better track employees' completion of training, Lincoln Laboratory implemented a web-based application that enables employees to view their training requirements, complete online training, and enroll in classes. This application, called the Learning Center, is based on the SAP Learning Solution module but modified for the Laboratory's particular needs. It provides a one-stop shop for the majority of internal training at the Laboratory. The new system notifies departments, divisions, and groups of their employees' upcoming training expirations and provides reporting of employees' training completions. Training providers, such as the Security Services Department or the Environmental, Health, and Safety Office, identify employees' training requirements on the basis of attributes such as job category and work activity; administer their courses in the system's back-end interface; and use back-end reports to monitor compliance.

Through the Learning Center, the Laboratory has decreased the effort and time spent by multiple people to track employees' training, has reduced the hours spent by trainers on delivering material that is now available online, and has empowered employees' to manage their training needs.

Digital Enterprise Transformation Project

The Digital Enterprise Transformation Project was initiated in 2017 to improve the services that enable and accelerate the Laboratory's research. This enterprise-wide strategic initiative aims to increase efficiency and effectiveness, promote collaboration, and reduce operational risks.

The goal is to provide a trusted, robust, integrated research business ecosystem that

- Simplifies processes, applications, and technology
- Standardizes enterprise tools and processes
- Automates and digitizes to reduce manual processes and paper
- Provides intelligent data and access
- Delivers applications with intuitive design

This project comprises three phases: business process transformation, technology enablement, and simplification.

Business process transformation

This first phase of the project is an assessment of the Laboratory's current business processes and an analysis of industry best practices that could be adopted. The emphasis is on facilitating an "idea-to-R&D-product" strategy that integrates business operations with technical research activities and that implements procedures and tools to improve, simplify, and automate processes.

Technology enablement

The first initiative in the technology enablement component is the migration to SAP HANA. SAP HANA is a modern, in-memory, cloud-based application-development platform designed to allow businesses to simplify information technology environments and business operations. The Laboratory will be using SAP HANA as its business applications digital core. Because SAP HANA removes the burden of maintaining separate legacy systems and siloed data, systems can run more efficiently in the digital economy. In a continuous cycle, business processes will be reviewed, redesigned, and then implemented by SAP HANA, thereby improving organizational effectiveness by streamlining processes and enhancing capabilities.

Simplification

During the simplification phase, enterprise-wide business capability enhancements defined and prioritized in the process transformation phase will be implemented on the Laboratory's SAP HANA or cloud platforms. Implementation will be executed in waves as processes are streamlined and tools and applications are evaluated.

Continual Improvement

An enduring outcome of the study is the newly formed Efficiency Improvement Team, cochaired by a division head and a service department head, and composed of representatives from across the Laboratory. The team is overseeing the implementation of the study's recommendations. Efforts to address the identified action items have been initiated. The team is also executing a plan to continually review processes and strategize solutions to improve business capabilities.

While in-house training at the Laboratory may take place in classroom settings like this, increasingly courses may be completed through interactive online modules that allow staff to fit training around their work schedules.

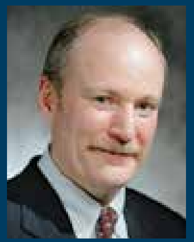
MISSION AREAS 37

Advanced tools in the Microelectronics Laboratory enable the fabrication of large silicon-based wafers.

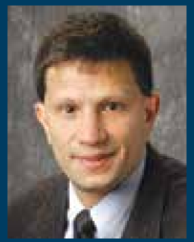
Space Control

Ensuring the resilience of the nation's Space Enterprise by designing, prototyping, operating, and assessing systems to provide space situational awareness, resilient space capability delivery, active defense, and associated cross-domain battle management

Leadership

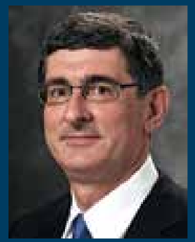


Dr. Grant H. Stokes
Division Head



Mr. Lawrence M. Candell
Asst. Division Head

Dr. William J. Donnelly III
Asst. Division Head



Mr. Craig E. Perini
Asst. Division Head

The four TESS flight telescopes with their detector arrays, shown assembled on their base plate, are ready for integration on the spacecraft. Lincoln Laboratory provided the detector arrays, optical subsystem, system engineering, integration and test, and program management for the science payload.

Principal 2017 Accomplishments

- The Space Surveillance Telescope was disassembled at White Sands Missile Range, New Mexico, and shipped to Naval Communication Station Harold E. Holt (HEH) in Australia. The new telescope enclosure at HEH is undergoing its final preparations for installation and reassembly of the telescope.
- The Transiting Exoplanet Survey Satellite (TESS) flight payload, jointly developed by the MIT Kavli Institute for Astrophysics and Space Research and Lincoln Laboratory under funding from NASA, was delivered to the spacecraft vendor in preparation for an early 2018 launch.
- The Microwave Radiometer Technology Acceleration (MiRaTA) cubesat, a development between MIT Space Systems Laboratory and Lincoln Laboratory that is funded by the NASA Earth Science Technology Office, was successfully launched and deployed on 18 November 2017. MiRaTA is undergoing on-orbit checkout of the spacecraft and its multiband radiometer and GPS radio occulation payloads. The Micro-sized Microwave Atmospheric Satellite-2a (MicroMAS-2a) cubesat passed qualification testing and was delivered to the launch provider in anticipation of a launch in early 2018.
- TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats), a NASA Earth Venture-Instrument program, is a constellation of cubesats equipped with advanced compact microwave sounder technology to provide high-revisit observations of precipitation, temperature, and humidity in tropical storms. The TROPICS System Requirements Review was successfully completed, and design work is underway.
- The Laboratory is designing a distributed radar prototype for deep-space surveillance. An exhaustive trade study examining the operating frequency, antenna quantity and size, and array configuration was conducted to determine the most cost-effective radar that meets mission objectives.
- A portfolio of activities continues to deliver critical space domain awareness information and tools to the National Space Defense Center in Colorado.

Future Outlook

Resilience of the nation's space enterprise is a major national security issue. The reliance of the military on space systems to deliver tactical warfighting effects continues to grow. Improved space situational awareness, and responses on tactical timelines, will be the foundation for increasing the survivability of space systems. In addition, space systems will need to be made fundamentally more resilient to potential adversary actions.

A major Laboratory focus is on information extraction, integration, and decision support. Development of a truly net-centric, multi-domain architecture, with the agility to discover and incorporate new data sources and services on short timelines, is critical to evolving the warfighting capability that can respond on the timelines required to support space survivability efforts.

SensorSat

SensorSat is a small satellite developed for the Operationally Responsive Space Office to meet a U.S. Strategic Command need in space situational awareness. SensorSat's use of a particular orbit exploits sensor viewing angles to reduce the apparent motion of targets and substantially increase detection sensitivity. This approach, which uses a small aperture, provides a substantial reduction in spacecraft complexity, size, mass, and cost. SensorSat, launched on 26 August 2017 from Cape Canaveral, Florida, on a Minotaur IV vehicle, underwent a successful vehicle and system checkout. SensorSat will be a contributing sensor to the Space Surveillance Network in early 2018.

Courtesy of Orbital ATK

Air, Missile, and Maritime Defense Technology

Investigating system architectures, prototyping pathfinder systems, and demonstrating these advanced, integrated sensor systems that are designed for use on tactical air and maritime platforms to provide defense against missiles and other threats

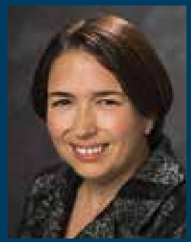
The Laboratory is developing advanced technology for unmanned undersea and surface vehicles. This Maritime Autonomy Test Tank is a controlled environment in which staff can refine capabilities in autonomy, sensing, signal processing, and communications prior to open-water demonstrations.

Principal 2017 Accomplishments

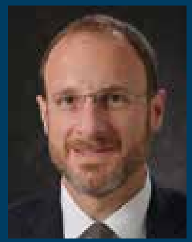
- Lincoln Laboratory is at the forefront of appraising the impact of rapidly evolving missile threats on Ballistic Missile Defense System (BMDS) performance. As Technical Direction Agent for the homeland defense system, the Laboratory is conducting system-level analyses of Ground-Based Midcourse Defense performance and is leading efforts to identify and develop system improvements to mitigate the impacts of these evolving threats.
- Design and development continued on flight test countermeasures that are used for evaluating the performance of the BMDS and its elements.
- Critical prototypes that were developed to explore new capabilities for future airborne sensors include a next-generation radar test bed to prototype waveforms and algorithms, and a wideband phased array for airborne testing and evaluation.
- In collaboration with MIT and Woods Hole Oceanographic Institution, the Laboratory conducted a demonstration at Buzzards Bay of enhanced path planning for unmanned undersea vehicles.

Leadership

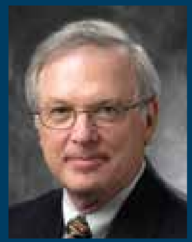
Dr. Justin J. Brooke
Division Head



Dr. Katherine A. Rink
Assoc. Division Head



Dr. Kevin P. Cohen
Asst. Division Head



Mr. Dennis J. Keane
Principal Staff

- A highly reconfigurable multiband seeker test bed was developed to assess the performance of emerging seeker concepts and technologies.
- To improve the performance of Navy sonar systems, the Laboratory developed adaptive beamforming architectures that exploit special characteristics of underwater environments. During the ICEX16 Arctic experiment, Laboratory researchers assessed noise recorded on sensors installed on a submarine and on an unmanned undersea vehicle to demonstrate improved calibration and signal processing techniques.
- System-level assessments of vulnerabilities of U.S. undersea capabilities utilized the Laboratory's expertise to inform Department of Defense leadership of improved tactics and future system development options.
- The Laboratory completed a major digital receiver architecture demonstration system on an existing over-the-horizon radar.

Future Outlook

Lincoln Laboratory will grow its portfolio of systems analysis and advanced concept development programs to ensure U.S. dominance in the undersea domain. System-level assessments will focus on understanding potential submarine vulnerabilities against conventional and unconventional threats.

The Laboratory will continue to prototype advanced sensor and seeker concepts to demonstrate future capability for the BMDS to address current and emerging ballistic missile threats. The Laboratory will also design and prototype innovative test articles for future missile defense flight tests.

To address regional threats to both the U.S. naval fleet and land bases, the Laboratory will develop advanced concepts and prototypes, including ones for future Navy fleet design and for sensor and engagement capabilities for future Navy surface combatants.

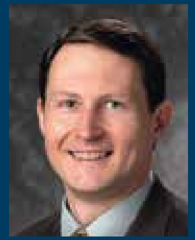
Pulse-to-Pulse Phase Diversity

A Lincoln Laboratory research team developed the Pulse-to-Pulse Phase Diversity technique for suppressing signal interference and eliminating the ambiguity in range measurements that is inherent in pulse-Doppler radar. The technique uses a specialized radar transmit waveform and a tailored chain of signal processing algorithms to eliminate range ambiguity and filter out interference, such as ground clutter and wind turbine effects. Pulse-to-Pulse Phase Diversity was recognized as one of the 2017 winners of R&D 100 Awards, which are presented by *R&D Magazine* to the 100 technologies that a panel of expert judges deems the year's most innovative inventions.

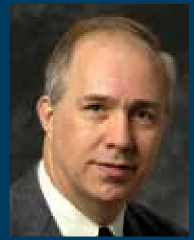
Communication Systems

Developing and demonstrating RF military satellite communications, free-space laser communications, tactical network radios, and quantum systems to expand and protect the nation's global defense networks

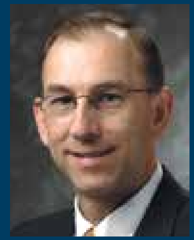
Leadership



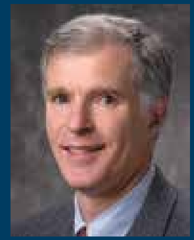
Dr. J. Scott Stadler
Division Head



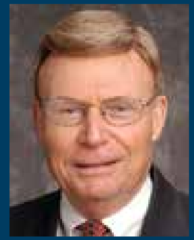
Dr. Roy S. Bondurant
Assoc. Division Head



Dr. James Ward
Asst. Division Head



Dr. Don M. Boroson
Laboratory Fellow



Dr. David R. McElroy
Principal Staff

The 6.3-meter Multi-band Test Terminal installed on a roof at Lincoln Laboratory operates in the Ku, Ka, X, and EHF frequency bands. This Air Force-funded antenna enables the testing and evaluation of waveforms and techniques that may increase antijam protection for satellite communications.

Principal 2017 Accomplishments

- During an operational flight exercise, Lincoln Laboratory demonstrated the use of real-time adaptive beamforming to provide enhanced jamming resistance to airborne tactical data links.
- The Laboratory used protected military satellite communication (MILSATCOM) terminals to define and demonstrate a method for local time transfer.
- Flight-testing of an initial production satellite communications terminal with an airborne antenna was conducted for the Family of Advanced Beyond Line-of-Sight Terminals, which will help to move large amounts of information to and from ground installations and airborne platforms.
- An acquisition detector array is under development for robust laser communication (lasercom) beam acquisition. A prototype device with the capability to differentiate multiple inputs and acquire and track the signal of interest was demonstrated.
- A concept was developed for a next-generation, low-size, -weight, and -power airborne lasercom terminal that enables high-data-rate communication over a wide field of regard.
- To validate the pointing, acquisition, tracking, and communication performance and interoperability among lasercom terminals, Lincoln Laboratory developed multiple test beds.
- Lincoln Laboratory implemented a configurable composable architecture for airborne tactical data links. The architecture was used to instantiate all major airborne Department of Defense waveforms and will simplify the development and deployment of future waveforms.
- For a prototype third-generation space lasercom beam director, prototype gimbal and telescope subassemblies delivered by contractors were integrated with a Laboratory-developed small optics assembly.

Future Outlook

Expertise in space-time adaptive processing will be used to develop antijam and low-probability-of-detection communications for terrestrial, airborne, maritime, and space environments.

The Laboratory will pursue efforts to develop fundamental optical technologies, including quantum illumination for use on sensing and communication, and to develop and demonstrate a quantum repeater.

A next-generation protected high-frequency waveform will be developed for beyond-line-of-sight communications. This adaptive waveform will be paired with digital arrays in a hub-based architecture to provide increased data rates, low probability of detection, and antijam connectivity.

Computational Leverage Against Surveillance Systems

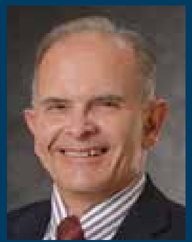
Lincoln Laboratory demonstrated the first-ever distributed coherent transmit radio system for low-probability-of-detection antijam communications. The Computational Leverage Against Surveillance Systems (CLASS) mobile radios cooperatively focus a message transmission on the base station to increase the received power by the square of the number of mobile radios. This cooperative radio arrangement results in an increase in throughput, a reduction in battery size, and a range extension to maneuvering squads of soldiers. This system was developed with funding from the Defense Advanced Research Projects Agency.

Cyber Security and Information Sciences

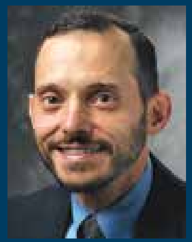
Conducting research, development, and evaluation of cyber components and systems, and developing solutions for processing large, high-dimensional datasets acquired from diverse sources, including speech, imagery, text, and network traffic

Leadership

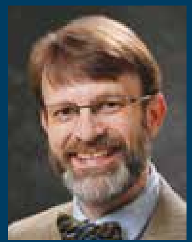
Mr. Stephen B. Rejto
Division Head



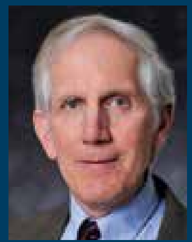
Mr. David R. Martinez
Assoc. Division Head



Dr. Marc A. Zissman
Assoc. Division Head



Dr. Jeremy Kepner
Laboratory Fellow



Dr. Richard P. Lippmann
Laboratory Fellow

Lincoln Laboratory staff, with Pacific Northwest National Laboratory collaborators and Department of Homeland Security sponsors, participated in the Aircraft Cybersecurity Evaluation at the Federal Aviation Administration's William J. Hughes Technical Center in New Jersey in September 2016.

Principal 2017 Accomplishments

- The Laboratory completed hands-on, in-depth cyber red team vulnerability assessments of the Joint Direct Attack Munition guidance system and the Joint Mission Planning System, both of which are used extensively by the military and are critical to warfighting effectiveness.
- The Lincoln Laboratory Supercomputing Center deployed a new petaflop-scale system that consists of 41,472 processor cores and can compute 10^{15} operations per second. This new system, with six times more processing power than the previous one, will enable research across all mission areas.
- The Department of Homeland Security's Cyber Security Division selected for its Transition to Practice program several Lincoln Laboratory technologies, including tools to support cyber defense planning, certificate distribution to the cloud, and cyber-based analysis.
- For the Office of Naval Research, the Laboratory developed a prototype that uses an augmented-reality display to enable Marines to maintain hands-on control of their weapons while they assess an adversary's cyber presence in the electromagnetic spectrum.
- The Laboratory provided test and evaluation support for the Defense Advanced Research Projects Agency (DARPA) Cyber Grand Challenge, the first automated Capture the Flag event showcasing cyber reasoning systems. Capture the Flag competitions challenge participants to find and mitigate computer threats.
- The Laboratory performed technical analyses and developed three prototypes for the U.S. Cyber Command Capabilities Development Group. The prototypes will enable joint warfighting capabilities for the Cyber Mission Forces.
- Lincoln Laboratory systems exhibited outstanding performance in the National Institute of Standards and Technology's (NIST) 2016 Speaker Recognition Evaluation and in the NIST 2015 Language Recognition Evaluation.

Future Outlook

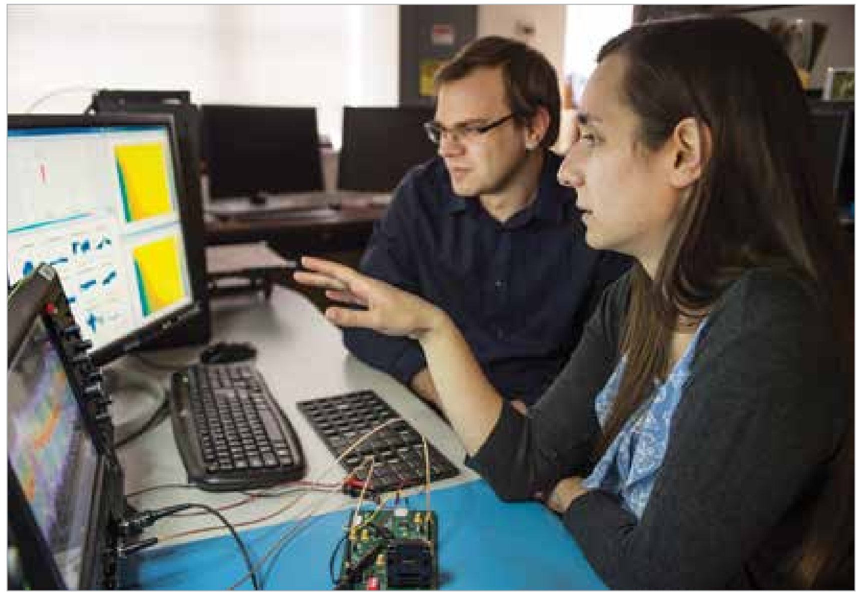
By combining natural language processing with graph and cyber analytics, the Laboratory will develop end-to-end system capabilities to combat the spread of misinformation via online media.

Development of novel interactive supercomputing and big data technologies will help enable the Department of Defense and Intelligence Community to leverage the potential of next-generation autonomous sensors and systems.

To enable rapid development of resilient prototype systems, the Laboratory will create a cyber-resilient toolbox with systems analysis capabilities and will compile software development best practices and tools.

Side-Channel Authenticity Discriminant Analysis (SICADA)

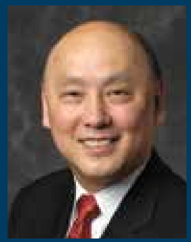
A practical approach for identifying counterfeit electronics, developed and validated by researchers at Lincoln Laboratory, utilizes side-channel analysis techniques. Counterfeit microelectronics represent billions of dollars in risk to operator safety and financial loss. SICADA was designed as a scalable, cost-effective solution to mitigate the growing counterfeit threat. At right, researchers are analyzing the results from SICADA.



ISR Systems and Technology

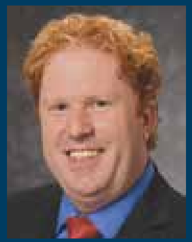
Conducting research and development in advanced sensing, signal and image processing, decision support technology, and high-performance embedded computing to enhance capabilities in intelligence, surveillance, and reconnaissance

Leadership

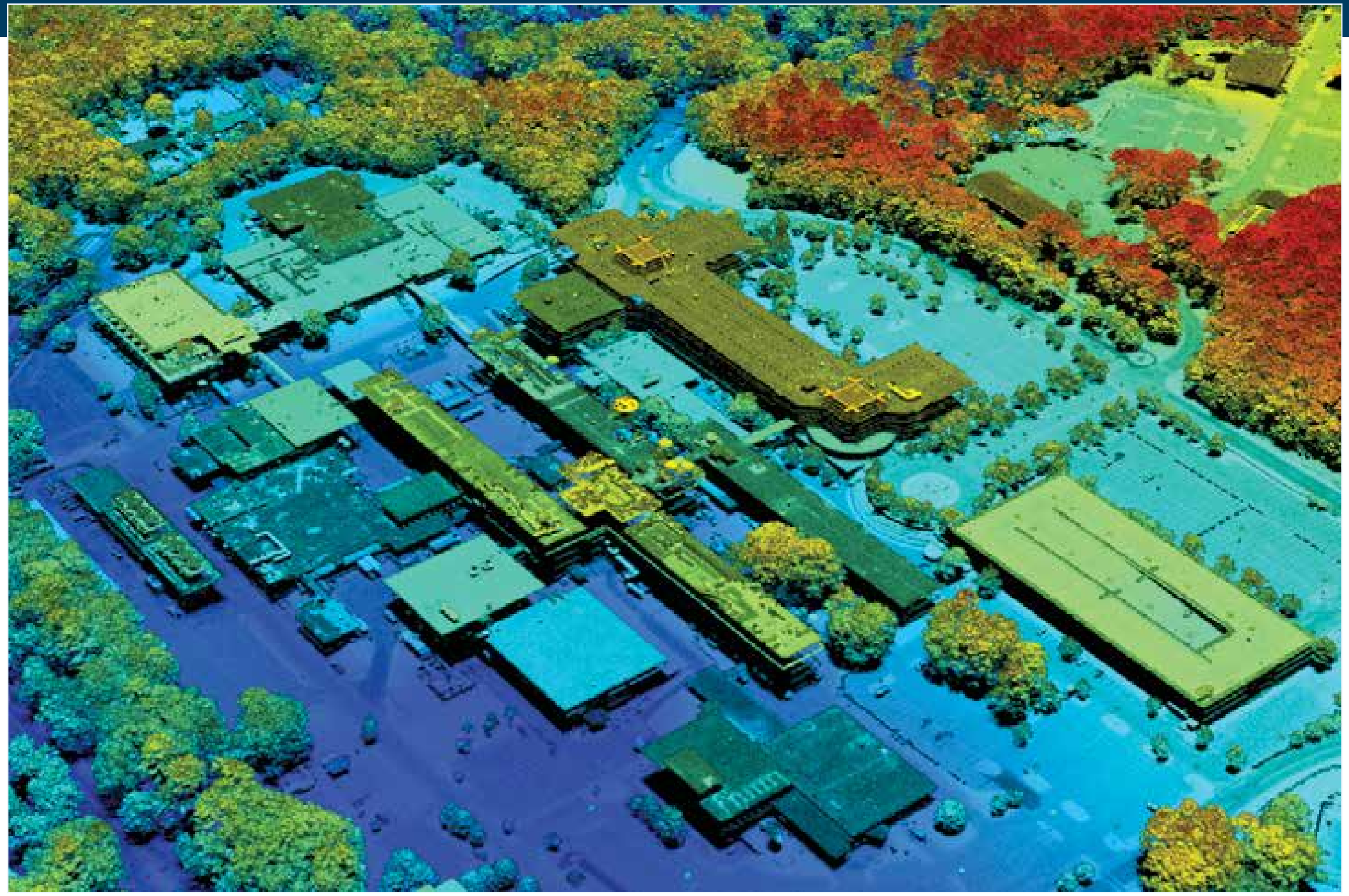


Dr. Robert T-I. Shin
Division Head

Dr. Richard M. Heinrichs
Asst. Division Head



Dr. Marc N. Viera
Asst. Division Head



The Multi-look Airborne Collector for Human Encampment and Terrain Extraction, a 3D ladar designed to uncover clandestine activity in heavily foliated areas, employs photodiode arrays to collect and process data to create 3D images, such as the above image of Lincoln Laboratory.

Principal 2017 Accomplishments

- The Laboratory provided technical analysis to support key decisions for U.S. Air Force and U.S. Navy acquisition programs, including the Joint Surveillance Target Attack Radar System (JSTARS) Recapitalization program. Techniques, technology, and tactics for the protection of airborne radar systems in jamming environments were developed and tested. Phenomenology experiments were conducted to characterize complex radio-frequency (RF) propagation and scattering in support of advanced system concepts. The airborne radar test bed for prototyping advanced RF and processor technology is under development.
- Work continued on Open Mission Systems (OMS) for the U.S. Air Force. OMS is an open architecture for avionics that facilitates development, integration, and capability upgrades. Recent accomplishments included a new standards release and the establishment of a systems integration laboratory.
- The world's first distributed uplink coherent radio system was demonstrated in operationally relevant environments and was enabled by a high-performance custom application-specific integrated circuit system on chip. By using novel adaptive signal processing techniques, this networked system of up to five coherent mobile emitters communicated successfully with a base station in the presence of substantial co-channel interference.
- New architectures for knowledge extraction from publicly available information continue to be developed and demonstrated. Research into network graph exploitation and deep-learning techniques emphasizes the delivery of real-time intelligence data to tactical analysts.
- Lincoln Laboratory developed a prototype of a novel ground-based infrared surveillance system. The prototype employs multiple uncooled microbolometer cameras mounted on a pan-tilt gimbal. Imagery from the cameras is processed by a custom suite of signal processing algorithms. Data collected from field tests of the system are used to assess the utility of inexpensive, commercially available infrared detectors for tactical applications and to develop advanced algorithms that optimize the detectors' performance.

Future Outlook

Integration of the airborne radar test bed will be completed, and flight tests will begin.

Lincoln Laboratory will continue its significant support to the Department of Defense and Intelligence Community by providing architecture engineering, systems analysis, technology development, and advanced capability prototyping.

Air- and space-based radar systems will evolve to support new unmanned and manned platforms while exploiting advances in antennas, signal processing, and low-power embedded processing. Electronic warfare capabilities will remain a major focus.

The Laboratory will help the government develop, prototype, and employ open-system architecture paradigms for sensors, avionic payloads, and ground control stations.

Low-VHF Radar Test Bed

To investigate the surveillance capabilities of phased array radars with modern digital signal processing, Lincoln Laboratory is developing a low-VHF (very high frequency) radar test bed, shown here during recent field testing. This instrumented sensor is used for measurements of the background radio-frequency environment and ground clutter, and supports the development of algorithms for detecting and tracking airborne targets.

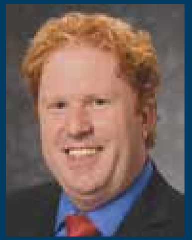
Tactical Systems

Improving the development of tactical air and counterterrorism systems through systems analysis to assess the impact of technologies on real-world scenarios; rapidly developing prototype systems; and conducting precise instrumented testing of systems

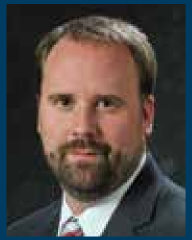
Leadership

Dr. Robert T-I. Shin
Division Head

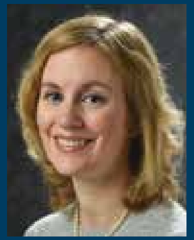
Dr. Richard M. Heinrichs
Asst. Division Head



Dr. Marc N. Viera
Asst. Division Head



Dr. Josh G. Erling
Group Leader



Dr. Janet T. Hallett
Group Leader

Lincoln Laboratory engineers evaluate flight characteristics of the Perdix micro–unmanned aerial vehicle in various aerodynamic design configurations during a series of ground-launched flight tests at Fort Devens, Massachusetts, on 15 June 2017.

Principal 2017 Accomplishments

- Lincoln Laboratory is developing and demonstrating innovative concepts for employing micro-sized air vehicles in national security contexts. In 2016, a major flight demonstration of coordinated autonomy was achieved by the nation's largest formation of air-launched micro air vehicles. Under the sponsorship of the Office of the Secretary of Defense, Strategic Capabilities Office, the Laboratory has been exploring follow-on system and mission concepts, and conducting flight tests of the micro air systems with the U.S. Air Force and Marine Corps.
- The Laboratory continues to conduct system analyses, laboratory testing, and flight-system data collections that inform its assessments of the performance and limitations of Air Force aircraft against current and future foreign threats. These assessments—which include investigations of missile systems performance, electronic attack and electronic protection, and radio-frequency and advanced infrared sensor kill chains—have been presented to Department of Defense (DoD) leadership to advise their decisions about technology investments and future system capabilities.
- To evaluate the performance of various Air Force options for airborne electronic attack, the Laboratory has performed systems analyses, developed detailed models, and fielded prototype threat radar systems, including systems used for surveillance, target acquisition, and fire control.
- The analytical assessment of a family-of-systems architecture that involves teaming manned and unmanned aircraft has shown the potential for new operational capabilities in a contested environment. The assessment's findings have been briefed to the DoD sponsor and are influencing the development of a demonstration system for these capabilities.
- The Laboratory continues to develop and analyze new concepts for air dominance and for space intelligence, surveillance, and reconnaissance. Several advanced technologies that will enable new capabilities in these areas have been identified for the Air Force. Detailed modeling and systems analyses are being performed to determine the feasibility and performance of these technologies.

Future Outlook

Lincoln Laboratory will continue to support the Air Force by performing systems analyses, prototyping systems with advanced capabilities, and demonstrating the capabilities through measurement campaigns. This research will investigate the ability of systems to operate in a contested environment, with an emphasis on operation in the Pacific and European theaters.

The anticipated growth in the development of micro air vehicles will focus on vehicles capable of autonomous operation and coordinated activity. This development work will entail the rapid prototyping and demonstration of new capabilities.

The Laboratory will expand the analysis and demonstration of technologies for electronic attack and electronic protection. These technologies will have particular application to tactical aircraft and missiles, as well as airborne signals intelligence.

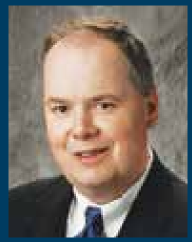
Airborne Seeker Test Bed

The Airborne Seeker Test Bed (ASTB) is a highly modified jet aircraft that is used for conducting research for radio-frequency and infrared sensors. The ASTB capabilities, first developed by Lincoln Laboratory in the 1990s, are currently flying on a Gulfstream G-II airframe. To carry these sensors in flight testing, the aircraft has been modified with wing pylons, a nose radome, forward chin-pods, at right, and computer and instrumentation racks in the interior. The ASTB flies locally or at other test ranges around the country, and data collected by the ASTB are analyzed to understand the engineering and science of tactical systems and threats to U.S. Air Force aircraft.

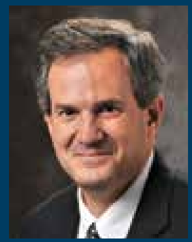
Advanced Technology

Leveraging solid-state electronic and electro-optical technologies, chemistry, materials science, advanced RF technology, and quantum information science to develop innovative system applications and components

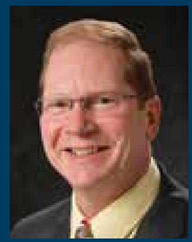
Leadership



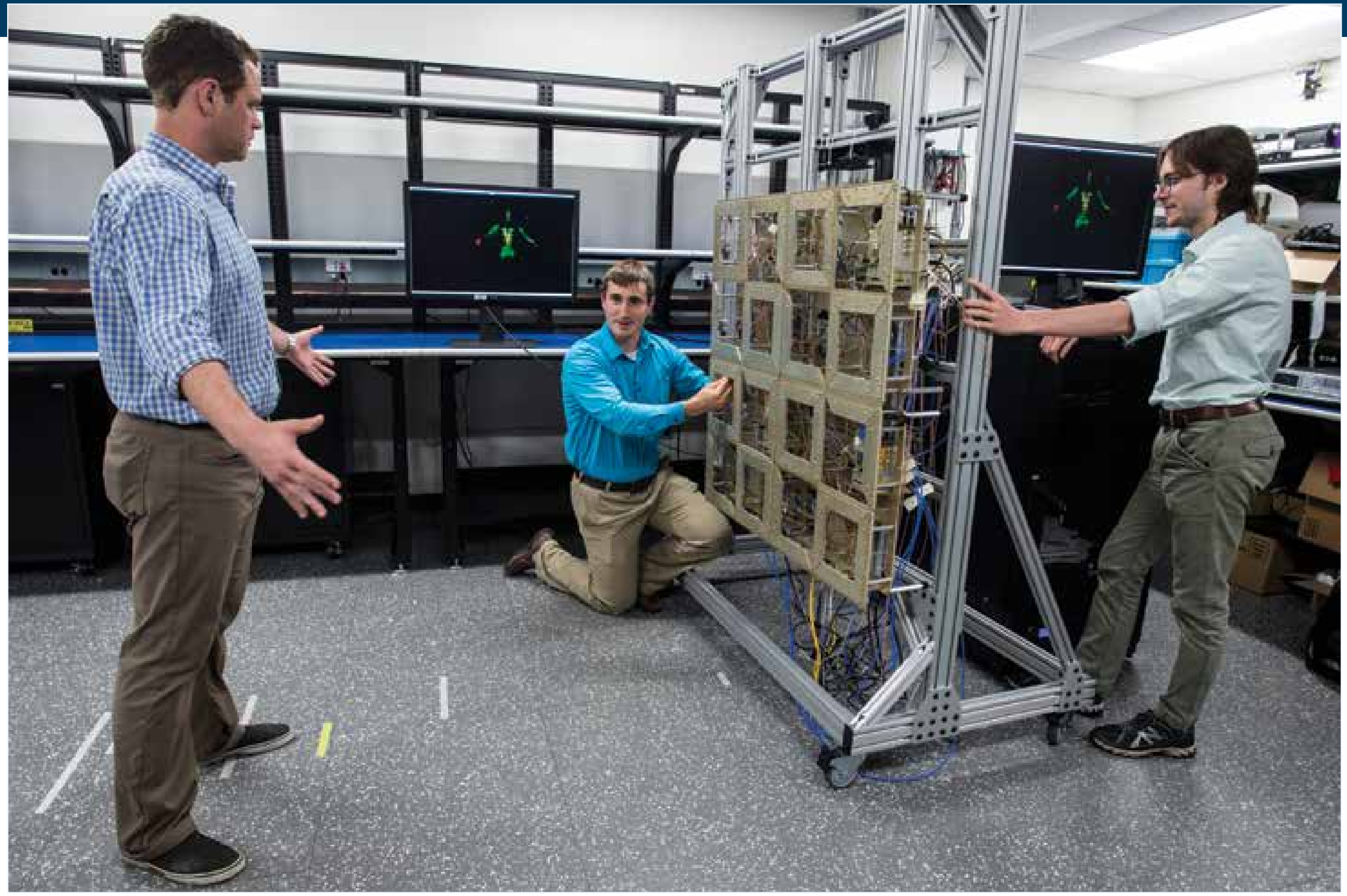
Dr. Robert G. Atkins
Division Head



Dr. Craig L. Keast
Assoc. Division Head



Dr. Mark A. Gouker
Asst. Division Head



Researchers examine a prototype standoff microwave imaging system for detecting concealed threats. This Laboratory-developed system provides unique video-rate imaging capabilities for rapid screening of subjects (see computer displays in background).

Principal 2017 Accomplishments

- Through an optical systems program funded by the Assistant Secretary of Defense for Research and Engineering, a multidivisional Lincoln Laboratory team developed a microscope capable of chemically identifying individual micron-sized particles. Detection of these micro-particles could one day enable rapid screening for trace amounts of dangerous materials, such as explosives and chemical or biological warfare agents.

- A new type of microactuator demonstrated by the Laboratory borrows design and operational concepts from biological muscle and stepper motors. By integrating surface-tension forces produced by electrowetting electrodes, this actuator offers a unique combination of power, efficiency, and scalability. The current actuator's output power density of 200 W/kg exceeds that of most biological muscles.

- In a cross-divisional effort, researchers developed a novel system prototype that provides timely (<30 s), accurate (<50 m) geolocation of handheld laser pointers shining up into the sky. This system was designed to provide law enforcement with information that will lead to the apprehension of the perpetrators of the increasingly frequent laser strikes aimed at commercial aircraft.

- After delivering three superwideband compressive receiver (SWCR) units to Navy sponsors in 2016, the Laboratory continued to provide support to the Office of Naval Research (ONR). The SWCR was deployed for data collection missions that used both wideband pulse descriptor word generation and energy mapping.

- Data collected from two prototype high-frequency electromagnetic vector sensors were used to develop a maximum-likelihood processing technique that generates a map of multiple electromagnetic sources from a single electromagnetic vector sensor.

- A 2 × 2 array of 4 Mpixel charge-coupled devices (CCDs) was launched aboard NASA's OSIRIS-REx satellite on a science mission to the asteroid Bennu. A 200 nm aluminum optical blocking layer is directly deposited onto the CCDs, which map elemental abundances of the asteroid via X-ray fluorescence spectroscopy.

Future Outlook

Growth in quantum information systems technology is expected to continue. Current Laboratory technology will exploit the strong vertical integration from materials growth to prototype quantum systems for several potential applications.

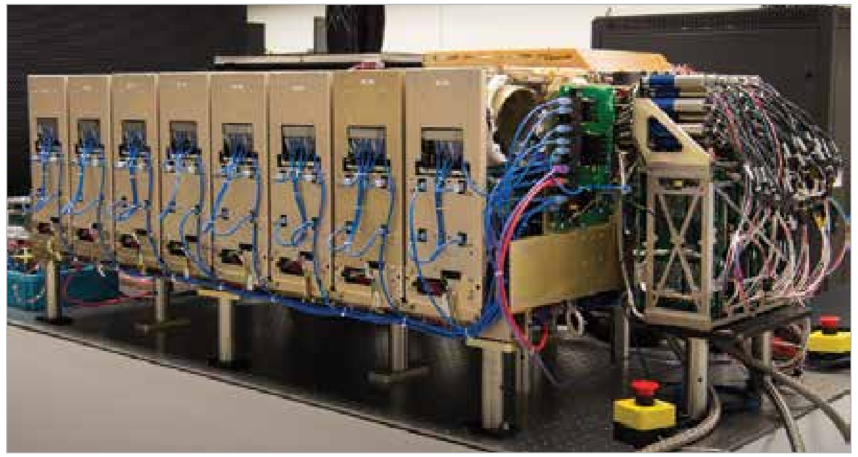
Activities in compound semiconductor–related technology will focus on chip-scale diode laser arrays, novel smart infrared focal plane arrays, and heterogeneous integrated photonics.

Lincoln Laboratory continues to develop high-energy laser technology and supporting sensor systems.

Development of new sensor capabilities is motivated by the need to find increasingly small signatures representative of threats from terrorist acts or weapons of mass destruction. The Laboratory will explore component technologies for advanced sensors.

Advanced High-Power Laser

Lead researchers from the Laser Interferometer Gravitational-Wave Observatory (LIGO) recently received the Nobel Prize in Physics for detection of gravitational radiation. The laser utilized for these discoveries was underperforming relative to design. Lincoln Laboratory staff saw an opportunity to quickly develop a new laser for LIGO that operates reliably at the desired 200 W power level rather than at the current 35 W level. This new laser, shown at right, leverages the Laboratory's long-established work developing high-power fiber lasers. The system is being fully characterized at MIT campus to investigate the feasibility of its use at the LIGO sites.

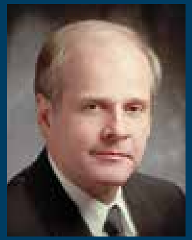


Homeland Protection

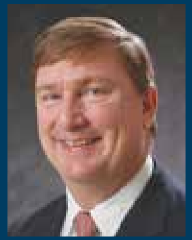
Innovating technology and architectures to help prevent terrorist attacks within the United States, to reduce the vulnerability of the nation to terrorism, to minimize the damage from terrorist attacks, and to facilitate recovery from man-made and natural disasters

Leadership

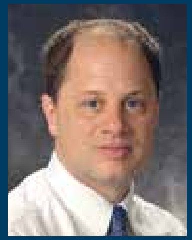
Dr. Melissa G. Choi
Division Head



Mr. James M. Flavin
Assoc. Division Head



Mr. Edward C. Wack
Asst. Division Head



Dr. Timothy J. Dasey
Group Leader

Dr. Ted David
Group Leader

The Sensorimotor Technology Realization in Immersive Virtual Environments Center enables the assessment of cognitive and physiological performance as a person interacts with a virtual environment. The researcher above is monitoring the person's performance.

Principal 2017 Accomplishments

- Under Department of Homeland Security sponsorship, Lincoln Laboratory conducted initial experiments on "screening at speed" sensing technologies to be used at airports and other potential venues. These technologies seek to automatically detect concealed threat materials without unnecessarily restricting passenger flows. The signal processing experiments included combining advancements in low-power radar technology with video camera networks to identify regions of interest and reduce false alarms.
- A test bed was established to evaluate concepts of operation and supporting technologies that help the Department of Homeland Security counter the illegal use of small unmanned aerial vehicles.
- A prototype system developed by the Laboratory to detect, track, and classify boats using video cameras began operating in a region of the nation's waterway borders.
- In collaboration with the Joint Improvised-Threat Defeat Organization, the Laboratory is transitioning the first fieldable homemade explosives sourcing and human DNA mixture identification toolkit.
- The Laboratory developed the world's fastest computational methods for searching DNA databases for human identification and forensics applications.
- The Sensorimotor Technology Realization in Immersive Virtual Environments (STRIVE) Center now operates as a Department of Defense (DoD)-wide nexus for collaboration on the development of next-generation medical and operational technology and for advanced training research. Recent work at the STRIVE Center includes assessing mild traumatic brain injury with clinical and operational experimentation, developing assistive devices for people with injuries or disabilities, and evaluating tools for the assessment of musculoskeletal injury.

Future Outlook

The DoD's goal of protecting the health of soldiers will require sensors for real-time physiological monitoring and injury assessment.

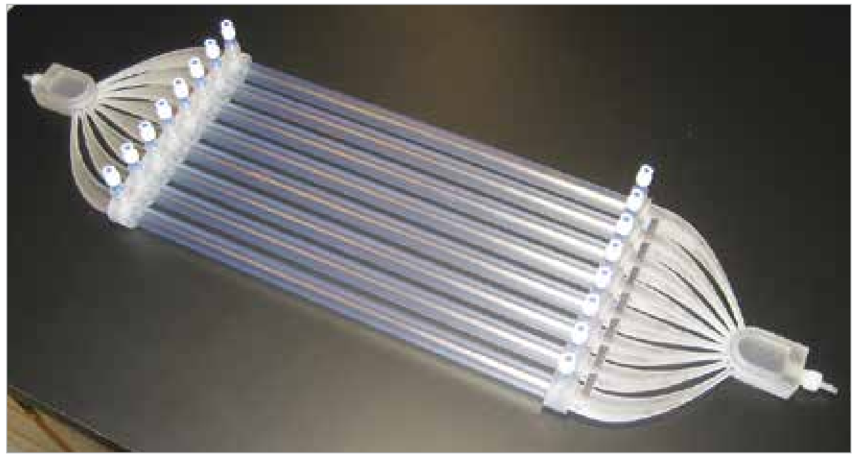
Integrated air, land, and maritime architectures are needed to advance border and critical infrastructure security. The Laboratory will provide systems analysis for threat understanding, architecture development, and technology assessments to fill capability gaps.

Improving humanitarian assistance and disaster response capabilities will necessitate new technology, including novel sensors, information-sharing architectures, and analytics for data mining and collaborative decision making.

The Laboratory will continue to develop system architectures, including biometrics and forensic technologies, for chemical and biological defense.

Artificial Gut

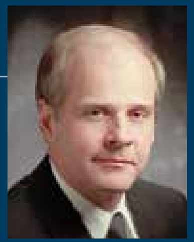
Lincoln Laboratory is developing new tools and capabilities that improve and accelerate R&D into the human microbiome, the trillions of microorganisms residing on or in the body. One such tool is the 3D-printed, multiplexed Artificial Gut (ArtGut), which emulates key aspects of the gut, the primary environment of the microbiome. The ArtGut is composed of an array of tubes that have innovative 3D-printed spline injectors at the input end and sampling ports at the output end. The injectors allow multiple test agents, such as probiotics or toxicants, to be introduced into the ArtGut and later sampled downstream without disturbing the culture environment.



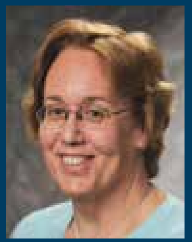
Air Traffic Control

Developing advanced technologies and decision support architectures for aircraft surveillance, integrated weather sensing and processing, collaborative air traffic management, and information security to support the nation's air transportation system

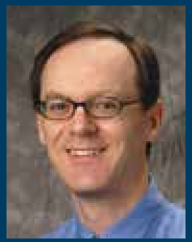
Leadership



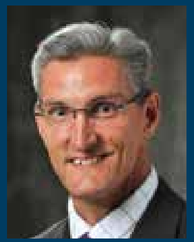
Mr. James M. Flavin
Assoc. Division Head



Dr. Marilyn M. Wolfson
Laboratory Fellow



Dr. James K. Kuchar
Group Leader



Dr. Gregg A. Shoults
Group Leader

The control tower simulation facility serves as a test bed for evaluating new procedures and technologies that have been developed to improve airport ground operations. Researchers use realistic flight data in their proof-of-concept demonstrations.

Principal 2017 Accomplishments

- Development work continued on a 76-panel Multifunction Phased Array Radar prototype. In partnership with the Federal Aviation Administration (FAA) and National Oceanic and Atmospheric Administration, the Laboratory established the array panel firmware and software to control and process beam-steering commands from the radar signal processor.
- The prototype Small Airport Surveillance Sensor demonstrated passive real-time surface surveillance for transponder-equipped aircraft and achieved 30 ft accuracy.
- In partnership with the FAA and industry partners, the Laboratory conducted operational test and evaluation of the Airborne Collision Avoidance System Xa (ACAS Xa), which will support new flight procedures and aircraft classes. Additionally, the Laboratory led planning for the second developmental flight test of the ACAS Xu system for unmanned aircraft.
- Algorithm improvements continued for the Offshore Precipitation Capability (OPC), which uses lightning, satellite, and meteorological model data to generate a global radar-like view of convective weather that is beyond the coverage of land-based radars. The Laboratory will expand the OPC domain and utilize data from the recently launched Geostationary Operational Environmental Satellite (GOES-16).
- Analyses are being conducted to guide the FAA on wind information needs, particularly for four-dimensional trajectory-based operations, for Next Generation Air Transportation System (NextGen) applications that are aimed at modernizing the way the National Airspace System is managed. The Laboratory is assessing the utility of aircraft-derived measurements to expand the nation's wind-sensing network.
- Operational improvements are being developed to mitigate the environmental impacts of aviation. The Laboratory is developing techniques and procedures to reduce taxiway congestion and to select efficient aircraft altitudes and speeds.

Future Outlook

Lincoln Laboratory will increase its role in developing NextGen concepts, including trajectory-based operations, collision avoidance, environmental impact mitigation, and surface operations management. A key component includes identifying cyber vulnerabilities to ensure the protection of aircraft systems and ground-based air traffic control services.

Ongoing support for next-generation weather capabilities will include improvements in sensing technology, data dissemination and processing architectures, and algorithms for estimating airspace capacity reductions.

The Laboratory's continued support for the integration of unmanned aircraft systems into civil airspace will include developing standards and requirements, safety evaluation methods, threat detection and maneuver algorithms, and real-time prototypes.

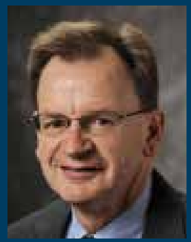
Runway Status Light System

The Laboratory led the development of a prototype Runway Status Light (RWSL) system that automatically warns pilots of potentially hazardous airport surface operations. After successful operational evaluations at international airports in Boston, Dallas-Fort Worth, Los Angeles, and San Diego, the RWSL technology was transitioned to industry and is now operational at 17 airports across the United States. Studies showed that RWSL can reduce serious runway incursions by up to 70%, significantly improving safety at busy airports. The last of the prototypes (at Boston, Dallas-Fort-Worth, and San Diego) are scheduled to be replaced with production systems within two years.

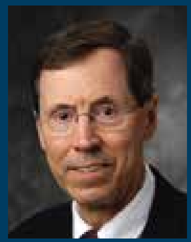
Engineering

Employing expertise in electrical, mechanical, structural, thermal, aeronautical, optical, and control systems engineering to build, integrate, and test prototype systems for application in space control, energy, communications, and autonomy

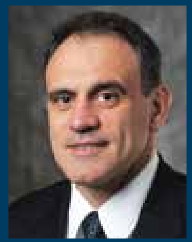
Leadership



Dr. Michael T. Languirand
Division Head



Dr. William R. Davis
Asst. Division Head



Dr. William D. Ross
Asst. Division Head

The Operationally Responsive Space-5 SensorSat was delivered to the Air Force after completion of testing to verify the hardware-to-software interfaces, vibration testing to replicate the launch environment, and performance testing in a thermal-vacuum chamber to simulate the space environment.

Principal 2017 Accomplishments

- Lincoln Laboratory developed a controller hardware-in-the-loop system that provides real-time simulation of distribution power grids with a variety of energy resources. It was the demonstration platform at the Microgrid and Distributed Energy Resource Controller Symposium, which the Laboratory co-hosted with the Massachusetts Clean Energy Center in February 2017.

- A methodology was developed to enable the design of freeform optics for the first time. Freeform optics offer significantly improved optical resolution and lower system size and weight. The Laboratory built and demonstrated the nation's first spline-based freeform telescope, a three-mirror system utilizing 6-inch optics.

- The Laboratory continues to set records for the brightness of beam-combined fiber lasers. This brightness has been possible, in part, because of the development of cooling systems using additively manufactured metal heat exchangers with complex internal flow geometries. The heat exchangers also provide structural support, greatly reducing the size and weight of the lasers.

- Advanced semiconductor devices, such as gallium nitride transistors, are enabling new capabilities for radars and other electronic systems, but their performance is quickly being limited by the inability to reject heat. The Laboratory has demonstrated a new technique using embedded microjets to cool individual devices.

- Advances in unmanned aerial vehicles (UAVs) have provided the Laboratory with opportunities to field a variety of sensors. The Laboratory has been exploring a new concept called electro-aerodynamic propulsion to minimize the UAVs' audible signature. A UAV with a 6 ft wingspan was successfully flown under electro-aerodynamic power.

- Autonomous systems employ complex autonomy algorithms with nondeterministic and adaptive behaviors that challenge traditional verification and validation approaches. The Laboratory developed new algorithm techniques that were applied to a mobile manipulation task in order to avoid dynamically unstable robot configurations.

Future Outlook

Work will continue on the establishment of engineering capabilities, including the characterization and improvement of additive manufacturing processes, and the enhancement of deployable structures, advanced heat exchangers, optical structures, and cubesat propulsion for prototype system development.

Energy systems efforts will focus on ensuring the resilience of the nation's electrical grid, designing and testing microgrids, and extending endurance for soldiers and unmanned vehicles. Autonomous systems projects will continue work in human-machine interfaces, vision-based and GPS-denied navigation, and UAV flight-test capabilities.

A product life-cycle management system will be implemented as part of a larger digital transformation initiative to enable the Laboratory to more efficiently develop prototype systems.

Protected Aerial Contested-Environment Communications Relay

The Laboratory delivered to the U.S. Navy two Protected Aerial Contested-Environment Communications Relay (PACECR) airborne pods, one of which is pictured at right installed on an aircraft. PACECR is part of the Joint Aerial Layer Network–Maritime demonstration to prove the utility of aerial layers for providing critical communications in contested areas. Each pod's six subsystems were individually qualified for the demanding airborne and thermal environment. Integrating capabilities into the pod required the development of a complex power-distribution system and specialized support equipment to handle assembly and transport.

LABORATORY INVOLVEMENT

In summer 2017, Lincoln Laboratory hired 210 interns from 82 colleges and universities to work on technical programs in all mission areas.

Research and Educational Collaborations

DEFENSE FABRIC DISCOVERY CENTER

Alexander Stolyarov, who manages the DFDC, explains the prototyping capabilities of the Defense Fabric Discovery Center to guests at the center's opening day event.

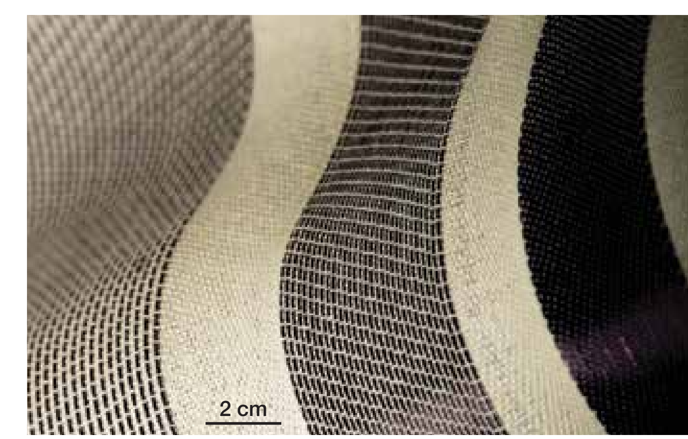
The Defense Fabric Discovery Center (DFDC) is a state-of-the-art, end-to-end prototyping facility for developing advanced fiber and fabric technology. The center was founded through a partnership of Lincoln Laboratory, the U.S. Army Natick Soldier Systems Center, the Commonwealth of Massachusetts, and the Advanced Functional Fabrics of America (AFFOA), a nonprofit founded by MIT that is funded in part by the Department of Defense through the Manufacturing Technology Program. The Laboratory celebrated the opening of the DFDC with a ribbon-cutting ceremony in October.

The center is furnished with computer-aided-design tools, multimaterial preform fabrication equipment, and fiber draw towers for producing polymer and glass fibers. It will have equipment for integrating microelectronic systems into the fibers and for creating textiles from those fibers. This facility is part of a planned national network of five fabric discovery centers that will conduct R&D in fiber and fabric technologies. The center at the Laboratory will focus on fabrics that have military applications, such as providing soldiers with garments that can sense RF and optical signals, store electrical energy, and monitor heart or heat stress.

Lincoln Laboratory received two state grants that have enabled DFDC operations. In May, Massachusetts Lieutenant Governor Karyn Polito announced the awarding of a $2.2 million state grant for the construction of the DFDC at the Laboratory's Lexington site. This award was followed by a $3.9 million state grant, announced by Secretary Jay Ash of the Massachusetts Executive Office of Housing and Economic Development at an event at the Laboratory in December. This second grant will enable an expansion of the facility and its equipment. This expansion will include an automated loom for weaving fabrics, a second draw tower capable of drawing silica optical fibers, and system integration technology to produce a finished product. The ability to complete all the prototyping steps in the DFDC will speed up the process of delivering a final product to the Department of Defense for operational use.

Counterclockwise from top left, Lauren Cantley, a postdoctoral associate in the Chemical, Microsystem, and Nanoscale Technologies Group, adjusts the gauge near the top of the fiber draw tower as it pulls a fiber. The roller guides below the tower keep the fiber straight before it is spooled. Knitting machines weave the fibers into textiles and garments.

Laboratory staff have begun drawing fibers embedded with light-emitting and light-detecting devices and investigating methods to integrate these fibers into fabrics. " Just as advances in semiconductor chip manufacturing over the past 50 years enabled a technological transformation and really a transformation in the human experience, so too can advances in fiber devices and fabrics," said Alexander Stolyarov, a technical staff member in the Laboratory's Chemical, Microsystem, and Nanoscale Technologies Group and the lead on the DFDC initiative.



Lincoln Laboratory staff have developed a fabric that is woven with microstructured photonic bandgap polymer fibers. The fabric can be mass produced on a conventional industrial loom. Fabrics like this will be transitioned into integrated systems at the Defense Fabric Discovery Center.

>> *Research and Educational Collaborations, cont.*

KEY-CENTRIC SECURE COMPUTING

Researchers at Lincoln Laboratory and MIT have been collaborating on the development of a processor architecture that exploits cryptographic techniques to help secure data in use, in transit, or at rest. Extensive technical discussion and exchange have led to the successful development of a key-centric processor architecture. This key-centric architecture integrates the cryptographic key management inside the processor's execution pipeline to permit distinct software codes to both coexist and interact while a high level of confidentiality is maintained through the use of a public key infrastructure engine and mandatory code and data decryption.

This novel processor addresses the vulnerability of data to infiltration from other processes running on the system. While the typical solution to this vulnerability is to minimize interactions among data, if the operating system itself is untrusted, the security of any data on it is not assured. Techniques that segregate processes have been used to thwart intersystem attacks, but these methods result in the creation of applications that carry their own security functions, e.g., libraries and encryption and decryption protocols. Such applications are thus prohibited from sharing and reusing data, present a large "attack surface," and can overburden computing resources on a system. The key-centric architecture includes a set of fully encrypted libraries that applications can access with their own private keys, therefore securely sharing data, without experiencing the high latency incurred when a system must run multiple application-specific libraries.

INDEPENDENT ACTIVITIES PERIOD AT MIT

In 2017, Lincoln Laboratory technical staff led seven activities offered during MIT's Independent Activities Period, a four-week term during the January semester break:

- Build a Small Radar System
- Free-Space Laser Communication
- Hands-on Holography
- Mathematics of Big Data
- RACECAR: Rapid Autonomous Complex-Environment Competing Ackermann-steering Robot
- Software Radio
- Technology Innovation Accelerator

Participants in the Free-Space Laser Communication class constructed the basic lasercom systems seen above. At left, instructors and students pose with the end products of the Build a Small Radar System activity.

SPOTLIGHT: BEAVER WORKS CAPSTONE PROJECT

Jungle Hawk Owl: A Long-Endurance UAV

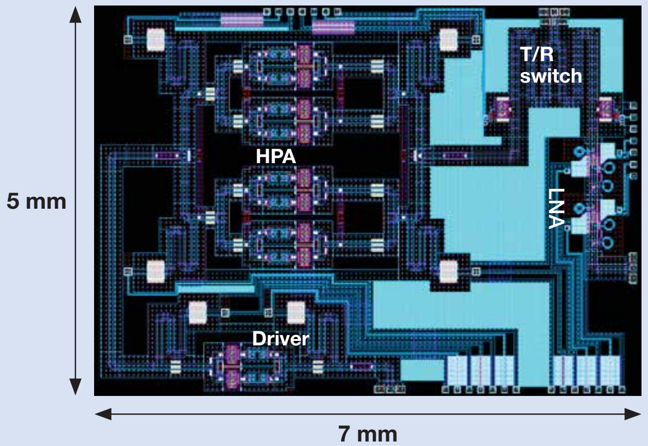
Students in the Flight Vehicle Development course offered by the MIT Department of Aeronautics and Astronautics were challenged to design, build, and test a medium-altitude, long-endurance unmanned aerial vehicle (UAV). Lincoln Laboratory technical staff served as consultants and mentors to the undergraduates whose design had to meet very specific requirements:

- Carry a payload that has a volume of 1 cubic foot, weigh up to 10 pounds, and consume less than 100 watts of power
- Maintain the ability to fly for 5 days on station anywhere and in any season
- Operate at 15,000 ft altitude
- Handle wind speeds up to those in the 90th percentile
- Operate autonomously at altitude and under manned control for takeoff and landing

On 4 May 2017, the students conducted a first flight test at Plum Island, Massachusetts. The UAV, which has a wingspan of 24 ft, was mounted to a launch rack on a car. When the car reached 45 mph, the aircraft took flight. The successful takeoff proved the viability of the launch system, and a short-duration flight that included several maneuvers was conducted to obtain airframe and engine data for further optimization of the aircraft. The aircraft landed with no damage, thus validating the skid landing system designed into the fuselage. Further flight testing planned throughout the year will lead up to a final 5-day-endurance test flight.

>> Research and Educational Collaborations, cont.

INTEGRATED CIRCUITS FOR NEXT-GENERATION PHASED ARRAYS



In this layout of a monolithic microwave integrated circuit (MMIC), the high-power amplifier (HPA), driver amplifier, low-noise amplifier (LNA), and transmit/receive switch can be seen.

In the development of advanced RF sensors, a significant challenge is lowering the cost of fabricating the high-power transmit and low-noise receive circuits used in the sensors' phased array antennas. Producing these circuits, which are necessary to maximize antenna sensitivity, requires specialized, and currently expensive, integrated circuit technologies.

A team from Lincoln Laboratory's Advanced Technology Division is working with researchers at MIT and the University of Colorado Boulder to explore a new approach to RF electronics that will greatly reduce the cost of building state-of-the-art phased arrays while enabling new capabilities. They are developing an integrated circuit process technology with gallium nitride (GaN) and complementary metal-oxide semiconductor (CMOS) transistors, all fabricated on silicon (Si) substrates with standard silicon processing. Fabrication of the GaN on Si significantly reduces the circuit materials and processing costs, and the integration with CMOS reduces the costs of assembly and testing.

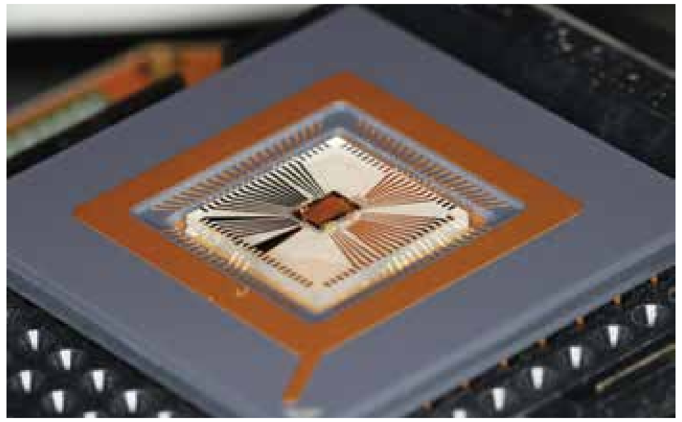
This approach has the potential to yield advanced mixed-signal circuits that enable new high-efficiency and linear power amplifiers for advanced radar and multifunction arrays. The 2017 work of this multiyear effort is focused on finalizing and testing the circuit designs for an X-band monolithic microwave integrated circuit (MMIC) that includes a high-power amplifier, driver amplifier, low-noise amplifier, and transmit/receive switch.

BIGDAWG POLYSTORE SYSTEM

Researchers from Lincoln Laboratory and the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL) have deployed a database management system that allows software developers and database administrators to efficiently exploit multiple databases. Called BigDAWG, this open-source technology is dubbed a polystore system because it interfaces with multiple, heterogeneous storage engines so that developers can access needed information contained in disparate databases. BigDAWG addresses a fundamental challenge presented by today's big data—the volume and variety of available data precludes the use of a "one size fits all" database or programming language. With a simple query, BigDAWG users can acquire and process data with the storage engines best suited to their applications.

Researchers from Intel and from several universities—Brown University, Northwestern, Portland State University, Carnegie Mellon University, University of Chicago, University of Washington, and University of Tennessee—are working with the Laboratory and MIT to make BigDAWG the solution that organizations will adopt to easily and effectively utilize data that are spread across several storage systems.

INTEGRATED QUANTUM INITIATIVE



An ion-trap chip is integrated with complementary metal-oxide semiconductor electronics to enable ion movement control in a large-scale quantum processor.

The Integrated Quantum Initiative is exploring ways for Lincoln Laboratory staff, MIT researchers, and occasionally faculty from other universities to leverage their unique expertise and resources to develop quantum information science solutions for sensing, communication, and computation.

The program helps support local graduate students who work part time at the Laboratory on projects, such as the development of magnetic sensors based on nitrogen vacancies in diamond and the investigation of quantum communication protocols.

MILITARY PROGRAMS

This year, Lincoln Laboratory awarded 42 fellowships to support the educational pursuits of active-duty military officers from all of the Services. This partnership acquaints military officers with the process of developing technologies that directly impact national security while providing the Laboratory with the constructive insights of the officers.

SPOTLIGHT

Second Lieutenant Ayesha Hein, U.S. Air Force

Second Lieutenant Ayesha Hein's interest in aerospace and Lincoln Laboratory began in 2014 when she participated in a summer internship working on cubesat modeling and test beds. "My advisors gave me hardware and said, 'Go build something.' It inspired and prepared me to continue working in the space field in graduate school."

Lt Hein is a graduate student in the Department of Aeronautics and Astronautics at MIT and a Military Fellow in the Laboratory's Applied Space Systems Group. She began work on the Microwave Radiometer Technology Acceleration cubesat, which could dramatically enhance weather and climate sensing. Lt Hein will take her Laboratory experience to Wright-Patterson Air Force Base in Ohio, where she will work as an astronautical engineer in space intelligence.

"I helped build a cubesat, and it was an amazing experience. I turned the screws on a satellite that is going into space. Not many people can say that they have had the opportunity to do that."

Lt Ayesha Hein

The first half of the 68 military interns who participated in the summer research program were photographed shortly after their arrival at the Laboratory. The interns are midshipmen from the U.S. Naval Academy and cadets from the U.S. Air Force Academy and U.S. Military Academy at West Point.

>> Research and Educational Collaborations, cont.

WORKSHOPS AND SEMINARS

2017 Schedule of Lincoln Laboratory Workshops

APRIL

4–6 Advanced Technology for National Security Workshop

24–28 Defense Technology Seminar for Military Officers

MAY

2–4 Space Control Conference

9–11 Air Vehicle Survivability Workshop

16–18 Air, Missile, and Maritime Defense Technology Workshop

23–25 Lincoln Laboratory Communications Workshop

JUNE

6–7 Cybersecurity, Exploitation, and Operations Workshop

13–15 Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop

27–29 Homeland Protection Workshop Series

NOVEMBER

1–2 Advanced Prototype Engineering Technology Symposium

7–9 Anti-access and Area Denial Systems and Technology Workshop

HIGHLIGHT: 20th Anniversary of Defense Technology Seminar

The 70 attendees of the 2017 Defense Technology Seminar gather with William Delaney, front row, ninth from right, who has chaired the event for 20 years. Standing on each side of Delaney are visiting distinguished speakers Andrew Krepinevich, left, and James Baker, right.

For 20 years, Lincoln Laboratory has offered a one-week seminar to inform mid-level military officers about the latest capabilities in modern electronics technology and systems that are relevant to their missions and national security needs. This seminar provides a broad technical perspective on research areas important to future national security.

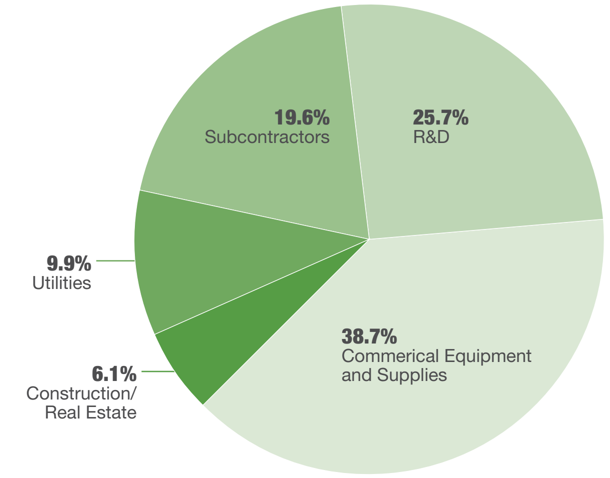
Our workshop was modeled after a two-week national security course offered at the Harvard Kennedy School. In 1995, David Briggs and William Delaney, then assistant directors, saw the potential of a course that would engage military officers, who often were unaware of the Laboratory and its capabilities, and Laboratory staff, who could gain insight into military needs. Ambitious goals were set: hold a one-week event with a wide range of lectures, tours and demonstrations; invite officers who are the day-to-day implementers of systems; and feature the Laboratory's special expertise in system development combined with distinguished policy analysts' broad view of national defense.

This year, 30 Laboratory experts provided insights on a wide variety of advanced systems, such as high-energy lasers and foliage-penetrating imagers; discussed problems the Laboratory is tackling, such as cyber security and ballistic missile defense; and examined potential technology solutions to homeland security concerns, such as border protection and air defense. The guest speakers covered topics from U.S.-China relations, to threats from the Islamic State of Iraq and Syria, to lessons learned as a Pentagon chief of staff.

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 2017, the Laboratory issued subcontracts with a value of approximately $522 million. The Laboratory awarded subcontracts to businesses in all 50 states. Massachusetts businesses were awarded $203 million in contracts, and states as distant as Colorado and Arizona also realized significant benefits to their economies. The Laboratory contracts with universities outside of MIT for basic and applied research. These research subcontracts include expert consulting, analysis, and technical support.

Contracted services*
(FY 2017)



**Estimates from $522.2M, total FY17 spend.*
– Includes orders to MIT–$32.2M
– Figures are net awards less reductions

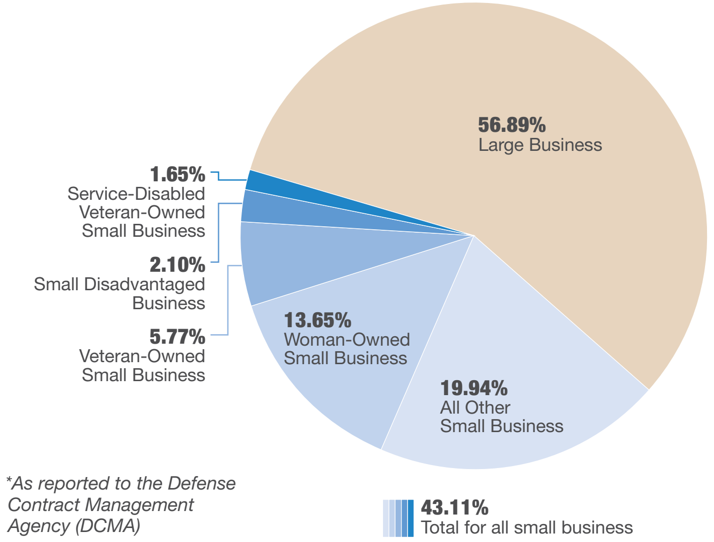
Massachusetts	202.7
Pennsylvania	63.7
California	52.0
Colorado	30.5
Virginia	27.3
New Hampshire	26.0
Arizona	19.4
All Other	100.6
Total*	522.2

**Includes orders to MIT–$32.2M*

Small Business Office

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 2017, more than 43% 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.

Contract awards by category of businesses (FY 2017)*



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

Diversity and Inclusion

Asian-Pacific American Heritage Month Celebrates the Diversity of Asian Cultures

The Pan-Asian Laboratory Staff (PALS) group, formed in January 2016, has grown to more than 140 members. Established to build awareness of the variety of Asian cultures represented at the Laboratory, PALS offers opportunities to share experiences, fosters professional development, and encourages outreach and networking through seminars and cultural celebrations. During the Lunar New Year Celebration, Charles Hughes, left, played Japanese folk music on the koto, a traditional stringed instrument, and the Angkor Dance Troupe from Lowell, Massachusetts, performed a time-honored Cambodian dance.

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:

- African American Network
- Employees with Disabilities Network
- Hispanic/Latino Network
- New Employee Network
- Out Professional Employee Network
- Pan-Asian Laboratory Staff
- Technical Women's Network
- Veterans Network

Seminars

Professors Tom Williams and Jason Wilson of the Department of Computer Science at Tufts University gave talks hosted by the Lincoln Employees with Disabilities Network. Williams presented "A Tale of Two Architectures: Integrating Natural Language and the Cognitive Map," which covered robotic software and hardware architectures that enable assistive technologies. Wilson's talk, "Designing a Social Robot to Assist a Person with Parkinson's Disease," detailed the design of a robot that sorts medications for patients with neurodegenerative conditions.

The Women's Network and Pan-Asian Laboratory Staff cosponsored MIT Professor Emma Teng's seminar "Piercing through the Great Wall of Isolationism: MIT's Pioneering Chinese Students." Teng delved into America's immigration history by using MIT's first group of Chinese students as a case study.

Sponsored by the Lincoln Employees African American Network, MIT's MLK Visiting Professor Dr. Steven Richardson presented "Using Supercomputers to Design New Quantum Materials for Computing and Communications." Richardson discussed the potential of new materials, such as graphene and germanium, to replace silicon in fast microprocessors.

GEM National Consortium

Through partnerships with universities and industries, the National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM) provides support to students from underrepresented groups who are seeking advanced degrees in science and engineering fields. As an employer member of the National GEM Consortium, Lincoln Laboratory offers paid summer internships to students in the GEM Fellowship Program.

In 2017, 18 GEM fellows performed research in groups across the Laboratory. These internships gave students a chance to apply their knowledge to real-world projects and to experience the demands of an R&D lab. The Laboratory, in turn, met young professionals who are good candidates for future employment. All 18 fellows received letters of intent for post-graduation employment.

In September, Director Eric Evans, who is president of the executive committee of GEM, and William Kindred, the manager of the Laboratory's diversity and inclusion initiatives, attended the 2017 GEM Annual Board Meeting and Conference in New York City. At the event, GEM officers and partnering organizations discussed ideas for addressing the conference theme "Maximizing the Value of the Consortium."

The 2017 GEM Fellows at Lincoln Laboratory were welcomed by the MIT mascot Tim the Beaver; Marcus Huggans, the senior director for external relations at the GEM Consortium, second from the right; and Director Eric Evans, far right.

>> *Diversity and Inclusion, cont.*

Forwarding Martin Luther King, Jr.'s Legacy

The Annual Martin Luther King, Jr. Luncheon, hosted by the Lincoln Employees African American Network, celebrates the impact that King has had on increasing diversity and inclusion within the technical domain. This year's keynote speaker, General (Ret) Lester L. Lyles, addressed the theme of Excellence through Diversity and Inclusion.

Veterans' Day Appreciation Luncheon

On 4 November 2016, Lincoln Laboratory held its annual Veterans' Day Appreciation Luncheon. At the event organized by the Veterans' Network (LLVETS), veterans who were active-duty personnel between 1 November 1955 and 15 May 1975 were honored with Department of Defense commemorative lapel pins. The awarding of these pins is part of the national Vietnam War Commemoration program, which was established to thank and honor Vietnam-era veterans and their families for their service and sacrifice.

Holi Celebration

In May, Asian-Pacific American Heritage month, PALs invited the laboratory community to a celebration of Holi, the Hindu welcome to spring, also called the festival of colors. This event featured a collaborative art project to decorate a large rangoli, traditionally a design that is created on a floor or courtyard with colored rice, sand, or flower petals, but created at the Laboratory with paints on a large banner for display in the main lobby.

The Age of Consequences

Four employee groups—the Advanced Concept Committee, Climate (ex)Change, LLVETS, and the Personal Sustainability Interest Group—sponsored the showing of the film *The Age of Consequences*, which depicts the challenges to global security resulting from the impacts of climate change on food and water shortages, international conflicts, and population migration. Sophie Robinson, executive producer from the film's maker, PF Pictures, conducted a question-answer session after the viewing.

Mentorship Programs

Recognizing that strong mentorships enhance an inclusive workplace, Lincoln Laboratory conducts four formal mentoring programs to support employees throughout their careers.

- New Employee Guides
- Career Mentoring
- Circle Mentoring
- Assistant Group Leader Mentoring

In 2017, 303 people participated in mentorship programs.

"International Women's Day is a day to reflect upon how much we have done so far to address women's issues and concerns at the Laboratory, and to become re-energized to tackle the tasks we have ahead of us."

Julie Arloro-Mehta,
coordinator of the panel discussion

Coordinator of the International Women's Day event, Julie Arloro-Mehta, far right, moderated the discussion conducted by panel members, left to right, Jennifer Watson, Stephanie Sposato, Katherine Rink, and Sandra Lechiaro.

International Women's Day

The Lincoln Laboratory Women's Network held a panel discussion on 12 April, International Women's Day. The discussion addressed the theme "Women in Leadership." Sandra Lechiaro, a member of the financial operations team in the Financial Services Department; Katherine Rink, an associate head of the Air, Missile, and Maritime Defense Technology Division; Stephanie Sposato, an assistant leader of the Fabrication Engineering Group; and Jennifer Watson, the leader of the Airborne Radar Systems and Techniques Group spoke about their experiences and challenges as they transitioned from staff positions to management roles in fields that have been predominantly led by men. The program was then opened to comments and questions from audience members.

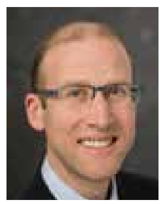
Star Spangled 5K

The Laboratory and the Recent College Graduates group sponsored the Star Spangled 5K run in Lexington, Massachusetts. Proceeds benefited the Troops First Foundation's 24-7 Battle Buddies program, which matches assistive canines to wounded veterans.

Awards and Recognition

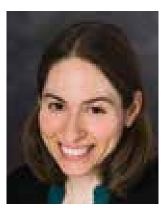
2016 MIT Lincoln Laboratory Technical Excellence Awards

Dr. Douglas A. Reynolds, for outstanding, original, and sustained technical contributions in automatic speaker recognition, and for his internationally recognized leadership in the application of human language technology to challenging information-extraction problems.

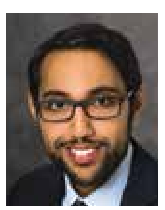


Dr. Daniel J. Ripin, for his strong technical contributions to the development and demonstration of critical laser technology, and for sustained leadership and innovation in building the nation's foremost high-energy laser technology development enterprise.

2016 MIT Lincoln Laboratory Early Career Technical Achievement Awards



Dr. Emily E. Fenn, for her significant technical contributions to the field of air vehicle survivability, and for her expert analysis of infrared systems in support of research programs at national laboratories and studies for the U.S. Air Force Red Team.



Dr. Vijay N. Gadepally, for his outstanding technical leadership, productivity, and creativity in advancing high-performance computing at Lincoln Laboratory and throughout the academic computing community, and for significant efforts in support of the Lincoln Laboratory Supercomputing Center.

2016 MIT Lincoln Laboratory Best Paper Award

Dr. Jakub T. Kedzierski, **Kevin Meng**, **Prof. Todd A. Thorsen**, **Dr. Rafmag Cabrera**, and **Dr. Shaun R. Berry**, for "Microhydraulic Electrowetting Actuators," published in *Journal of Microelectromechanical Systems*, vol. 25, no. 2, April 2016.

2016 MIT Lincoln Laboratory Best Invention Awards

Dr. Sukraj Bramhavar and **Dr. Paul W. Juodawlkis**, for the invention of the Photonic Integrated Resonant Accelerometer.

Dr. Jude A. Kelley, **Dr. Richard P. Kingsborough**, **Alla Ostrinskaya**, and **Dr. Roderick R. Kunz**, for the invention of the Substrate Containing Latent Vaporization Reagents.

2016 Superior Security Rating

Awarded to Lincoln Laboratory's collateral security program from the U.S. Air Force 66th Air Base Wing Information Protection Office. This is the 11th consecutive Superior rating for the Laboratory.

2016 SAF/AQ Team Award for Innovation

The U.S. Air Force Red Team, whose large membership includes staff from both the Air Force and Lincoln Laboratory, was awarded the Assistant Secretary of the Air Force for Acquisition (SAF/AQ) Team Award for Innovation. This team was recognized for its successful execution of several projects that significantly impacted decisions about the acquisition of air, space, and cyber systems.

2017 MIT Excellence Awards

Bringing Out the Best Award: **Dr. Raoul O. Ouedraogo** and **Dr. Alexia Schulz**

Outstanding Contributor Award: **Edison W. Arana**, **Katherine Barlett**, **Benjamin R. Nahill**, **Aida Riley**, and **Jeffrey S. Stewart**

The recipients of 2017 MIT Lincoln Laboratory Administrative and Support Excellence Awards are, left to right, Irene Oliver, Curt Heintz, Erin Jones-Ravgiala, and Robert McLaren.

2017 MIT Lincoln Laboratory Administrative and Support Excellence Awards

Administrative category: **Curt A. Heintz**, for outstanding collaborative project leadership of efforts to develop and deploy important new information technology services; **Irene Oliver**, for exceptional work in processing government funding to ensure that technology development programs move forward efficiently.

Support category: **Erin M. Jones-Ravgiala**, for effective, dedicated support to the members and mission of a growing technical group; **Robert S. McLaren**, for excellent work as a technician supporting the design and fabrication of cutting-edge systems.

2017 American Association for Crystal Growth Award

Dr. Christine A. Wang, "for seminal and innovative contributions to epitaxial crystal growth of III-V compound semiconductors and the design of high-performance OMVPE [organometallic vapor phase epitaxy] reactors."

2017 AFCEA 40 Under 40 Awards

Dr. Francesca D. D'Arcangelo, **Dr. Emily E. Fenn**, and **Dr. Vijay N. Gadepally** were named by the Armed Forces Communications and Electronics Association International (AFCEA International) to its annual list of 40 individuals under the age of 40 who have shown leadership and made innovative contributions to information technology.

2017 Aviation Week Network's 20 Twenties Honoree

Kristen E. Railey was selected by Aviation Week Network as one of its 20 Twenties, an annual recognition of 20 outstanding engineers in their twenties by the network in partnership with the American Institute of Aeronautics and Astronautics.

2017 NDIA Young Professional Award for Combat Survivability

Eva B. Nickelson was presented this National Defense Industrial Association award that recognizes significant contributions to the field of aircraft survivability.

2017 NASA Agency Honor Award

Thirteen people from Lincoln Laboratory were on the Geostationary Operational Environmental Satellite-R Series (GOES-R) team that was honored with a NASA Agency Honor Award in the Group Achievement category: **Dr. Peter Armstrong**, **Dr. William Blackwell**, **Kristin Clouser**, **Dr. Monica Coakley**, **Dr. David Marden**, **Sundie Meroth**, **Dr. Adam Milstein**, **Dr. Frederick Rich**, **Dr. Danette Ryan-Howard**, **Michael Shields**, **Dr. John Solman**, **Dr. John Taylor**, and **M. Robert Wezalis**.

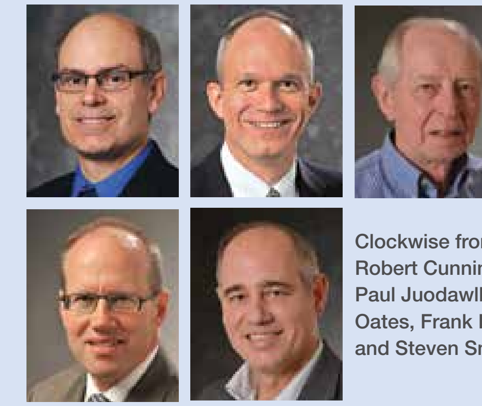
Secretary of Commerce Gold Medal for Excellence

The GOES-R team, whose membership includes representatives from NOAA, NASA, and Lincoln Laboratory, was honored by the Secretary of Commerce for the successful launch of GOES-R in November 2016.

IEEE Photonics Society 2017 Distinguished Service Award

Dr. Paul W. Juodawlkis, for sustained leadership in society governance with significant contributions to membership and conferences.

2017 IEEE Fellows



Clockwise from top, Robert Cunningham, Paul Juodawlkis, Daniel Oates, Frank Robey, and Steven Smith.

Dr. Robert K. Cunningham, for leadership in computer security.

Dr. Paul W. Juodawlkis, for contributions to optically sampled converters and waveguide amplifiers.

Dr. Daniel E. Oates, for contributions to high-temperature superconductors and applications to RF receiver technology.

Dr. Frank C. Robey, for leadership in development of advanced radar systems.

Dr. Steven T. Smith, for contributions to statistical signal processing and applications to radar and sonar.

IEEE Golden Core Member and Outstanding Contribution Recognition

Dr. Robert K. Cunningham, for his service as chair of the IEEE Cybersecurity Initiative and as a cofounder of the IEEE Secure Development Conference.

2017 International Serious Play Gold Medal Winner

Strike Group Defender, a serious game developed by Lincoln Laboratory in collaboration with the Office of Naval Research and Metateq, was awarded the 2017 Serious Play Conference's gold medal for outstanding game in the government and military category.

2018 Associate Fellows of the American Institute of Aeronautics and Astronautics

Dr. J. Scott Stadler and **Dr. Thomas G. Reynolds**, for notable and valuable contributions to the arts, sciences, or technology of aeronautics or astronautics.

>> *Awards and Recognition, cont.*

R&D 100 Awards

The principal researchers of Lincoln Laboratory's ten finalists for R&D 100 Awards are seen here with Lincoln Laboratory Director Eric Evans, far left. The principal researchers for the six winning technologies display their award plaques.

Six technologies developed at Lincoln Laboratory were named 2017 recipients of R&D 100 Awards. Presented annually by *R&D Magazine*, these international awards recognize the 100 most technologically significant innovations introduced during the prior year. A panel of independent evaluators and editors of *R&D Magazine* selects the recipients from hundreds of nominated candidates that represent a broad range of technologies developed in industry, government laboratories, and university research facilities.

CO_2/O_2 Breath and Respiration Analyzer

This wireless, low-cost sensor that determines from a person's breath the fraction of metabolic energy produced by carbohydrate versus fat oxidation can provide information to guide weight loss and training.

LINCOLN LABORATORY TEAM: G. Shaw, project lead; J. Blanchard, L. Candell, M. Hansen, F. Knight, P. LaFauci, J. Mahan, A. Siegel, R. Standley, and K. Thompson; and staff from the U.S. Army Research Institute of Environmental Medicine.

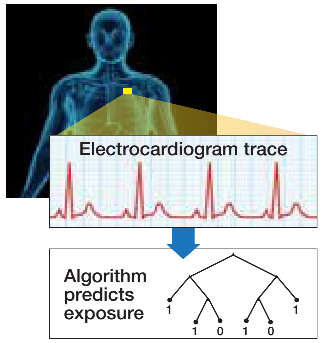
Ground-Based Sense-and-Avoid System for Unmanned Aircraft Systems

This first-in-production ground radar system that enables unmanned aircraft to see and avoid other aircraft meets federal and international standards for airspace safety.

LINCOLN LABORATORY TEAM: R. Cole, project lead; E. Cowen, A. Davis, C. Edwards, J. Eggert, D. Griffith, C. Heisey, D. Johnson, M. Krichman, A. Mezhirov, W. Olson, M. Owen, C. Parry, G. Shoults, N. Underhill, C. Williams, and S. Yenson; and staff from the U.S. Army, SRC Inc., and Kutta Technologies.

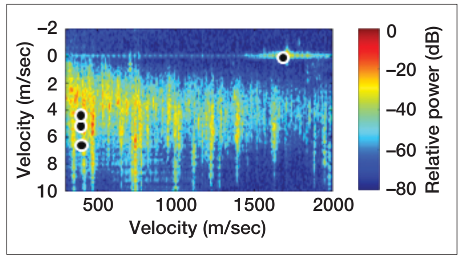
Presymptomatic Agent Exposure Detection

This algorithm exploits data from noninvasive wearable medical sensors to detect if a person had been exposed to viruses or bacteria several days before overt symptoms, such as fever, appear.



LINCOLN LABORATORY TEAM: A. Swiston, project lead; C. Cabrera, G. Ciccarelli, S. Davis, J. Fleishman, M. Hernandez, L. Milechin, T. Patel, A. Reuther, S. Schwartz; and staff from the National Institutes of Health and U.S. Army Medical Research Institute of Infectious Diseases.

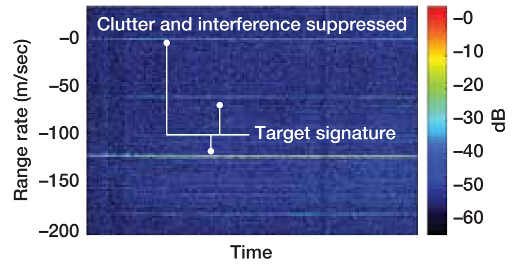
Polarimetric Co-location Layering



This novel algorithm leverages polarimetry in maritime radar to mitigate the high false-alarm rate caused by radar returns from the sea surface.

LINCOLN LABORATORY TEAM: M. Crane, project lead; D. Mailhiot, D. Mooradd, J. Morse, T. Navien, M. Ramirez, K. Rink, and S. Uftring.

Pulse-to-Pulse Phase Diversity Processing for Interference Suppression and Range Disambiguation



This low-cost technique uses phase-diverse waveforms and specialized processing to help mitigate the interference that wind turbines can impose on radars that track aircraft and weather.

LINCOLN LABORATORY TEAM: P. Berestesky, project lead; V. Amendolare, K. Cole, S. Krich, M. Montanari, and I. Weiner.

Wide-Area Infrared System for Persistent Surveillance

This portable system for long-range, day and night surveillance detects and alerts operators to all moving objects in a monitored area.

LINCOLN LABORATORY TEAM: C. Colonero, project lead; G. Balonek, J. Bari, M. Beattie, P. Boettcher, C. Bowen, M. Bury, D. Coe, R. Fontaine, D. Fouche, J. Ingraham, M. Karas, M. Kelly, D. Kettler, D. Klick, C. Perron, L. Retherford, W. Ross, H. Shepherd, and T. Shih.

Students in the one-day LLRISE workshop celebrate the successful testing of their self-built radars.

Educational Outreach

SCIENCE ON SATURDAY

Emily Clemons explains the concept of soundwaves to a group of curious attendees at the Sound of Science demonstration.

The free Science on Saturday demonstrations hosted by Lincoln Laboratory technical staff continued to fill the auditorium. This school year, 1600 children enjoyed the new shows: Welcome to the Jungle, which explained how animals make and hear sounds in a noisy habitat; The Science of Weather, in which participants learned about air pressure, tornadoes, and lightning; and The Sound of Science, which explored the basic science involved in music and sound, such as frequency, pitch, vibration, and wavelengths.

Lincoln Laboratory Community Outreach

CYBERPATRIOT

CyberPatriot is a nationwide Air Force program and competition that teaches high school students defensive computer security. The students learn how to identify malware, "clean" a computer system, and establish a secure network in a simulated corporate network setting. After being mentored by three Laboratory staff members, the 17 students competed in digital forensics and networking challenges.

Students from the three Lincoln Laboratory-sponsored CyberPatriot teams participated in a state competition and ranked second and fourth in the platinum tier (highest difficulty level) and third in the gold tier (second-highest difficulty level).

LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS

Lincoln Laboratory offers high school students a summer workshop that provides an understanding of radar systems and a chance to do hands-on engineering. In this two-week, project-based program, 18 seniors from across the United States build their own small radar systems. The students attend classes on physics, electromagnetics, Doppler radar, pulse compression, signal processing, circuitry, and antennas. In the Laboratory's makerspace, they learn how to design and create parts on a 3D printer. The students also tour Lincoln Laboratory's Flight Test Facility and other labs. When the radars are completed, the students stage experiments and discuss their results at a final presentation. The students are housed at MIT, where they attend sessions on careers and the college application process.

Local LLRISE – One-Day Workshop

Crystal Jackson, far left, assists students in conducting their radar experiments

During school vacation week in April 2017, Lincoln Laboratory held a one-day radar workshop for 18 eighth- to twelfth-graders at the Beaver Works facility in Cambridge, Massachusetts. This program, based on the two-week LLRISE workshop, is an introduction to the design and uses of radar systems. Students in the full program build their own working small radar systems, but limiting the program to one day did not allow time for this labor-intensive activity. Chiamaka Agbasi-Porter, the coordinator of LLRISE, excluded the hardware build portion of the workshop and gave the students a prebuilt radar for their experiments. Students used an oscilloscope to calibrate their radars, viewed the signal in waveform, and created Doppler spectrograms.

LLRISE for Teachers

High school physics teachers Gary Campbell, left, and Scott Brunner, right, joined students in the classroom to learn about building small radar systems.

For the first time since LLRISE began in 2012, high school teachers participated in the program. The Laboratory opened up the program for teachers to let them see how physics and math lessons can be enhanced by a hands-on project. During their one week at the Laboratory, two physics teachers joined the students at lectures on the basics of radar systems, workshops on the assembly of radar systems that perform range-Doppler imaging, and demonstrations of computer-aided design and 3D printing. The teachers were interested in how the workshop's curriculum could be incorporated into their physics classes and were excited about supplementing conceptual lectures with hands-on building activities.

Scott Brunner, who has been teaching for 10 years in Grosse Pointe Woods, Michigan, plans to implement lessons about the construction and use of radar into his electricity and magnetism class. Gary Campbell, who has taught for 20 years in Rochester, Michigan, was impressed by the challenging work the LLRISE instructors expected of students and by the students' ability to handle the work.

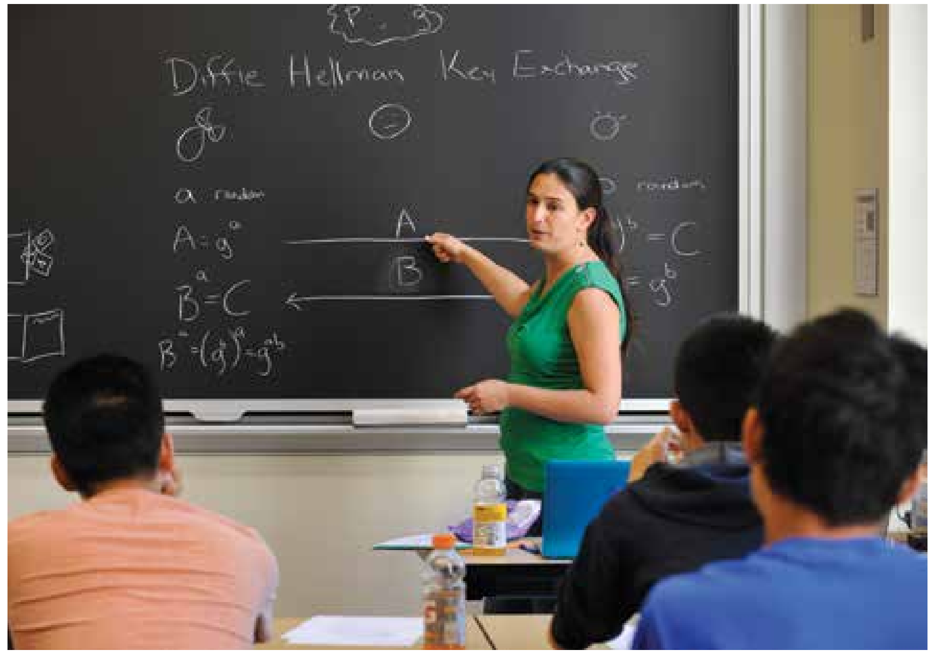
"This year," said Chiamaka Agbasi-Porter, LLRISE coordinator, "there was a different dynamic in the classroom. It was nice to see the teachers building their radar and thinking about how to incorporate the LLRISE curriculum into their schools."

>> *Educational Outreach, cont.*

LLCIPHER

During 14 to 18 August from 10 a.m. to 4 p.m. each day, 16 high school juniors and seniors attended the LLCipher workshop to learn how modern cryptography is used to secure data. The program, held on the MIT campus and developed by Sophia Yakoubov of the Laboratory's Secure Resilient Systems and Technology Group, offered lessons in the abstract algebra and number theory that students used to understand theoretical cryptography. With the help of colleagues Uri Blumenthal and Jeffrey Diewald, Yakoubov created an online tutorial that included challenges in two different cryptosystems to allow students to apply the theory behind cryptography.

"Students could see examples of flawed cryptography and understand how easily it can be broken," Yakoubov said. Guest lecturers from Lincoln Laboratory, David Wilson and Emily Shen, gave the students an overview of some specialized cryptography topics.



Sophia Yakoubov lectures the LLCipher class on public key encryption, a method that uses both public keys that many people can use and private keys that belong to just one person.

Following the program, students indicated that their interest in taking computer science courses in college had grown. "LLCipher helped us understand the cryptography-based concepts that we see in our everyday lives," one student said. "We were doing things that seemed impossible at first—I definitely feel smarter and more empowered now than when we started."

KWAJALEIN SCHOOL OUTREACH

In 2017, Laboratory staff members at the Kwajalein Field Site continued the lecture series they began in 2016 for the seniors at Kwajalein High School in the Marshall Islands. Through nine lectures, a different one each month of the school year, they talked about the projects they have worked on at the Laboratory and emphasized the variety of topics a scientist can explore.

"We hope that these lectures are planting the seeds for the next generation of great scientists and engineers," said Edward Shultz, a co-organizer of the series.

"Kwajalein High School students don't typically go on field trips to museums or technology exhibits," said Alexander Divinsky, the other series organizer. "Sharing our expertise is a way to bring those experiences to the students."

Among the lecturers who reprised their talks were Aaron Enes, who gave a presentation titled "Talking to the Moon with Lasers," named after his experience with the Lunar Laser Communication Demonstration program, and Jessica Holland, who taught students about satellite technology and the role it plays in their everyday lives.

Divinsky discussed the roles of art and design in technology development. "The topic struck a chord," he said. "One student asked, 'So if I work on video games, I don't have to choose between art and science?' That's the kind of realization we were hoping to see."

Through the nine topics covered in the series, the Laboratory staff showed students how their team depends on diverse science and engineering skills.

SPOTLIGHT
Beaver Works Summer Institute

The MIT Beaver Works Summer Institute (BWSI) offers rigorous programs for high school seniors from across the country. In 2016, BWSI held the Rapid Autonomous Complex-Environment Competing Ackermann-steering Robot (RACECAR) course, in which 46 students learned to program a small autonomous vehicle. Students developed algorithms to teach a miniature robot to navigate, map a course, detect objects, and win a race.

This year, BWSI added two new courses, Autonomous Air Vehicle Racing and Autonomous Cognitive Assistant. Also new this year, more than 300 students participated "long distance" by completing online courses and building an autonomous vehicle with help from online videos.

Students worked in teams to program miniature racecars in preparation for the Grand Prix concluding the RACECAR program.

RACECAR Grand Prix

The 2017 summer program for 44 students included in-depth coverage of pose estimation and recovery for localization, visual servoing for local navigation, machine learning with neural networks for object detection and identification, simultaneous localization and mapping, and global planning for navigation in unknown and dynamic environments. The 2017 Grand Prix Challenge expanded to invite teams that adopted the RACECAR platform for a robotics program in their schools.

Autonomous Air Vehicle Racing

In this air vehicle racing workshop, students built and programmed autonomous drones to race through an aerial course. The students engaged in rapid testing on a quadcopter and demonstrated basic vision-based autonomy. Working with advanced sensors and processors, the 27 participants from across the nation demonstrated the cutting edge of airborne autonomy while implementing computer vision techniques.

Autonomous Cognitive Assistant

The Autonomous Cognitive Assistant program helped 27 students learn how to build and apply the foundational technologies of artificial intelligence for building cognitive assistants like Apple's Siri. The class taught students how to work with audio, visual, and linguistic data; what the fundamentals of deep learning are; and how to customize their own cognitive assistants by using Amazon's Alexa.

In 2017, BWSI accepted 98 students from across the country. They were assisted by 54 instructors.

>> Educational Outreach, cont.

CODE CREATIVE

To make computer science more accessible, Lincoln Laboratory's Karishma Chadha organized a new outreach program called Code Creative. The 10-week course held at Beaver Works from February to April taught high school students the core concepts and problem-solving skills behind computer science. "Our goal was to show students that computer science is fun and powerful. We wanted to emphasize code as a tool to feed creativity," Chadha said.

In the weekly two-hour Saturday sessions, staff gave lessons on different fields within computer science to show the range of career possibilities. Benjamin Kaiser shared insight on what cyber security is, why it is important, and what cyber security professionals do. Andrew Fishberg taught students how to build and customize a game by using the GameMaker program. Fishberg said, "We helped influence career paths and, at the very least, promoted code literacy."

Code Creative organizer Karishma Chadha connects with students while teaching coding exercises.

GIRLS SPACE DAY ADVENTURE

On 13 May at the MIT Johnson Ice Rink, the Society of Women Engineers, Lincoln Laboratory, MIT Department of Aeronautics and Astronautics, and the MIT Women's Graduate Association of Aeronautics and Astronautics held the first-ever Girls Space Day Adventure to provide middle school girls the opportunity to do hands-on engineering through interactive demonstrations, such as determining star orientation, mapping asteroids, understanding planetary orbits, and discovering exoplanets. To shed light on possible career choices, Laboratory volunteers led discussions about planetary science, materials science, spectroscopy, light spectra, satellite mechanics, and solar system dynamics.

JOB SHADOWING

As part of 2017 Daughters and Sons Days, the Human Resources Department piloted a job-shadowing program for junior and senior high school students of Lincoln Laboratory employees. The students explored careers by following employees to learn about a typical day in a particular field. The 23 students selected for the job-shadow program also enjoyed two lectures developed specifically for their age group: Intro to Managing Money and Thinking about College and Your Future. Mentor Naomi Hachen said, "I was thrilled to expose a high school student to exciting biology-related activities, and perhaps when she decides what to study in college, she will be influenced by what she saw here at Lincoln Laboratory."

AFCEA INTERNATIONAL INTERNS

Darian Rivera spent his summer modifying firmware in a camera.

The Lexington-Concord chapter of the Armed Forces Communications and Electronics Association (AFCEA) coordinates an internship program that offers summer jobs at local businesses to high school seniors interested in STEM careers. In 2017, three AFCEA interns worked at Lincoln Laboratory. Darian Rivera helped staff member Gregory Rowe in the Active Optical Systems Group modify a camera's firmware. Two interns contributed to projects in the Surveillance Systems Group; Ryan Harm helped to develop an automated avionics test bed, and Pooja Patel assisted staff in building a modeling and simulation environment to support an airborne collision avoidance system. "This year's interns worked independently and asked complex questions," said Luis Alvarez, who mentored Harm and Patel.

Community Giving

ALZHEIMER'S ASSOCIATION

This year marks the ninth year of Lincoln Laboratory's participation in the Greater Boston Walk to End Alzheimer's in May and the fifth year of participation in the Ride to End Alzheimer's in June. With more than 45 members, the Laboratory team ranked second in dollars raised, contributing more than $56,000 for Alzheimer's research. Since 2009, the Lincoln Laboratory Alzheimer's Support Community has donated $267,000 to the Alzheimer's Association.

The 19-member Lincoln Laboratory Ride to End Alzheimer's Team raised more than $15,000 while cycling 62 miles of coastline near Rye, New Hampshire.

MORE THAN WORDS

LEAN volunteers sort through donated books while helping staff the More Than Words book store in Waltham, Massachusetts.

Lincoln Employees African American Network (LEAN) hosted a book drive for the More Than Words organization, which helps at-risk youth develop life skills by running a bookstore. Jamal Grant chaired the volunteer effort to collect books and help staff the bookstore in April.

SUPPORT THE TROOPS

Lincoln Laboratory runs an ongoing campaign of support for deployed U.S. troops. Donations of food, books, games, and toiletries are collected daily, boxed by volunteers, and mailed monthly to military personnel serving in Iraq and Afghanistan. Each year, more than 200 care packages are sent to approximately 37 troops overseas.

AMERICAN HEART ASSOCIATION

Lincoln Laboratory's Heart Walk Team gathered in February for the American Heart Association's National Wear Red Day. Each year, the first Friday of February is a day to call attention to heart disease and stroke. Efforts of the team are spearheaded by Sandra McLellan and Susan Curry. The team raised $5000 for the Boston Heart Walk in September.

Lincoln Laboratory's Heart Walk team stands together on National Wear Red Day to support the fight against heart disease.

GOVERNANCE AND ORGANIZATION

Laboratory Governance and Organization

MIT

Dr. L. Rafael Reif
President

Dr. Martin A. Schmidt
Provost

Dr. Maria T. Zuber
Vice President for Research

DoD Joint Advisory Committee

The committee annually reviews the Laboratory's proposal for programs to be undertaken in the subsequent fiscal year and five-year plan.

Ms. Mary Miller, Chair
Acting Assistant Secretary of Defense for Research and Engineering

Major General William Cooley
Commander, Air Force Research Laboratory

Ms. Darlene Costello
Principal Deputy Assistant Secretary of the Air Force for Acquisition

Ms. Steffanie Easter
Acting Assistant Secretary of the Army for Acquisition, Logistics and Technology

Ms. Betty Sapp
Director, National Reconnaissance Office

Ms. Allison Stiller
Acting Assistant Secretary of the Navy for Research, Development and Acquisition

Vice Admiral James D. Syring
Director, Missile Defense Agency

Dr. Steven H. Walker
Acting Director, Defense Advanced Research Projects Agency

Lincoln Laboratory

Eric D. Evans
Director

Marc D. Bernstein
Associate Director

C. Scott Anderson
Assistant Director – Operations

Office of the Director

Israel Soibelman
Strategic Initiatives

Robert A. Bond
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
Robert D. Solis
Chief Information Officer

Facility Services
Joseph Dolan

Human Resources
Brian S. Donahue

Security Services
Shawn S. Daley
Chief Security Officer

Air, Missile, and Maritime Defense Technology

Justin J. Brooke
Head

Katherine A. Rink
Associate Head

Kevin P. Cohen
Assistant Head

Cyber Security and Information Sciences

Stephen B. Rejto
Head

David R. Martinez
Associate Head

Marc A. Zissman
Associate Head

Engineering

Michael T. Languirand
Head

William R. Davis, Jr.
Assistant Head

William D. Ross
Assistant Head

Advanced Technology

Robert G. Atkins
Head

Craig L. Keast
Associate Head

Mark A. Gouker
Assistant Head

Intelligence, Surveillance, and Reconnaissance and Tactical Systems

Robert T-I. Shin
Head

Richard M. Heinrichs
Assistant Head

Marc N. Viera
Assistant Head

Homeland Protection and Air Traffic Control

Melissa G. Choi
Head

James M. Flavin
Associate Head

Edward C. Wack
Assistant Head

Communication Systems

J. Scott Stadler
Head

Roy S. Bondurant
Associate Head

James Ward
Assistant Head

Space Systems and Technology

Grant H. Stokes
Head

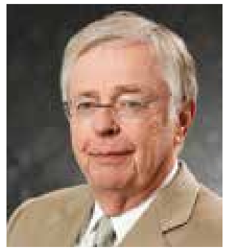
Lawrence M. Candell
Assistant Head

William J. Donnelly III
Assistant Head

Craig E. Perini
Assistant Head

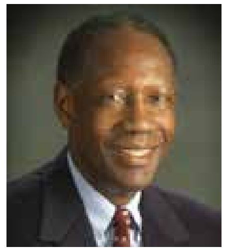
MIT Lincoln Laboratory Advisory Board

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, Northrop Grumman

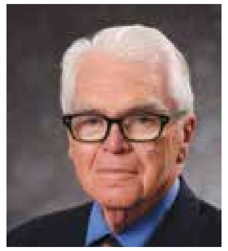
Prof. Daniel E. Hastings
Cecil and Ida Green Education Professor, MIT; CEO and Director, Singapore-MIT Alliance for Research and Technology



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

Mr. Denis A. Bovin
Senior Advisor, Evercore Partners; Life Member, MIT Corporation; Former Member, President's Foreign Intelligence Advisory Board

Deborah Lee James
Board of Directors, Textron and MKA Cyber; Former Secretary of the Air Force



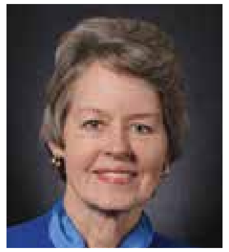
Prof. Hans M. Mark
Professor Emeritus, University of Texas at Austin; Former Secretary of the Air Force

Dr. Mark Epstein
Senior Vice President for Development, Qualcomm Incorporated; Life Member, MIT Corporation

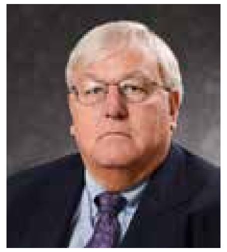
Dr. Miriam E. John
Vice President Emeritus, Sandia National Laboratories

Prof. Jeffrey H. Shapiro
Julius A. Stratton Professor of Electrical Engineering, MIT

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



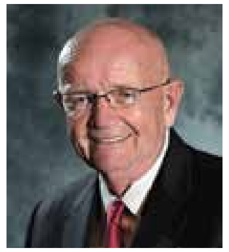
Prof. Anita K. Jones
Professor Emerita, University of Virginia; Former Director of Defense Research and Engineering



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, The Analytic Sciences Corporation

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



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

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

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

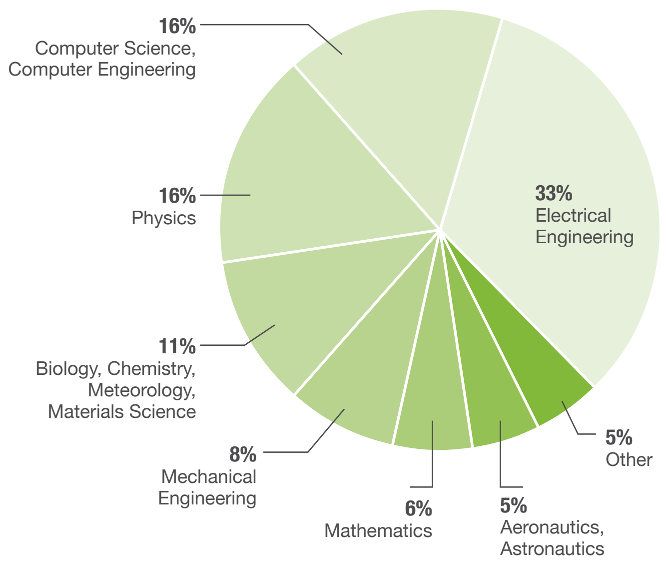
Prof. Ian A. Waitz
Vice Chancellor, MIT; Jerome C. Hunsaker Professor of Aeronautics and Astronautics, MIT

Staff and Laboratory Programs

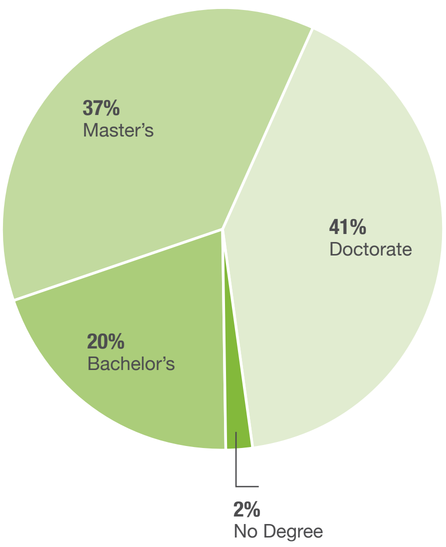
1823	Professional Technical Staff
1168	Support Personnel
544	Technical Support
516	Subcontractors
4051	**Total Employees**

Composition of Professional Technical Staff

Academic Discipline

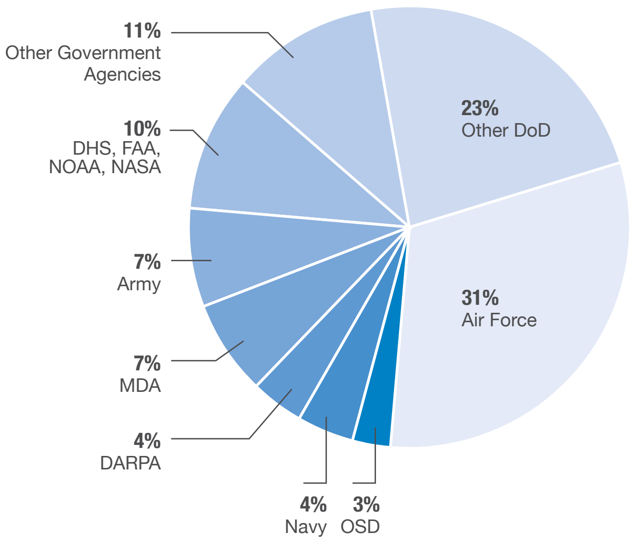


Academic Degree



Breakdown of Laboratory Program Funding

Sponsor



Mission Area