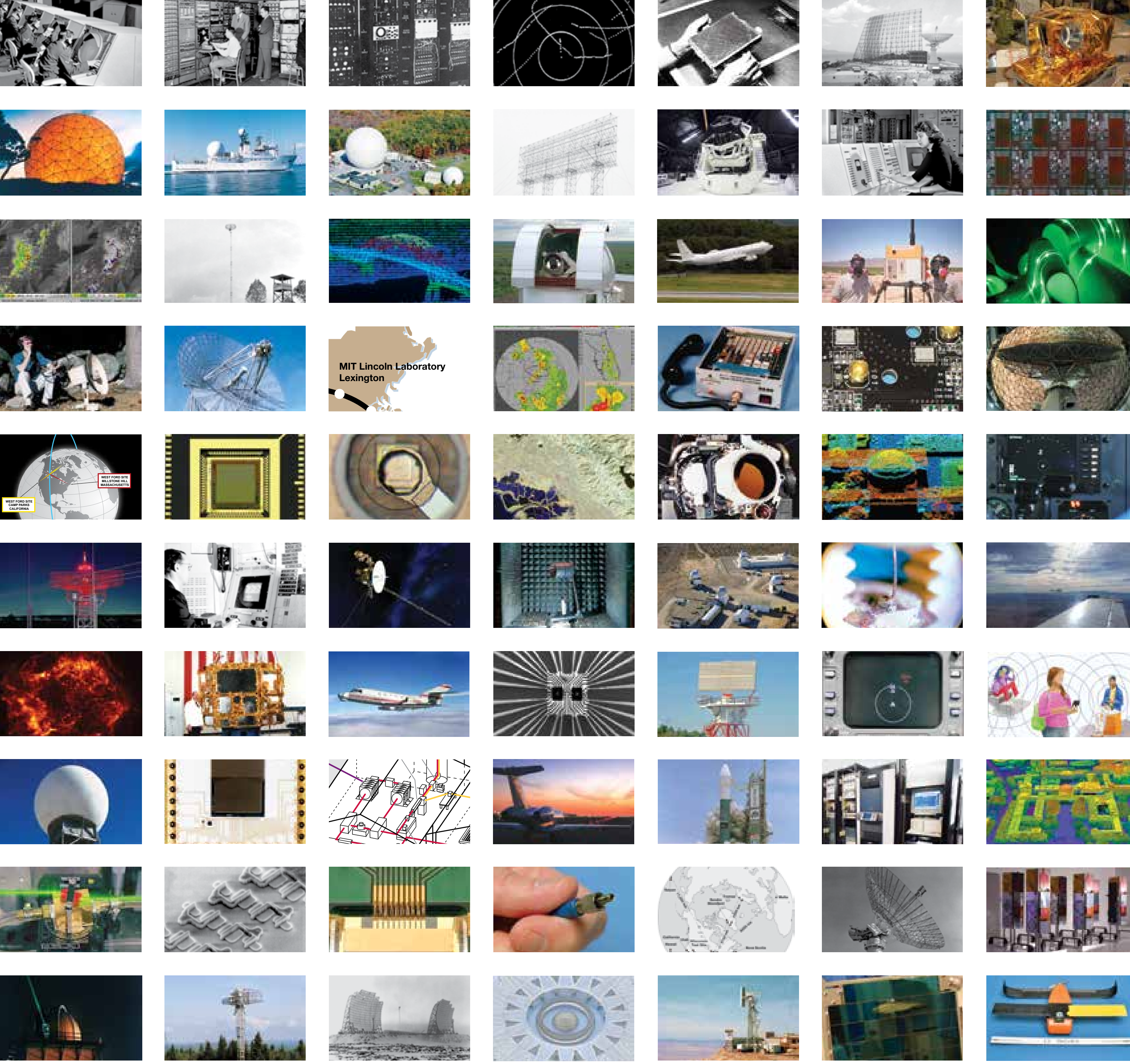
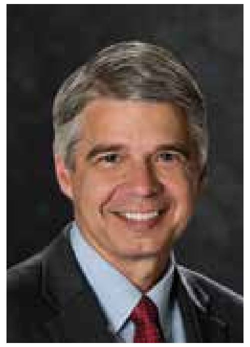


70 INNOVATIONS

OVER SEVENTY YEARS

Highlights of Technology Advancements at MIT Lincoln Laboratory



In 1951, when the first employees joined MIT Lincoln Laboratory, they received employment packages with a promise to pay moving expenses to their next place of work. Lincoln Laboratory was chartered by the Department of Defense to develop a new air defense system for North America, and the work was expected to be completed in five years. Now 70 years later, the Laboratory is still providing technology to support national security. The mission has evolved from solving the original air defense problem to addressing a broad set of national security challenges; yet, the key factors to our sustained service—technical excellence, integrity, and innovative thinking—have remained constant.

A legacy of innovation

The Semi-Automatic Ground Environment, or SAGE, air defense system was the Laboratory's first major system demonstration, enabled by a number of technological innovations. The system's real-time computing capability was revolutionary, and its development was responsible for breakthroughs in radar technology, communication systems, and computer graphics and programming. In 1958, the MITRE Corporation was spun off to serve as the lead organization for the systems engineering of SAGE, and Lincoln Laboratory moved on to other DoD needs, including space surveillance, advanced electronics, satellite communications, and ballistic missile defense.

Throughout its 70-year history, Lincoln Laboratory has developed many new technologies in several mission areas. In the 1960s, the first Lincoln Experimental Satellites (LES) were used to demonstrate new techniques for reliable satellite communication to ground terminals. LES-8 and LES-9, launched in 1976, communicated with air, ground, and submarine terminals, and were among the first to demonstrate the use of radioisotope thermoelectric generators.

Starting in the early 1970s, the Laboratory's work on laser radar systems significantly advanced their imaging performance. The United States' space situational awareness capability has been enhanced by the highly sensitive radars at the Lincoln Space Situational Complex in Westford, Massachusetts, and by the ground-based electro-optical deep-space surveillance systems at the White Sands Missile Range in New Mexico. Laboratory expertise in sensors and algorithm development led to influential work for the Federal Aviation Administration in the areas of air traffic control and safety.

To support its diverse projects, the Laboratory developed a strong foundation in enabling technologies such as advanced electronics, adaptive signal processing, and high-performance computing. The Laboratory has done pioneering work in charge-coupled device imagers, enabling such systems as the National Aeronautics and Space Administration's (NASA) Chandra X-Ray Observatory and the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) at the University of Hawaii's Institute for Astronomy. The open systems architecture implemented in the suite of radar systems at the Reagan Test Site continues to influence architecture design for many sensor systems.

A future of service

The success of the SAGE development motivated the DoD to continue looking to Lincoln Laboratory for technical support. The qualities that allowed the SAGE program to succeed continue to flourish here. The Laboratory looks beyond the "here and now" to anticipate how emerging technology might be used to address our future national security concerns. The future is sure to have new, difficult problems, and our talented staff are ready to develop creative solutions.

In recognition of our 70th anniversary, this booklet highlights 70 of the Laboratory's important innovations throughout its history. To learn more about these and other systems and technologies, we invite you to read through our interactive timeline at https://timeline.ll.mit.edu/timeline.

Eric D. Evans

Eric D. Evans
Director

About Lincoln Laboratory

Lincoln Laboratory is a Federally Funded Research and Development Center (FFRDC) focused on the development and prototyping of new technologies and capabilities to meet national security needs. Principal core competencies are in sensors, information extraction (signal processing and embedded computing), communications, biotechnology, and integrated systems. Program activities extend from fundamental investigations through design and field testing of prototype systems using new technologies.

Lincoln Laboratory continues to meet the government's FFRDC goals of providing independent perspective on critical issues, maintaining long-term competency, and developing technology for both long-term interests and short-term, high-priority needs. The Laboratory also places a strong emphasis on transitioning its innovative systems and technology to the military services, government agencies, industry, and academia. 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.

Program activities are centered in eleven mission areas:

- Space Security
- Air, Missile, and Maritime Defense Technology
- Biotechnology and Human Systems
- Communication Systems
- Cybersecurity and Information Sciences
- Intelligence, Surveillance, and Reconnaissance Systems and Technology
- Tactical Systems
- Advanced Technology
- Homeland Protection
- Air Traffic Control
- Engineering

70 INNOVATIONS

OVER SEVENTY YEARS

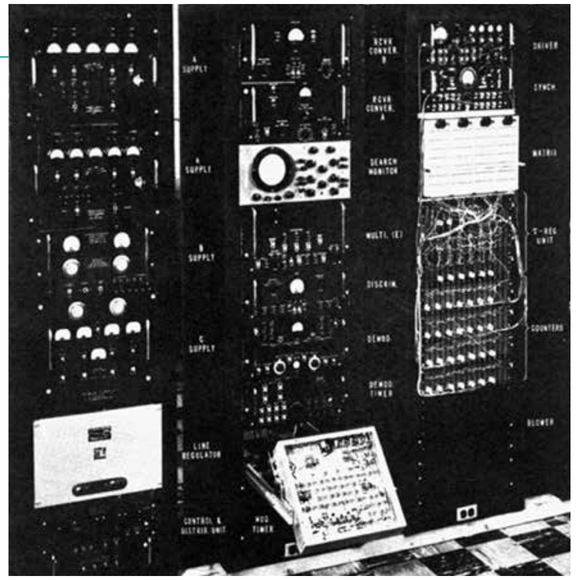
SAGE

1951 Lincoln Laboratory was established in 1951 to prototype the Semi-Automatic Ground Environment (SAGE) system for the strategic air defense of the United States. The SAGE program developed much new technology for real-time surveillance, communications, and command and control. The breakthroughs in computing created for the SAGE system led to the development of the commercial computer architectures used in the 1960s and 1970s. By the time of its full deployment in 1963, SAGE consisted of more than 100 radar sites, 24 direction centers equipped with advanced computers, and 3 combat centers spread throughout the United States. The direction centers were connected to 100s of airfields and surface-to-air missile sites, providing a multilayered engagement capability to address the threat of Soviet bombers.

Whirlwind I + II, AN/FSQ-7 Digital Computers

1951 Whirlwind and its next generation, the AN/FSQ-7, were the first large-scale, high-speed digital computers that operated in real-time and used video displays for output. The Whirlwind Project at MIT's Digital Computer Laboratory had demonstrated real-time computation, a key ingredient for the Project Lincoln air defense concept. By spring 1952, the Whirlwind computer was working well enough to be used as part of the Cape Cod System prototype for the SAGE air defense system. The focus within the Digital Computer Division of Lincoln Laboratory shifted to development of a production computer, called Whirlwind II, to support the full SAGE system. Whirlwind II was renamed the AN/FSQ-7, and it replaced Whirlwind in the Cape Cod System during 1955. Each AN/FSQ-7 weighed 250 tons, had a 3000 kW power supply, and required 49,000 vacuum tubes. To ensure continuous operation, each computer consisted of two machines.

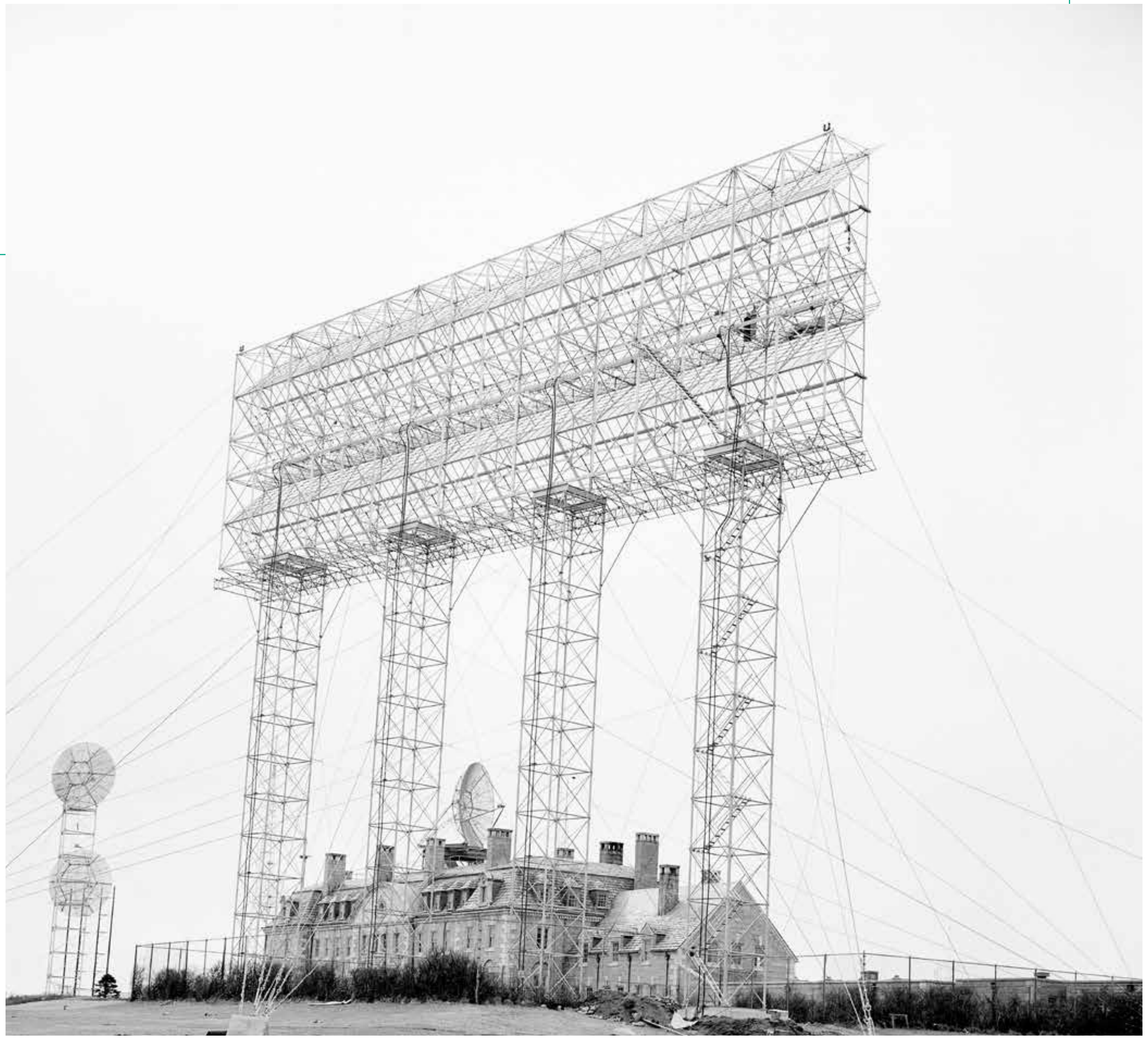
NOMAC Secure High-Frequency Communications



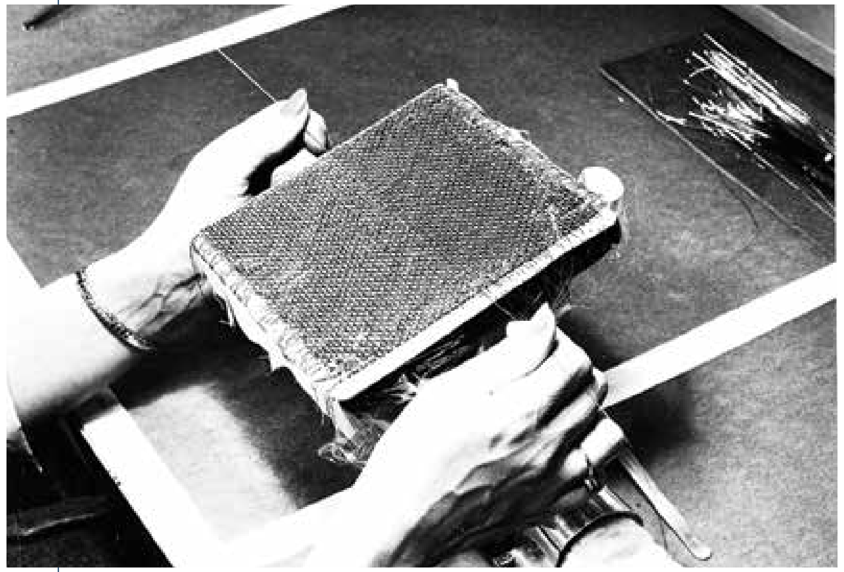
1952 Lincoln Laboratory developed the NOMAC (noise modulation and correlation) system to provide anti-jamming protection for high-frequency military radio communications. NOMAC proved to be vital to maintaining communications in the presence of enemy jamming. In this system, transmitted signals were generated with the aid of noise modulation (adding "noise" to the signal), and received signals were decoded by means of a correlation technique. One method for producing jam-resistant communications is to hide the carrier signal, and NOMAC hid the carrier signal with a pseudonoise pattern that was provided only to the intended decoding receiver.

Ionospheric Scatter Communications Demonstration

1953 Lincoln Laboratory, with Bell Telephone Laboratory, demonstrated the first use of high-frequency (HF) ionospheric scatter communications. The new system provided the first reliable long-range communications over 1000-mile distances and was important to the development of systems that allowed the U.S. military to have unbroken control of overseas forces. Prior to 1953, the only available HF long-range communication systems, ionospheric reflection systems, were unreliable because of day/night and solar disruptions of the reflectivity. The new ionospheric scatter system was first used to relay potential detections of enemy bombers crossing the Distant Early Warning Line of radars deployed along the northern coast of Canada.



Magnetic-Core Memory Array

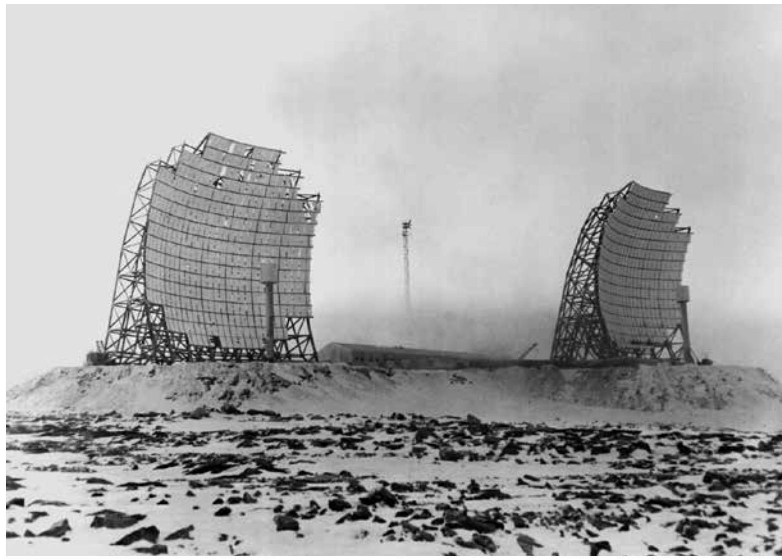


1953 The greatest breakthrough in the development of the Whirlwind computer was the invention of magnetic-core memory, a three-dimensional structure of small toroidal-shaped ferromagnetic cores that stored data. The magnetic-core memory addressed the limitations of storage-tube memories that had been used up to the early 1950s; storage tubes were large, slow, and worst of all, unreliable. Because it resolved those limitations, the magnetic-core memory enabled the widespread adoption of computers for industrial applications. Magnetic-core memories were used in almost all computers until 1974, when they were superseded by semiconductor integrated-circuit memories.

Ballistic Missile Early Warning System Architecture

1955 Lincoln Laboratory's work on a reliable radar system to warn of attacks by intercontinental ballistic missiles resulted in the Ballistic Missile Early Warning System (BMEWS). The BMEWS project was the foundation for the Laboratory's later ballistic missile defense work. BMEWS consisted of detection radars scanning several pencil beams in azimuth at fixed elevations and an associated pencil-beam tracking radar. The Laboratory designed, developed, and vigorously tested components for BMEWS, including the entire organ-pipe feed system required for the system's scanning-beam surveillance radar, the AN/FPS-50. BMEWS ultimately consisted of three radar sites in Alaska, Greenland, and Yorkshire, England. BMEWS continues in operation today, with the original surveillance and tracking radars replaced by phased-array radar systems.

Tropospheric Scatter Communications



1956

On the basis of the success of the Laboratory's program in ultra-high-frequency (UHF) tropospheric scatter communications, numerous military and civilian UHF systems were installed, some of which continue to be used around the world today. Tropospheric scatter communications, which utilize inhomogeneities in the troposphere to scatter radio signals back to Earth, offer reliability, wide bandwidth, and many communications channels. One of the most important advances of this effort was a diverse signal combination technique that enabled long-range systems to overcome the effect of signal fading. Lincoln Laboratory's final project in tropospheric scatter communications was to design a system with the longest possible range. This system, the AN/FRC-47, became a vital part of the Air Force's Arctic operations.

Millstone Hill Radar

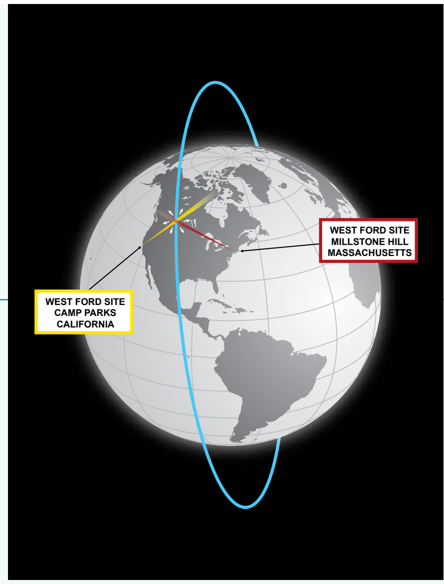
1957

Lincoln Laboratory pioneered the use of high-power radars for space surveillance. In 1957, the Laboratory's Millstone Hill radar successfully detected the first Soviet Sputnik satellite, and in 1958, it was the first radar to track a satellite, the Sputnik II, from horizon to horizon. This tracking capability was provided by the unique conical-scan automatic angle-tracking system developed by the Laboratory. Today, the high-power L-band Millstone Hill radar tracks space vehicles and space debris, and plays a key role in the national deep-space surveillance program. It is also a broad-based observatory capable of addressing a wide range of atmospheric science investigations. As a contributing sensor to the Space Surveillance Network, the Millstone Hill Radar provides ~18,000 deep-space satellite tracks per year and coverage for almost all deep-space launches.

All-Solid-State Computers: TX-0, CG-24, TX-2

1955–1958

Lincoln Laboratory's pioneering research into solid-state computers led to the development of increasingly more powerful and sophisticated methods of machine organization, programming, and man-machine communication. The early TX-0 computer was designed, constructed, and operated to evaluate the use of transistor circuitry and large-scale magnetic-core memory in a high-speed computer. The memory drive currents were provided by a combination of vacuum tubes and transistors that showed an advance toward solid-state architecture, making it among the first "almost-all-solid-state" machines. The CG-24 computer was the first all-transistor machine. Perhaps the greatest innovation in the design of the CG-24 was the development of a register-transfer language, which enabled the designers to simulate the logic design of CG-24 before the machine was built. The TX-2, an experimental digital computer, was in operation from 1958 to 1975. It was one of a few first-generation large digital computers in which transistors largely supplanted vacuum tubes.



Project West Ford Dipole Belt Scatter Communications

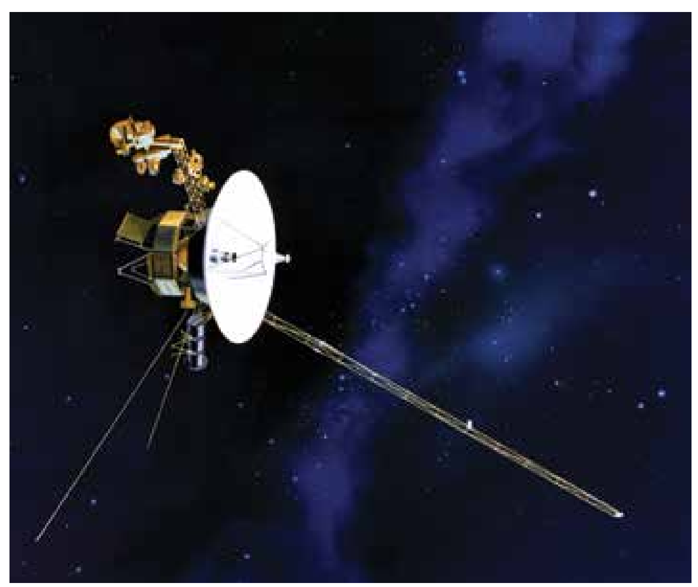
1958

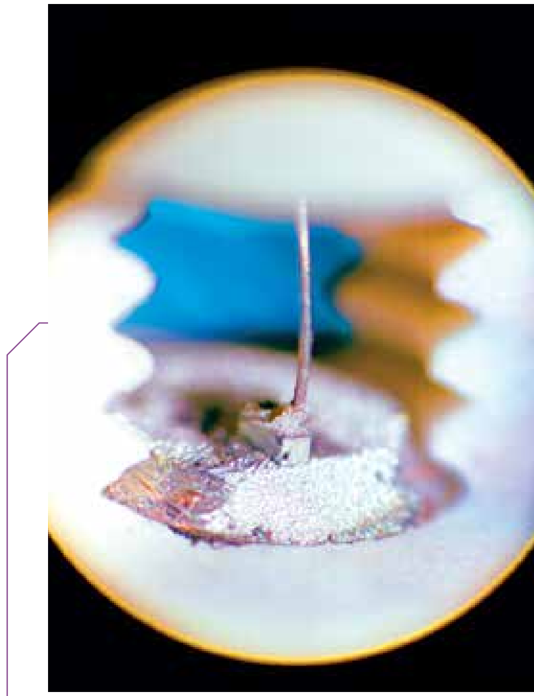
Project West Ford was a revolutionary answer to the problem of high-frequency radio communications failures caused by thermonuclear detonations or natural phenomena such as solar storms. The concept was to demonstrate long-range, reliable communications by scattering radio energy from a belt of orbiting dipoles. The dipole belt was intended to be a surrogate for the ionosphere. The challenges were the needs for high-gain antennas, high-power transmitters, and a sufficiently large number of dipoles to act as the surrogate ionosphere. In 1963, the concept was successfully demonstrated with communication between Millstone Hill in Westford, Massachusetts, and Camp Parks, California.

1960

Reed-Solomon Error-Correcting Codes

The Reed-Solomon error-correcting codes solved a crucial problem in the development of high-density digitally recorded data. In 1960, technical staff members Irving Reed and Gustave Solomon published a paper introducing the idea of coding groups of bits, rather than individual zeros and ones. This feature made the Reed-Solomon code particularly good at dealing with bursts of errors in digital data. Just as the eye can recognize and correct for a few bad points in what is otherwise a smooth curve, the Reed-Solomon code can spot incorrect values and recover the correct message. This short, highly mathematical paper provided basic ideas that developed into powerful, widely used error-correction schemes. These codes have enabled the development of compact disks, digital audio tape, high-definition televisions, and the Voyager and Galileo spacecraft. Reed and Solomon received the 1995 IEEE Masaru Ibuka Consumer Electronics Award for this work.





GaAs Semiconductor Laser Demonstration

1962

Lincoln Laboratory research pioneered the use of gallium arsenide (GaAs) for lasers. In August 1962, Laboratory scientists presented a paper on the luminescence efficiency for GaAs-diffused diodes at the Solid State Device Research Conference. The focus of semiconductor lasers at that time was on silicon technology. However, during research into GaAs for use in high-speed electronic devices, the Laboratory discovered that GaAs diodes were efficient light emitters. By October, groups from Lincoln Laboratory and three other organizations, independently applying the ideas from the Laboratory's conference paper, had produced GaAs diode lasers. In following years, various other semiconductor materials were employed to cover different parts of the wavelength spectrum, enabling the use of lasers in more numerous applications.

Sketchpad Computer-Aided Design

1963

The Sketchpad system was the first graphical computer interface. It made it possible for a man and a computer to interact rapidly through the medium of line drawings. Previously, most interaction between man and computers had been slowed down by the need to reduce all communication to typed statements. For many kinds of communication, such as describing the shape of a mechanical part or the connections of an electrical circuit, typed statements are cumbersome. The Sketchpad system, by eliminating typed statements in favor of line drawings, opened up a new area of man-machine communication.

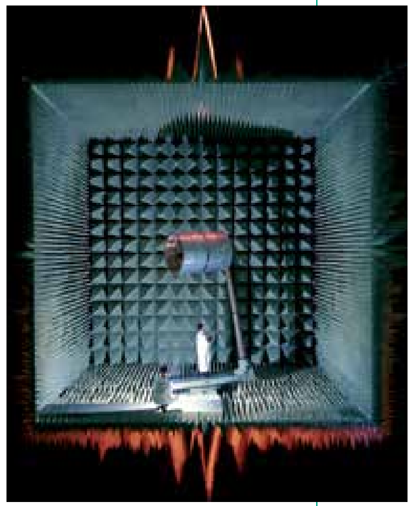
1964

Haystack Radar

The Haystack X-band radar, which became operational in 1964, was a giant step forward in high-performance space-sensing instrumentation. The radar features a fully steerable parabolic antenna 37 meters in diameter, one of the largest X-band apertures in the world. The antenna is enclosed in the world's largest space-frame radome. For the first 10 years, the primary role of Haystack was as a planetary astronomy radar. It was used to examine topographical characteristics of the lunar surface in support of landing sites for the Apollo mission, and to make similar observations for the Viking mission on Mars. In the late 1970s, Haystack was upgraded to have a wideband signal capability, and since that time has been the nation's leading source of high-resolution radar images of satellites. Today, Haystack continues as both a radar/radio astronomy instrument and a defense-oriented space sensor.

Lincoln Experimental Satellites

1965 The field of satellite communications was advanced significantly by Lincoln Laboratory's development of the Lincoln Experimental Satellites (LES). Designed to test techniques for future communications satellites, the LES series demonstrated innovative technology and accomplished a number of "firsts." In 1965, LES-1, -2, and -4, along with the Lincoln Experimental Terminals, demonstrated super-high-frequency capabilities for reliable communication between large fixed and mobile ground terminals. LES-5, launched in 1967, was the first satellite to demonstrate communications in the military ultra-high-frequency (UHF) band to terminals in ships and aircraft in the field. The next year, LES-6 placed substantially more UHF communications resources in geostationary orbit. LES-6 successfully completed its test program and continued to provide operational communications support until being placed on reserve status in 1976.



The experimental LES-8 and -9 satellites, launched in 1976, demonstrated the use of radioisotope thermoelectric generators, instead of solar cells or batteries, for power. They operated in geosynchronous orbits and communicated with each other via intersatellite links at extremely high frequency and with surface (or near-surface) terminals at both extremely high and ultra-high frequencies. LES-8 was retired in 2004, and LES-9 was decommissioned in 2020 after 44 years of successful service.

Extremely Low-Frequency Submarine Communications

1966 The Laboratory's breakthrough in submarine communications was the reduction of transmitted power (thus transmitter size) through nonlinear noise processing and efficient signal coding. This reduction decreased both cost and environmental impact of the system, making it a feasible option for undersea communications. At the request of the U.S. Navy, the Laboratory developed an extremely low-frequency (ELF) communications system that could communicate from a U.S.-based transmitter to submerged submarines worldwide. The Laboratory conducted and analyzed signal and noise propagation measurements and carried out system engineering for the system.

Camp Sentinel Radar

1968 In the 1960s, Lincoln Laboratory applied its expertise in radar technology to support U.S. troops in Vietnam. The Camp Sentinel Radar was a ground-based system for situational awareness at the "fire bases" that U.S. troops were carving out of the jungle. The radar's role was to detect persons moving in foliage-covered areas. The challenge was to detect these slow movers in the foliage background clutter. An initial system took radar measurements locally with a large semicircular antenna at the Laboratory, mounted on Katahdin Hill. A second model mounted on a van was demonstrated in Puerto Rico, where the foliage resembled that of Vietnam. An advanced model was developed with an antenna mounted on a high tower, so that the electromagnetic waves could reach targets by propagating and diffracting over treetops, rather than by propagating through foliage. The Camp Sentinel Radar was transitioned to Vietnam in August 1968 and used until the end of the war.

ALTAIR

1969 The Advanced Research Projects Agency (ARPA) Long-Range Tracking and Instrumentation Radar (ALTAIR) is the most sensitive of the radars constructed at the Kiernan Reentry Measurements Site (KREMS) on the Kwajalein Atoll. Today, ALTAIR provides coverage of the deep-space geosynchronous belt, tracking ~1000 deep-space orbiting satellites every week. Beginning operations in 1969 at both ultra-high and very high frequencies, ALTAIR could view a ballistic missile shortly after it broke the horizon, at a distance of 4500 km. A 1977 upgrade enabled ALTAIR to detect and track foreign space launches. Later modifications allowed ALTAIR to track deep-space satellites.

Mode S Beacon System

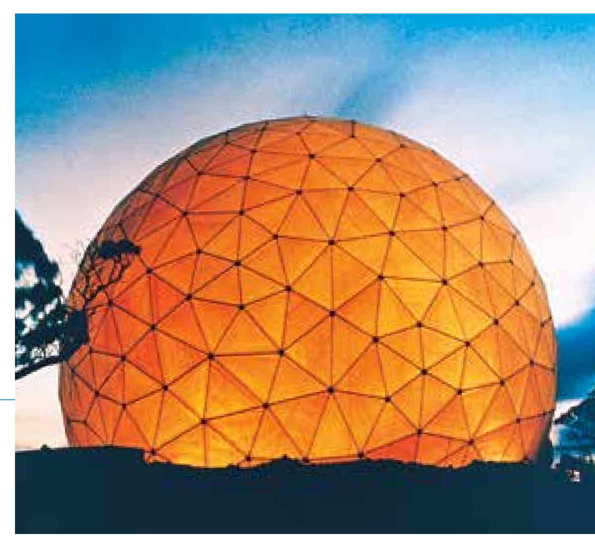
1970 In use worldwide today, the Mode Select (Mode S) system greatly augmented the air traffic control (ATC) radar beacon system that provided radar surveillance and aircraft separation data. Under a program begun in 1970, Lincoln Laboratory helped the U.S. Department of Transportation improve the civil ATC system by enhancing the radar surveillance of aircraft and adding a data link for two-way communications between ATC facilities and aircraft. The resulting system, first called the Discrete Address Beacon System, took advantage of the Laboratory's expertise in radar, signal processing, digital communications, and data processing.

1970

ALCOR

The Advanced Research Projects Agency (ARPA)-Lincoln C-band Observables Radar (ALCOR) was the first long-range radar to generate, amplify, radiate, and process a very wideband signal. The use of a very wideband signal that has high enough range resolution to "dissect" typical missile targets into discrete range bins allows a refined estimate of the object's shape and potential lethality. Military radars need this high resolution because it helps mitigate clutter and jamming, improves tracking accuracy, and enhances the identification of enemy targets. This identification is particularly important in ballistic missile defense radars because a typical missile threat may contain many objects, most of which are incidental missile hardware or nonlethal decoys.

ALCOR was also the first radar to image a reentry vehicle and to achieve wideband, two-dimensional range-Doppler images of satellites. In 1970, ALCOR became an operational sensor at Roi-Namur Island in the Kwajalein Atoll. Many U.S. missile defense radars feature wideband signals, and radar imagery of satellites has become an important national capability.

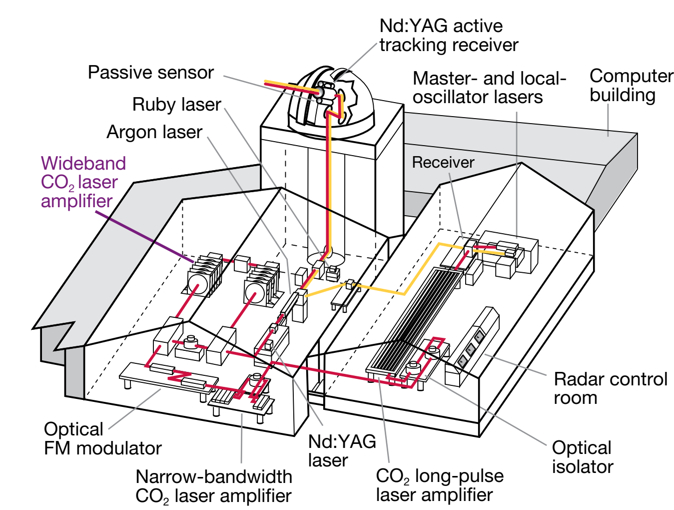


Adaptive Optics Program

1971 Adaptive optics is a technique for real-time measurement and compensation for the effects of optical aberrations such as atmospheric turbulence. Since the early 1970s, Lincoln Laboratory has been a leader in the development and demonstration of adaptive optics technology. The Laboratory demonstrated the first atmospheric compensation of a ground-to-space laser beam, the first closed-loop compensation using a laser guide star, and the first compensation for a high-energy laser beam. Following these seminal accomplishments, the astronomical community embraced adaptive optics as a mainstream technique for improving the optical imaging capability of large telescopes, making them competitive with space telescopes but at a much lower cost. No astronomical enterprise could go forward today without the benefit of adaptive optics.

High-Power CO_2 Laser Radar

1972 Lincoln Laboratory's work on high-power CO_2 laser radar began in 1972 and culminated with the successful collection of the first range-Doppler images of an orbiting satellite on March 4, 1990. These images, collected at ranges of 800 to 1000 km, realized a plan originally developed in the Laboratory's study of the feasibility of a wideband, very-high-power, range-Doppler laser radar for space-object surveillance and identification. The development of high-power imaging laser radar was a complex engineering effort. Work on the CO_2 laser radar continued through the 1970s and early 1980s with the testing of the narrowband, 11 kW Laser Radar Power Amplifier, and through the late 1980s and early 1990s with the construction and testing of the wideband Coherent Optical Radar Amplifier incorporated in the system illustrated here.

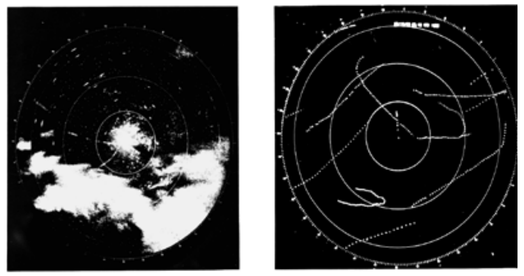


Moving Target Detection Radar

1972

The Moving Target Detector (MTD) radar achieved a new performance level for the detection of aircraft in the presence of radar clutter and became the world-recognized standard for Airport Surveillance Radar. It employed an antenna with two fan-beams to provide coverage from the immediate vicinity of an airport to a distance of 60 nmi. Its new digital signal and data processing techniques achieved improved clutter rejection performance, and its radar displays were nearly as clean as displays provided by beacon surveillance. MTD radar also included a digital weather channel to provide timely reports of storm reflectivity. Data processing included algorithms that adapt to maintain performance in the presence of rapidly maneuvering aircraft and to reject moving automotive traffic.

MTD performance in rain



Five-mile range rings

Ground-Based Electro-Optical Deep-Space Surveillance

1975

Lincoln Laboratory proposed using electro-optical technology for the search and detection of small, distant satellites. Electro-optic low-light-level television (LLTV) cameras at the focal planes of telescopes offered clear advantages over other cameras. The advantages include real-time output (since no film needed developing), high sensitivity, large field of view, and a high frame rate. The Laboratory developed a portable electro-optical camera that was demonstrated at the focal plane of the 31-inch-diameter telescope at the Lowell Observatory in Arizona. The resulting videotaped images of satellites in the geosynchronous belt and beyond were outstanding. The success of the camera led the Air Force to select the Laboratory as the lead for the development and technological support of a facility for electro-optical systems for space surveillance, the Experimental Test Site (ETS) near Socorro, New Mexico. The ETS's first ground-based electro-optical deep-space surveillance (GEODSS) system became operational in 1975. Shortly thereafter, a second tracking telescope was added to the site, and the Aerospace Defense Command used the dual telescopes at ETS for deep-space surveillance for five years. The Laboratory has continued its involvement in GEODSS systems, supporting the Air Force's development of new GEODSS systems in 1978 on the White Sands Missile Range at Socorro, and from 1991 to 2005 developing advanced charge-coupled imagers that were integrated into the telescopes to provide enhanced sensitivity and accuracy.

Air Vehicle Survivability Evaluation Program

1978

The development of the modern cruise missile, embodied in the Navy Tomahawk missile in the late 1970s, caused a substantial stir in the air defense community concerning the survivability of these missiles against air defenses. The debate was fueled by a dearth of scientific knowledge and experimentation about defense engagement of low-flying, low-observable air vehicles. The Cruise Missile Detection Technology Program was initiated at Lincoln Laboratory in 1978 to quantify cruise missile survivability and examine air defense against cruise missiles. Renamed the Air Vehicle Survivability Evaluation program in 1983, this still-active program has covered an enormous range of issues associated with low-observable vehicles, including phenomenology, air defense system analysis and modeling, field instrumentation and experimentation, and advanced air defense technology.

Radar Clutter Measurements

1981

Lincoln Laboratory's program to characterize low-grazing-angle ground clutter provided seminal data for researchers working on radar detection of aircraft. The program addressed a basic fact: the ability to detect and track low-altitude, low-observable aircraft is determined mainly by a radar's ability to find a target within background clutter reflected from the Earth's surface. The program also addressed an existing serious problem: most clutter models at the time were unreliable. In 1981, the Phase Zero Clutter Measurement System began characterizing a variety of sites for their clutter effects. At the same time, the more capable Phase One system, a transportable five-frequency dual-polarization instrument, was the principal source of data that allowed the Laboratory to uncover the basis for wide variations seen in the strengths of ground clutter.

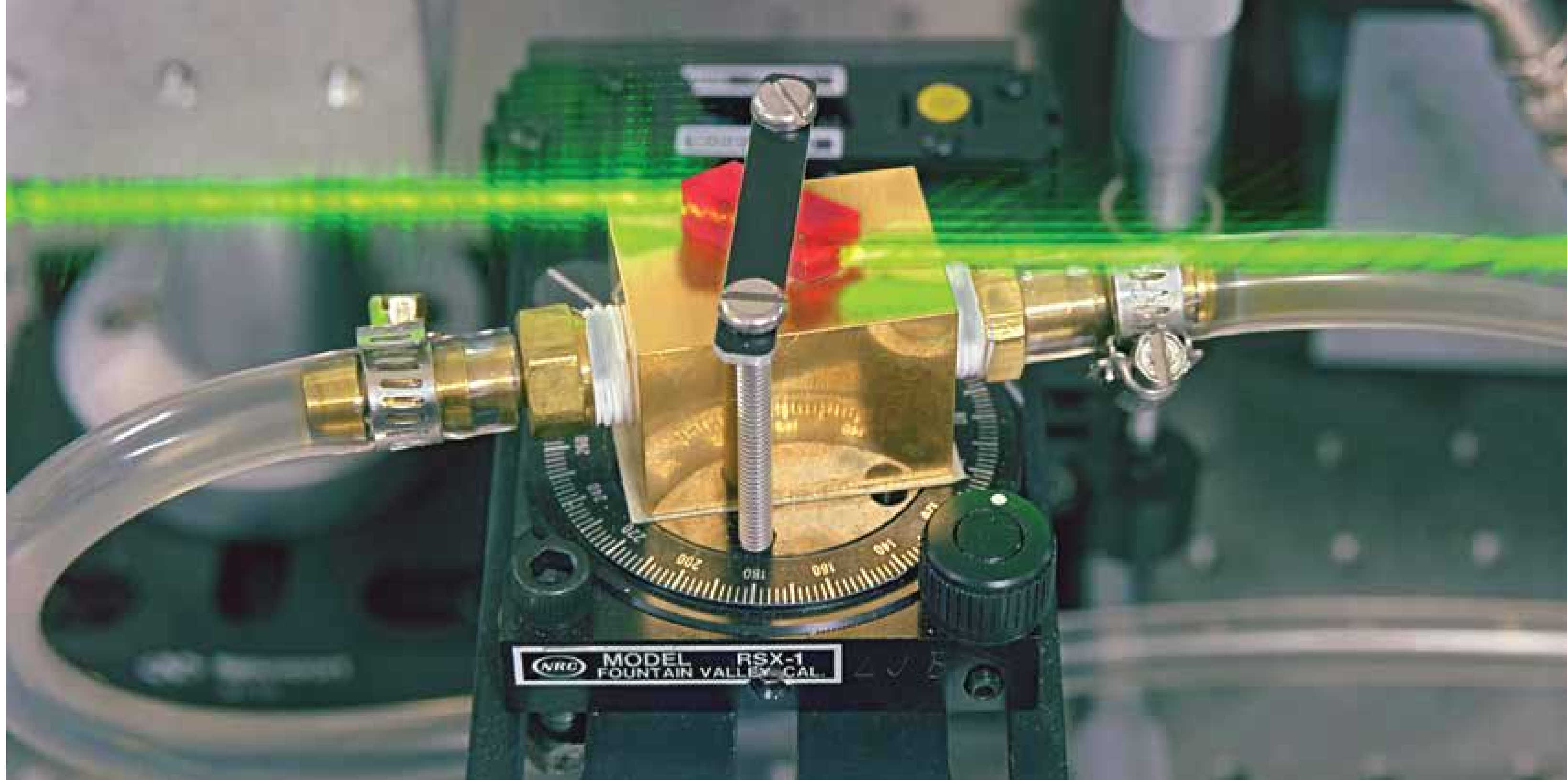
Digital Speech Coding and Packet Speech

1982 Lincoln Laboratory developments in digital speech coding and packet speech were enabling technologies for secure voice systems and voice-over-Internet-protocol (VoIP) communications. Secure voice systems are now ubiquitous for government applications, and VoIP is now used worldwide for all types of phone calls and videoconferencing. In 1974, the Laboratory developed the Lincoln Digital Voice Terminal (LDVT), a programmable signal processor that provided the computational basis for implementing narrowband (typically 2.4–4.8 kbps) vocoder algorithms in real time. The LDVT was used in 1974 to demonstrate the first real-time narrowband speech communication over a packet-switched network (the ARPAnet, the progenitor of today's Internet). In 1982, the Laboratory used new-generation digital signal chips to develop a compact vocoder that enabled wide deployment of secure voice terminals for government applications.

Additionally, in 1982, Internet packet speech and conferencing were demonstrated, linking voice terminals on local-area cable networks at Lincoln Laboratory, a mobile packet radio net at SRI International in California, and a telephone interface at the University of Southern California Information Sciences Institute, all connected via a wideband packet satellite network. In 2011, an IEEE Milestone in Electrical Engineering and Computing was awarded and dedicated at Lincoln Laboratory for the "First Real-Time Speech Communication on Packet Networks, 1974–1982."

1982 Ti:Sapphire Laser

In 1982, researchers at Lincoln Laboratory demonstrated a tunable laser based on Ti:Al_2O_3 (titanium-doped aluminum oxide) for the first time. This laser amplifies over the wavelength range of 0.65 to 1.12 µm—the widest bandwidth available at that time and for many following years. The Ti:sapphire laser has two important properties: (1) it is tunable to a wide range of wavelengths, and (2) it has a wide gain bandwidth, which permits the generation of extremely short pulses. These properties made the Ti:sapphire laser a valuable tool for researchers in many fields. The Ti:sapphire laser spawned an entire field of research, involving ultra-short-pulse (femtosecond) lasers. Ti:sapphire lasers are now widely available commercially and are used in biology, chemistry, and physics research throughout the world.



1983 Infrared Airborne Radar

The successful deployment of the Infrared Airborne Radar (IRAR) represents the first in-flight demonstration of a 3D imager capable of simultaneously generating range-resolved pictures and Doppler maps. The IRAR was conceived in the late 1970s as a compact imaging infrared radar that could be mounted in a pod on a tactical aircraft. The system was developed to provide real-time 3D battlefield imagery for target detection, tracking, and identification in highly cluttered environments. Proof-of-principle experiments were conducted using a single heterodyne detector, but for the higher frame rates and spatial resolution required in an operational system, the Laboratory developed a novel holographic optical element to support simultaneous operation of 12 heterodyne detection channels. This binary optical component represented a major breakthrough. A compact IRAR prototype and a passive infrared imager were mounted on the bottom of a Gulfstream G-1 aircraft in 1984, and data were collected on a variety of terrain features, man-made structures, and tactical targets.

Single-Channel Anti-Jam Man-Portable Terminal

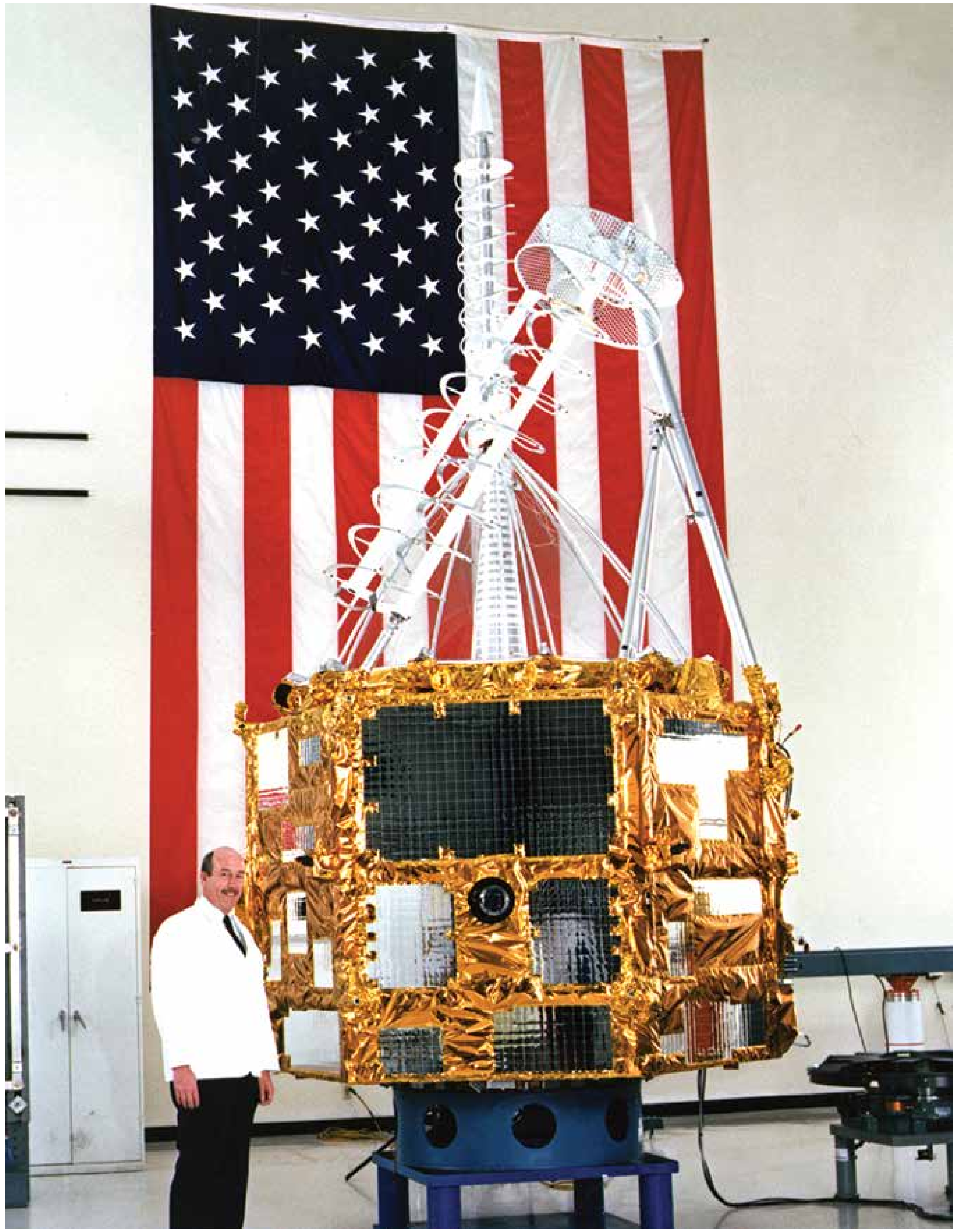
1983

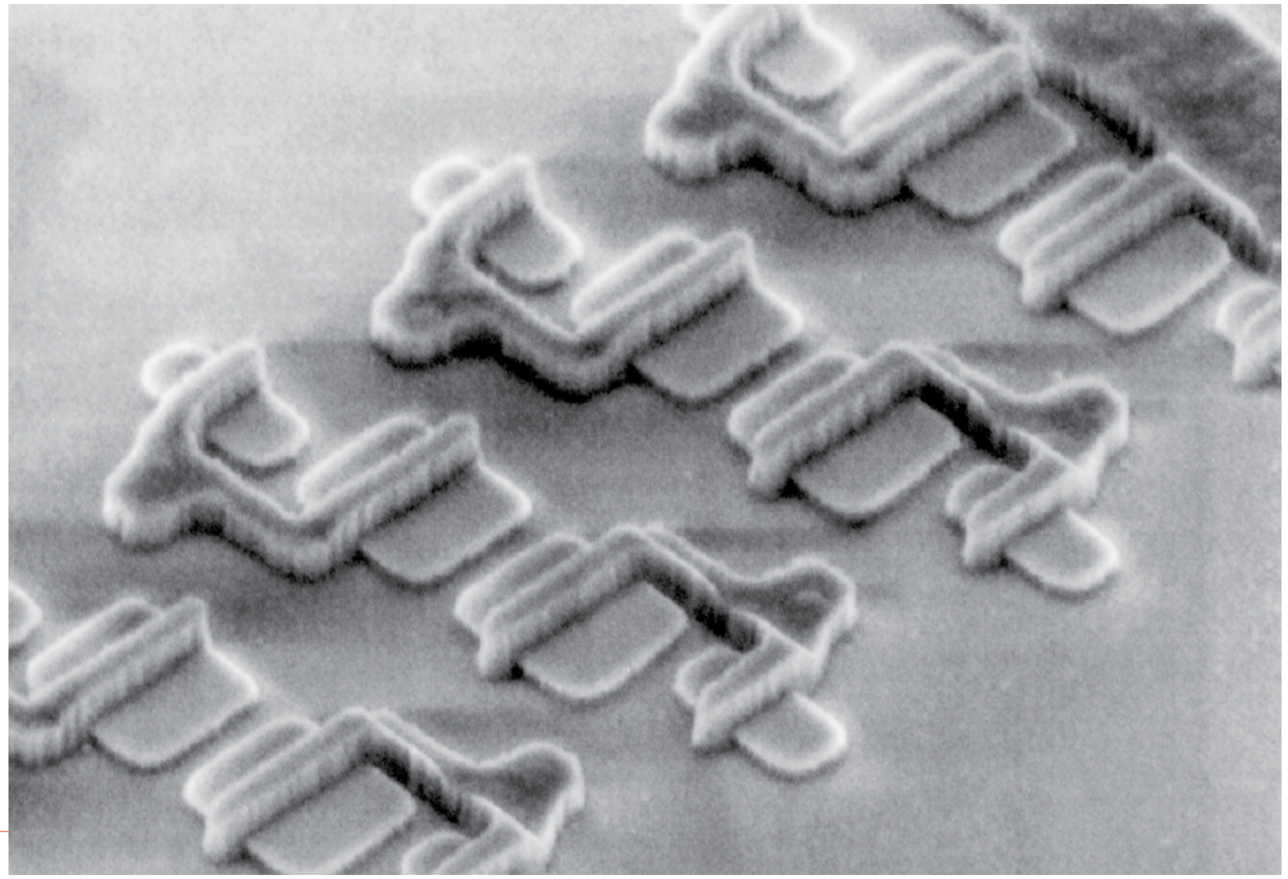
Lincoln Laboratory's Single-Channel Anti-Jam Man-Portable (SCAMP) extremely high-frequency terminal was the first protected satellite communications terminal that could be carried by a soldier and operated on battery power. All other such terminals of that era weighed nearly a thousand pounds, required much more power than practical for batteries (at least a kilowatt), and had to be vehicle mounted. SCAMP achieved successful operation with the Air Force's extremely high-frequency Milstar satellite communication system and was the early prototype for a production run of ~800 fielded terminals.

1986

Extremely High-Frequency Packages for Communication Satellites

Lincoln Laboratory's Extremely High-Frequency (EHF) Packages were the first to provide simultaneous, jam-resistant, EHF communications to multiple small mobile terminals. The packages were carried on board the U.S. Navy's ultra-high-frequency (UHF) communications satellites (FLTSATs), designed to provide worldwide, high-priority communications between naval aircraft, ships, submarines, and ground stations and between the Strategic Air Command and the national command authority network. The Laboratory's first package was integrated with the FLTSAT-7 satellite and launched from Cape Canaveral on December 4, 1986. The second was launched on FLTSAT-8 in September 1989. The EHF packages featured an access/resource controller that provided a "switchboard in the sky" function to widely dispersed users (e.g., ships, aircraft, soldiers, civilians) of the communications satellites. These payloads reduced risk for the development of the anti-jam, low-probability-of-detection, low-probability-of-interception waveforms and processing for the Milstar satellite system, and provided service to Milstar ground terminals.





Advances in Lithography (193 nm)

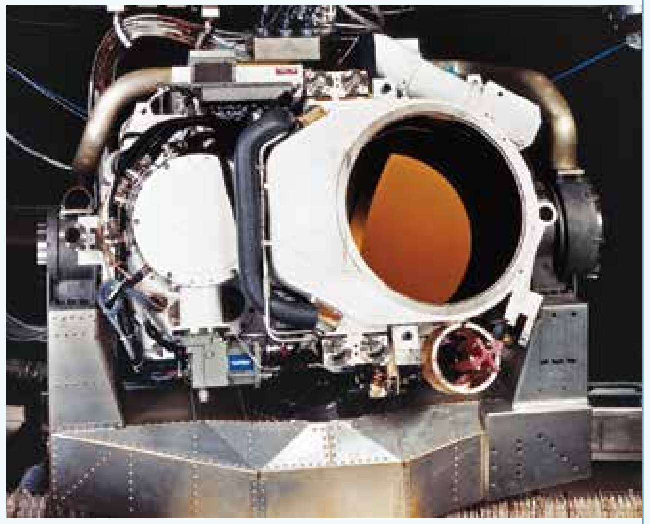
1988 Optical projection lithography at 193 nm, pioneered by Lincoln Laboratory, became the industry standard by the early 2000s. This work has enabled the microelectronics industry to continue following Moore's Law of miniaturization for at least one more decade, well into the 2010s. The Laboratory started a project in 1988 to demonstrate the feasibility of using the deep-ultraviolet wavelength of 193 nm for optical projection lithography (a process for producing patterned silicon wafers for the fabrication of integrated circuits). At the time, 248 nm lithography was considered the limit of wavelength reduction. This limit had been achieved as industry sought to reduce the size of microelectronic circuits by using shorter wavelengths of radiation in optical lithography. By 1993, the Laboratory had addressed challenges of the lens materials and the wafer coatings needed for 193 nm lithography, and a prototype projection system was used to fabricate microelectronic devices. The Laboratory is continuing research to further reduce the size of microelectronic circuits, especially through seminal efforts in interference lithography and multiple-exposure patterning.

Space-Based Visible Sensor for Midcourse Space Experiment

1989 The Space-Based Visible (SBV) sensor was the first successful space-based space surveillance system. This small (6-inch aperture) visible-band electro-optical camera was created to detect faint objects, comparable in size to a golf ball at 1000 km distance, against faint stellar backgrounds. The SBV instrument was launched in 1996 as part of a larger Midcourse Space Experiment (MSX) satellite. Over its life, the SBV sensor collected data on several domestic ballistic missile tests, providing a wealth of knowledge on the properties of sun-illuminated objects and the capabilities of visible-band optics to capture their signatures and estimate their trajectories. The SBV system was shut down in 2008 and left a legacy of visible-band space surveillance data. The technology developed and the lessons learned are being applied to the Air Force's next-generation system, the Space-Based Space Surveillance satellite.

Optical Aircraft Measurements Platform/Cobra Eye

1989 Lincoln Laboratory led the technical development of the Optical Aircraft Measurements Platform (OAMP), a one-of-a-kind infrared sensor integrated into an RC-135X aircraft, designated Cobra Eye. The OAMP sensor collected thermal (heat) signatures of ballistic missiles in flight to better understand their performance and behavior. In 1989, although Cobra Eye and the OAMP sensor were only in the engineering test phase, its crew was tasked to attempt data collection on both foreign ballistic missile and U.S. strategic weapons system tests. Both data collections were successful despite initial computer and weather challenges. The Cobra Eye crew members from the 24th Reconnaissance Squadron who participated in these historic first data collections received the General O'Malley Award, recognizing them as the Air Force's top reconnaissance crew of 1989.

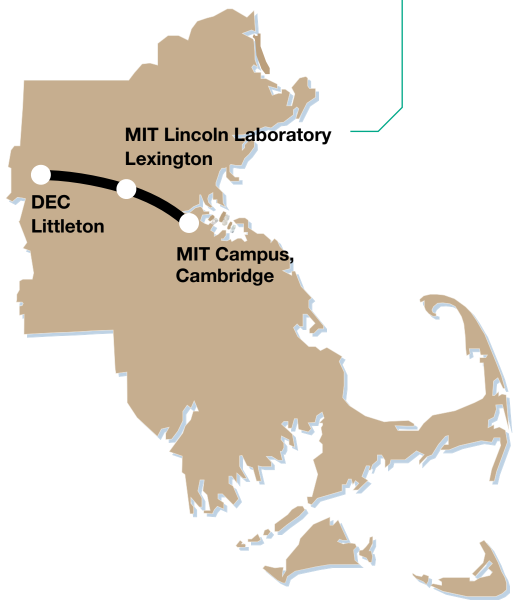


Electromagnetic Test Bed

1990 The Electromagnetic Test Bed, which was flown throughout the 1990s on a Boeing 707, featured one of the first airborne, real-time, embedded, digital adaptive signal processors and a very advanced and sensitive antenna system. The test bed was the pathfinder for implementing space-time adaptive processing (STAP) by using an advanced parallel computing infrastructure and a new modular, scalable software architecture to allow processing of large data sets on board in real time. This capability gave the system operators the significant advantage of real-time detection of small signals in the presence of large interference.

1991

Optical Networks



In the early 1990s, the Laboratory developed a prototype optical network test bed that achieved data rates as high as one trillion bits per second in a single fiber. This rate of a terabit per second is still quite advanced 15 years later. The optical network effort was supported by a consortium that included Lincoln Laboratory, MIT campus, AT&T Bell Laboratories, and the Digital Equipment Corporation. A strong desire for scalability of these networks in geographic extent, data rate, and number of users led to a design having distinct long-haul, metropolitan-area, and local-area network components supporting simultaneous wavelength-division-multiplexed and time-division-multiplexed services, all controlled by a separate control channel. The prototype was undertaken to address the problem of defining dual-use (commercial and DoD), fiber-based, all-optical networks that might alleviate the electronic "bottlenecks" anticipated with the increased demand for high-data-rate communications networks. This work contributed to the emergence of the optical communication industry. Existing companies began offering new optical networking equipment, and new companies formed.

1992

Radar Surveillance Technology Experimental Radar

The Radar Surveillance Technology Experimental Radar (RSTER), prototyped and tested at Lincoln Laboratory, was one of the first high-power, digital adaptive array radars. RSTER featured an ultra-high-frequency planar array antenna that scanned mechanically in azimuth and electrically in elevation. The radar's transmitter was a new, highly stable, solid-state design that enabled the rejection of severe clutter. The antenna, developed by Westinghouse, consisted of 14 stacked ultra-low-sidelobe antennas. The antenna rows connected to 14 receivers and analog-to-digital converters through a multichannel rotary coupler. The Laboratory developed a state-of-the-art digital processor for RSTER to implement real-time digital adaptive elevation beamforming, as well as advanced waveform and data processing. RSTER demonstrated a viable approach for detecting medium- and high-altitude cruise missiles in challenging environments.

Passively Q-Switched Microchip Laser

1992 The passively Q-switched microchip laser converts a low-power, steady-state optical input into a train of short-duration, high-peak-power laser pulses. The pulses are turned on and off by a saturable absorbing material that responds to the rapid buildup of light in the laser cavity. Similar to the microchip laser invented at the Laboratory in 1987, this invention offers a dramatic reduction in size and weight over other lasers capable of producing comparable output. The short pulses produced by passively Q-switched microchip lasers have enabled applications in high-resolution, 3D, airborne laser radars. The high peak power makes the lasers ideal for generating light at a variety of wavelengths through nonlinear optical processes. Generation of deep-ultraviolet light has enabled sensors to detect biological aerosols for defense against biological agents; conversion to the mid- and long-infrared wavelengths is used for a variety of chemical detection applications. To date, over 40 variants of the laser have been built to support ~70 Laboratory programs. The technology has also been licensed by eight different companies for a wide range of applications, including 3D imaging for engineering and architectural applications.

Terminal Doppler Weather Radar

1992 Lincoln Laboratory's work on the detection of weather hazards near airport terminals has had a significant impact in improving the awareness of weather conditions that could cause wind-shear-related accidents. The Terminal Doppler Weather Radar (TDWR) program, begun in 1992, developed an automated Doppler-radar-based system to detect weather hazards in airport areas and to help pilots avoid these hazards when landing and departing. The TDWR prototype, using Laboratory-developed signal processing and pattern recognition algorithms, provided highly reliable, fully automated detection of wind-shear phenomena. After operational TDWR demonstrations at Denver, Kansas City, and Orlando validated the system's capabilities, the Federal Aviation Administration (FAA) procured 47 TDWRs and deployed a national TDWR network. The TDWR system now provides wind-shear protection at 45 U.S. airports and incorporates the Laboratory's clutter-detection and microburst-detection algorithms. There has not been a major U.S. wind-shear-related air traffic accident since 1994.

Traffic Alert and Collision Avoidance System

1993 The Traffic Alert and Collision Avoidance System (TCAS) prototyped at Lincoln Laboratory is currently mandated on all large transport aircraft. In operation worldwide for over a decade, TCAS has been credited with preventing several catastrophic midair collisions. The FAA funded the development of TCAS in the 1990s to reduce the possibility of midair collisions. This airborne electronics system senses the presence of nearby aircraft by interrogating the transponders carried by the aircraft. When TCAS senses that a nearby aircraft is a possible collision threat, it issues an advisory to the pilot, indicating the presence and location of the other aircraft. If the encounter becomes hazardous, TCAS issues a collision avoidance maneuver advisory. The Laboratory developed the surveillance technology used by TCAS, and built and flight-tested the TCAS prototype.

1995

Advanced Land Imager

The Advanced Land Imager (ALI) optical system was developed at Lincoln Laboratory under sponsorship of the National Aeronautics and Space Administration (NASA) to validate new instrument and spacecraft technologies that could be used in future Landsat (land-observing) satellites. ALI was designed to realize significant decreases in size, weight, and power consumption, while improving instrument sensitivity and image resolution. The image resolution, sensitivity, and dynamic range of the ALI surpassed that of earlier land-mapping instruments flown aboard satellites. ALI met all its performance objectives and was selected as the main instrument on NASA's Earth Observing 1 satellite launched in 2000. In 2017, ALI was decommissioned. In its 16+ years of operation, ALI collected more than 90,000 images, many of which were groundbreaking: the first mapping of a lava flow from space and the first tracking of regrowth of an Amazon forest as seen from space. ALI also captured many dramatic scenes—depictions of ash deposits left by the 2001 World Trade Center attacks, flooding caused by Hurricane Katrina in 2005, and the 2015 eruption of the Momotombo volcano in Nicaragua.

Cobra Gemini Shipborne Radar System

1996

Lincoln Laboratory's role in developing high-power wideband radars led to its involvement in the U.S. Air Force's Cobra Gemini project. The project was motivated by the increasing number of nations that were obtaining tactical ballistic missiles. The goal was to rapidly produce a radar prototype whose baseline design could be transitioned to industry after test and evaluation. The Laboratory successfully developed the Cobra Gemini prototype, a transportable dual-band (S- and X-bands) radar for collecting signature and metric intelligence data on tactical ballistic missiles. The rigorous signature data-collection requirements included wide and narrow bandwidth radar data collection at both S- and X-band frequencies to support analysis of tactical missile dynamics as well as identification of objects in the missile threat complex.

Mountaintop Program

The Navy and the Defense Advanced Research Projects Agency (DARPA) sponsored the Mountaintop program to test advanced space-time adaptive processing (STAP) techniques for airborne radar clutter and jammer mitigation, and to demonstrate air-directed surface-to-air missile (ADSAM) engagements against low-flying cruise missiles. Central to the effort was a surveillance radar test bed and measurements program developed by Lincoln Laboratory. Measured data was collected from various locations including the White Sands Missile Range in New Mexico and the Pacific Missile Range Facility in Hawaii. Much of the new technology prototyped as a part of the Mountaintop program transitioned to the development of new airborne early-warning radars.

1996

1997

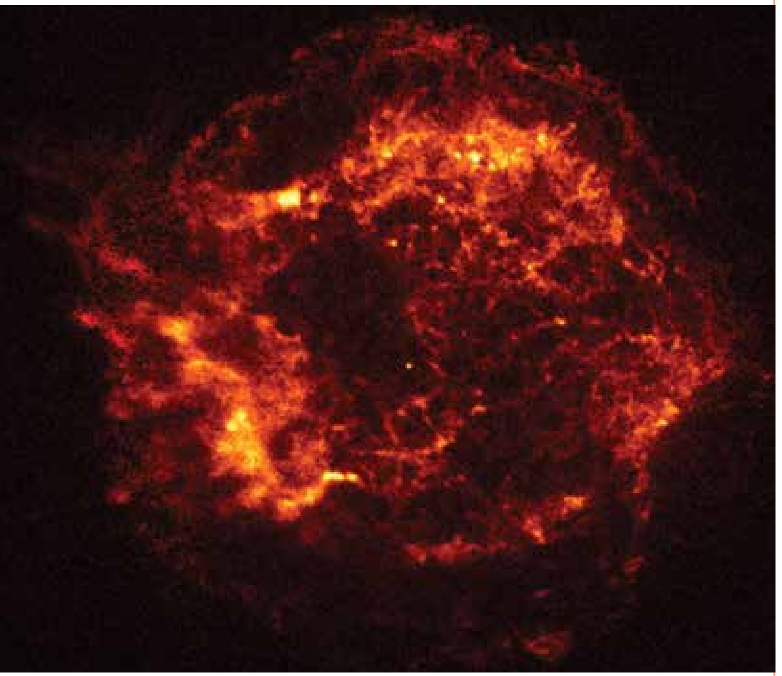
Biological-Agent Warning Sensor

Lincoln Laboratory developed the novel Biological Agent Warning Sensor (BAWS) for early warning of an aerosolized bioattack. BAWS successfully detects individual particles with good sensitivity, good discrimination, and high speed. It represented a dramatic improvement in biodetection technology and was chosen for insertion into the U.S. military's Joint Biological Point Detection System. Based on the principle of laser-induced fluorescence, BAWS's use of the Laboratory-developed passively Q-switched microlaser light source enabled it to achieve significant improvements in performance and to meet small size and low power consumption goals desired in a practical detection system.

Lincoln Near-Earth Asteroid Research

1998

The Lincoln Near-Earth Asteroid Research (LINEAR) program has discovered more than one-third of all known near-Earth asteroids (NEA) to date, nearly half of large NEAs, and more than 24% of all known potentially hazardous asteroids. Funded by the U.S. Air Force and NASA, the program's goal was to successfully apply technology originally developed for the surveillance of Earth-orbiting satellites to the problem of detecting and cataloging NEAs that may threaten Earth. LINEAR uses a pair of ground-based electro-optical deep-space surveillance telescopes (equipped with Laboratory-developed charge-coupled device detectors) at the White Sands Missile Range in New Mexico to collect data that are then processed onsite to generate observations. In 2011, LINEAR's lead researchers were among the recipients of a NASA achievement award for their participation in the Near Earth Object Observation Program that has discovered and characterized 98% of the worldwide observations of near-Earth objects.



Chandra X-Ray Telescope CCD Camera

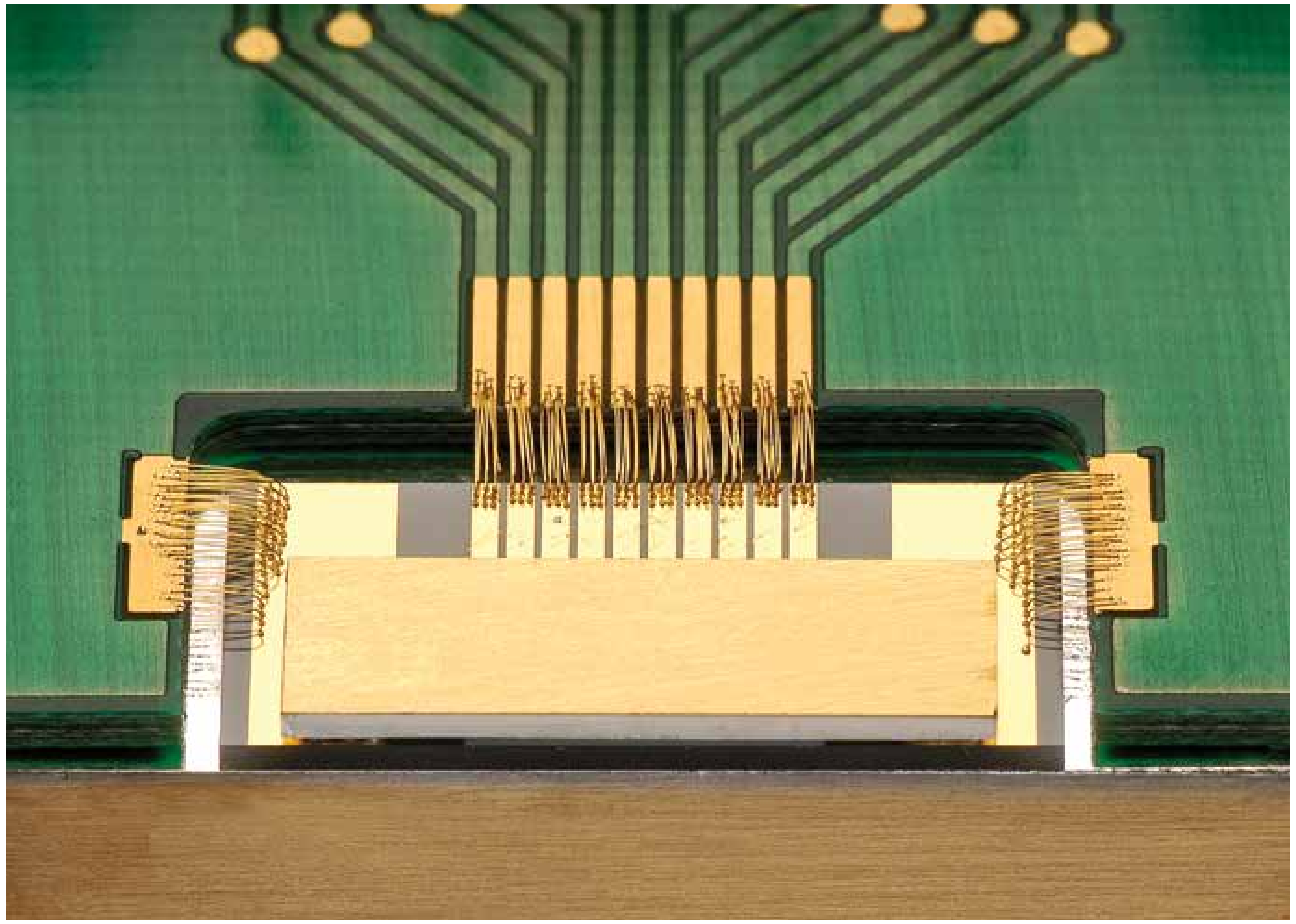
1998

The Chandra X-Ray Observatory, one of the NASA Great Observatories, was deployed by the Space Shuttle *Columbia* in 1999. It was designed for high-resolution imaging of X-ray astronomical objects from space. Lincoln Laboratory developed and assembled the Advanced CCD Imaging Spectrometer (ACIS), one of two imaging systems on board Chandra. The ACIS contains ten charge-coupled device (CCD) imaging arrays that were fabricated in Lincoln Laboratory's Microelectronics Laboratory. Each CCD array comprises a million pixels. Two of the imaging arrays were specially designed back-illuminated devices fabricated by using a novel high-temperature oxidation and annealing technology developed at the Laboratory in order to achieve high quantum efficiency for the detection of very-low-energy X-rays. The Chandra Observatory continues to make important contributions to astrophysics and to rely on the ACIS for 95% of its science imagery.

2000

Slab-Coupled Optical Waveguide Laser

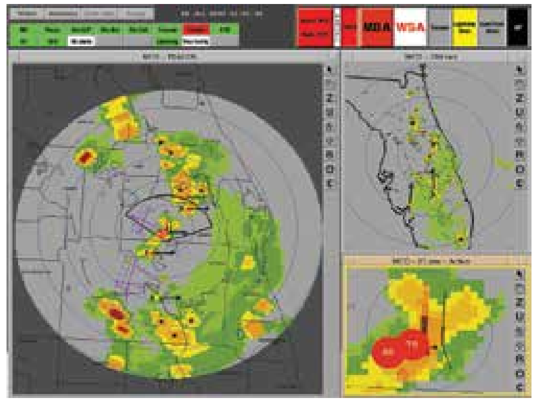
The Slab-Coupled Optical Waveguide Laser (SCOWL) concept is enabling significantly higher-brightness diode lasers. Several years after the initial development of SCOWL devices, Laboratory researchers combined 100 devices to produce a single beam with record high brightness for a diode-laser system. Unlike conventional diode lasers, which operate with multiple modes, SCOWL produces a single mode by using a design that couples the higher-order modes into the slab modes of the waveguide structure. SCOWL devices have produced >1 W continuous-wave output in large, circular, single-mode beams. Recently, the Laboratory is coherently combining arrays of SCOWL lasers to produce many 100s of watts of power. Such high-brightness diode lasers are important in a variety of applications, including materials processing, laser radar, and optical communications.

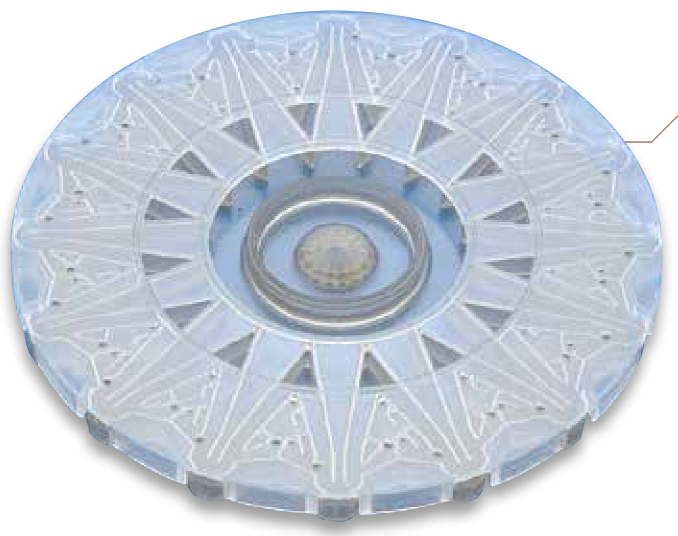


Radar Hazardous Weather Detection System

2001

The Weather Systems Processor (WSP), a hardware and software modification to existing FAA Airport Surveillance Radars (ASR-9), provides low-cost detection of wind-shear and microburst activity. Because thunderstorms (predicted from microburst activity) and associated low-altitude wind shear constitute significant hazards to aviation, the WSP's assessment of near-term severe weather enables more efficient, safer management of both air traffic and runway usage. Following successful operational demonstrations of a prototype ASR-WSP, the FAA procured approximately 35 WSPs for nationwide deployment. Lincoln Laboratory was responsible for development of all data processing algorithms and reconfiguration of the microwave receiving components of the ASR-9.





CANARY

2001

The Cellular Analysis and Notification of Antigen Risks and Yields (CANARY) is a sensor that is able to identify pathogens in a very rapid, sensitive, and specific manner. CANARY can detect minute amounts (<50 colony-forming units) of pathogen in less than three minutes, including the time required to concentrate the samples. The sensor uses genetically engineered white blood cells that emit light within seconds after being exposed to particular pathogens of interest. Cells have been produced to identify a variety of bacteria and viruses, including anthrax, smallpox, plague, E. coli, and foot-and-mouth virus. Because of its speed and sensitivity, CANARY may have significant benefits for biological aerosol sampling, point-of-care diagnostics, pre-symptomatic diagnosis in the aftermath of a biowarfare attack, detection of agricultural pathogens at ports of entry, and screening of perishable food supplies.

2001

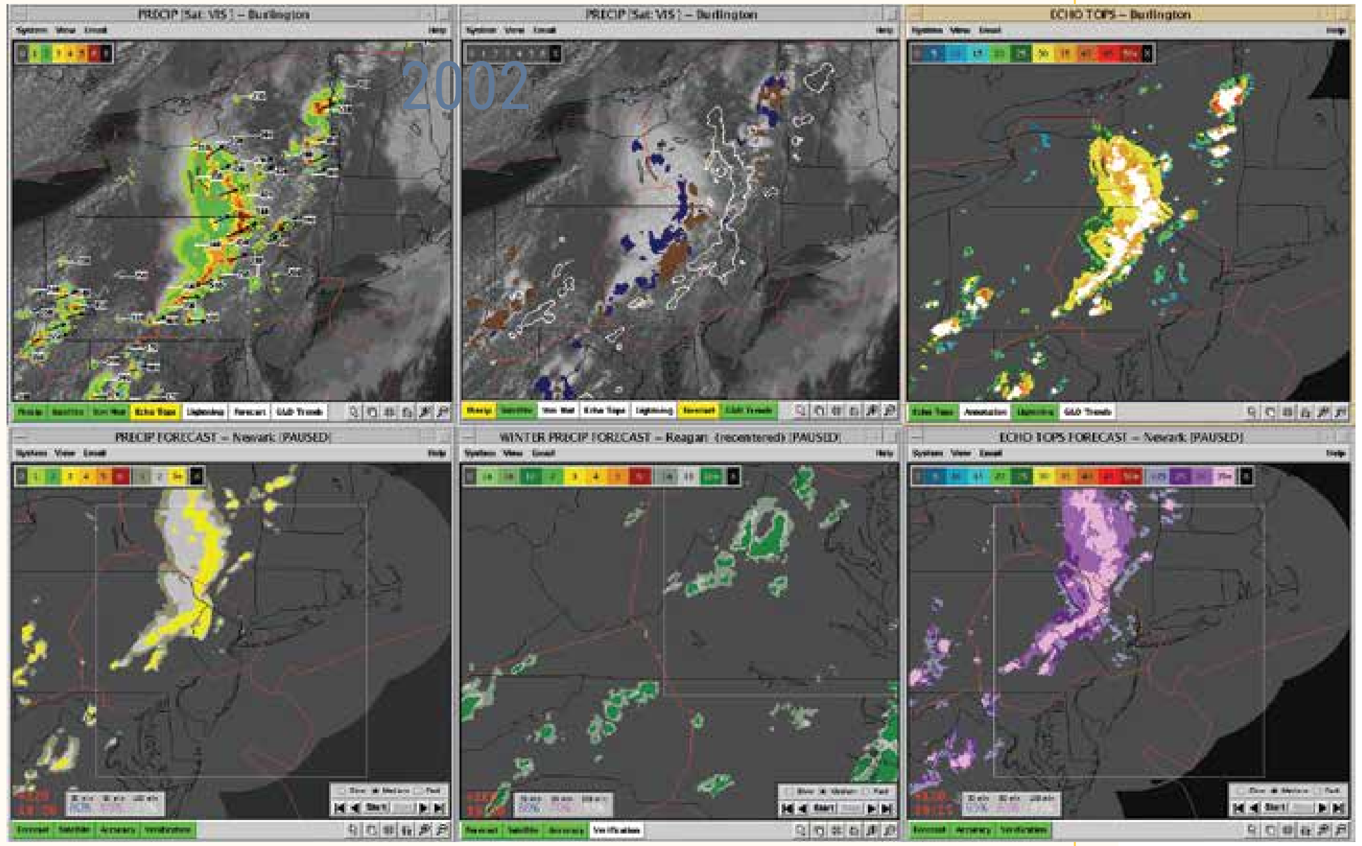
Geosynchronous Lightweight Integrated Technology Experiment

A laser communications system was developed by Lincoln Laboratory as part of the National Reconnaissance Office's Geosynchronous Lightweight Integrated Technology Experiment (GeoLITE) program. The GeoLITE advanced demonstration satellite was launched in 2001. The laser communications system was successfully operated, demonstrating the viability of inserting laser technology into operational systems.

2002

Corridor Integrated Weather System

The very accurate, low-latency, high-resolution, 3D weather information and forecasts provided by the Corridor Integrated Weather System (CIWS) enable efficient and safe management of en route air traffic congested by convective weather (thunderstorms). CIWS integrates data from national weather radars with thunderstorm-forecasting technology. Lincoln Laboratory supports the CIWS system with algorithm, architecture, and software research and development. CIWS was deployed to eight en route centers in the northeast United States, six major terminal control areas, and the Aviation Research System Command Center. In 2008, CIWS was expanded to provide continental United States coverage, and winter precipitation depiction and forecast were added in 2009. Today, the CIWS displays are incorporated into the Federal Aviation Administration's modern Aviation Weather Display.



3D Imaging: ALIRT/Jigsaw

2002 The Airborne Ladar Imaging Research Testbed (ALIRT) is an airborne laser radar (ladar) imaging system that provides both high-resolution, 3D views of terrain from altitudes up to 9000 meters, as well as decimeter (10 cm) accuracy from altitudes of 3 km. ALIRT's high data-collection rates (7 to 12 times larger than any other available ladar system) and high operational altitudes (4 times that of other systems) enable unparalleled functionality. ALIRT has been used by the U.S. military to map earthquake-affected regions of Haiti and terrain in Afghanistan.

The Jigsaw program developed high-resolution, 3D imaging ladar sensor technology and systems for use in airborne platforms to image and identify ground vehicles hiding under camouflage or foliage. Both programs provided key technologies to address the difficulties of providing imagery of problematic scenes: wide expanses obstructed by structures or targets obscured by foliage.

Radar Open Systems Architecture

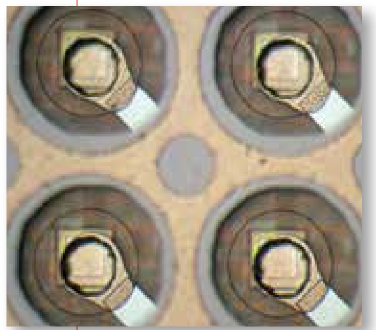
2003 The Radar Open Systems Architecture (ROSA) led to the evolution of sophisticated radar systems from ones that are built from custom-designed hardware and proprietary interfaces to ones that utilize widely available, commercial off-the-shelf components and open-standard interfaces. The modular ROSA system is more cost-effective and more easily maintained because components can be acquired and integrated more readily when replacements or upgrades are needed. ROSA was the backbone of the modernization of the four signature radars at the Army's Reagan Test Site in the Marshall Islands. In this expansion of the radars' data-collection capabilities, the ROSA implementation saved the military millions of dollars in procurement and development costs. ROSA was also successfully used in two shipborne radars and the upgrade of three radars at the Lexington Space Surveillance Complex in Westford, Massachusetts. The next-generation open system architecture features net-centric functionality and is being applied to optical systems.

Runway Status Lights

2005 Of the few technologies specifically addressing runway incursions, the Runway Status Lights (RWSL) system provides the most timely, most effective, and most highly automated technology to directly alert pilots and vehicle operators on the airport surface of potential incursions. The RWSL system alerts pilots when a runway is unsafe by turning on special red lights, embedded in the runway pavement, that are fully visible to pilots and nearby personnel. The lights are controlled by safety logic that automatically processes surveillance information from a preexisting surveillance system. The RWSL system serves as an independent backup to the clearances issued by air traffic controllers. An FAA-sponsored study of runway incursions in the United States between 1997 and 2000 at 100 of the busiest airports determined that RWSL might have prevented or mitigated 75% of the 167 identified incursions. In 2005, the first prototype RWSL system was installed at the Dallas/Fort Worth International Airport. Today, RWSL systems are being evaluated at a number of other major airports, including Boston Logan International.

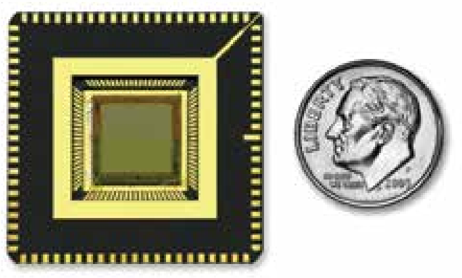
Avalanche Photodiode Array 2005

Lincoln Laboratory developed some of the first large-sized imaging arrays of avalanche photodiodes (APD) fabricated in the indium-gallium-aluminum-phosphide–material system. This material system is sensitive at a 1-micron wavelength, where small-sized and powerful laser sources are available. An APD is a highly sensitive, high-speed semiconductor electronic device that converts light to electricity. The Laboratory's work has extended APD technology to large-area arrays of single-photon-counting detectors that have become the foundation of new communications, 3D imaging, and foliage penetration concepts. The Laboratory has also demonstrated an array of Geiger-mode avalanche photodiodes for adaptive optics uses. Future work will integrate these arrays in telescope systems, speed up the image acquisition in large sky surveys, and improve imaging performance.



Digital-Pixel Focal Plane Array

2007 The digital-pixel focal plane array (DFPA) revolutionizes infrared imaging by providing real-time, in-pixel processing that permits an extreme dynamic range and wide-area coverage from a minimally sized, low-powered package. The DFPA is designed to meet demands of emerging infrared imaging applications, such as day/night persistent surveillance, aerial search and rescue, and environmental remote sensing. These applications require high-sensitivity, high-resolution, large-field-of-view, and fast-data-rate imaging. The DFPA includes a low-power analog-to-digital converter in every pixel and enables greater computational capability. It combines a commercial focal plane sensor with a Lincoln Laboratory–designed readout integrated circuit to enable low-power, high-component-density designs. The DFPA can function as a conventional imager; however, its architecture also provides a simple way to implement real-time image processing algorithms on chip prior to reading out the data.

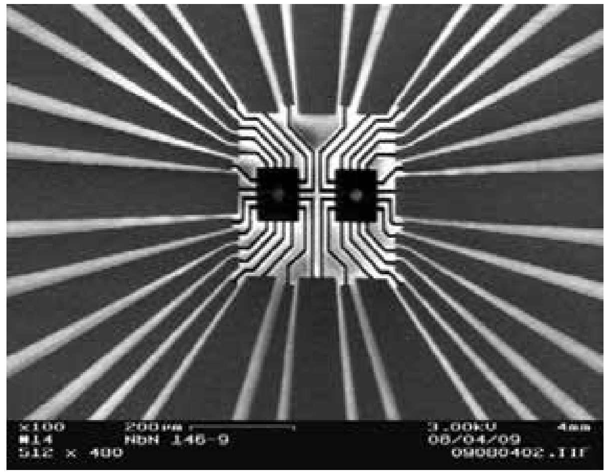


Pan-STARRS Focal Plane Array

The Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) gigapixel focal plane array (FPA) built by Lincoln Laboratory is currently the world's largest and most advanced FPA. It utilizes a unique architecture called the orthogonal transfer array (OTA), which the Laboratory developed in collaboration with the University of Hawaii's Institute for Astronomy.

2008 An OTA uses an array of orthogonal charge-coupled devices to compensate electronically for image motion at the pixel level. The Pan-STARRS FPA is equipped with sixty 8 × 8 OTAs that enable the high-quality imaging. This large focal plane was installed in the prototype Pan-STARRS telescope in Hawaii and has been used in regular science observations beginning in 2009. The prototype focal plane and three additional ones will compose the full Pan-STARRS, which will be able to image a large percentage of the night sky with great sensitivity and will be used to detect Earth-approaching asteroids and comets that could be dangerous to the planet.

Superconducting Nanowire Single-Photon Detector Array



2009 The superconducting nanowire single-photon detector array is a fast, highly sensitive component in an optical detection system. It enables broadband single-photon detection with high efficiency and low noise at rates exceeding one billion photons per second, and it can operate in the ultraviolet, visible, and near-infrared spectral regions. The detector array was developed through a collaboration with MIT Research Laboratory of Electronics to enable the next generation of optical communication technologies, which demand large-capacity data rates. The array improves the performance and capability of standard single nanowire photodetectors, which cannot resolve the position or wavelength of detected photons and can detect, at most, one photon at a time with a minimum time of several nanoseconds between detection events. By using a spatially interleaved array of up to eight serpentine, superconducting nanowires that occupy an area 7 to 20 micrometers in diameter, nanowire photodetector arrays overcome the limitations of the single nanowire.

Advanced Miniaturized Receiver on a Chip

2010 This radio-frequency (RF) receiver, formed from a single chip set, is considerably smaller, has greater sensitivity, and demands significantly less power than existing commercial RF systems. The system demonstrates the largest measured spur-free dynamic range (an indicator of how well a target signal can be distinguished from interference) for an RF receiver of any size. With dimensions about the same as a standard 6-inch school ruler, the miniaturized receiver is suitable for military and commercial applications that have only a small platform for RF sensing.

2011 Space Surveillance Telescope

The Space Surveillance Telescope (SST) originally installed at the White Sands Missile Range in New Mexico provides an unprecedented wide-angle view of deep space. The SST is an advanced ground-based optical system designed to enable detection and tracking of faint objects in space while providing rapid, wide-area search capability. Lincoln Laboratory was responsible for the development of critical technologies for the SST as well as for integration of the entire SST system. The system combines innovative curved charge-coupled device imager technology developed at the Laboratory with a very wide field-of-view, large-aperture (3.5 meter) telescope. The SST program was initiated in 2002 under the sponsorship of the Defense Advanced Research Projects Agency (DARPA). In February 2011, the telescope achieved “first light” and transitioned to the Air Force as part of its Space Surveillance Network. The SST was moved to Western Australia under a partnership between the U.S. Air Force and the Australian Department of Defence. After a multi-year effort to relocate the telescope in its new enclosure, the SST in Australia achieved first light in 2020.

Airborne Collision Avoidance System X

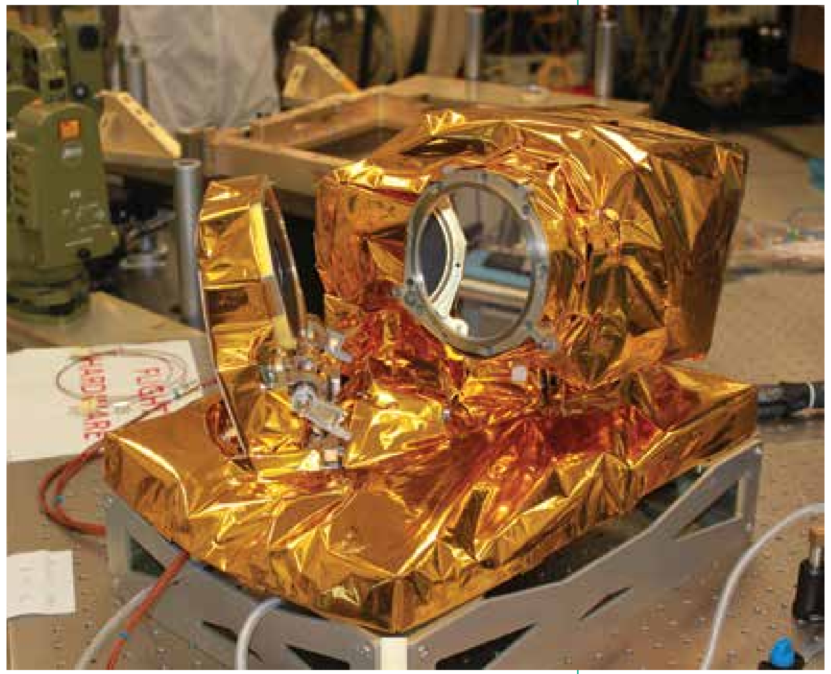
2012

The Airborne Collision Avoidance System X (ACAS X) is an onboard flight safety system designed to replace the Traffic Alert and Collision Avoidance System II used on commercial aircraft. ACAS X detects nearby aircraft by receiving sensor measurements from onboard surveillance systems and estimates the relative position and speed of these aircraft by using tracking algorithms. The system then considers the probabilities of a conflict, weighs the actions the pilot could take, and then decides on a single best action if action is necessary. This information is sent directly to the pilot via the flight deck displays. ACAS X is compatible with new airspace procedures and technologies of the FAA's Next-Generation Air Transportation System, which aims to use new technologies to reduce gridlock in the sky and at airports.

Lunar Laser Communication Demonstration

2013

In October 2013, the Lunar Laser Communication Demonstration (LLCD) used a pulsed laser beam to transmit data over the 239,000 miles from the Moon to Earth at a record-breaking download speed of 622 megabits per second. The LLCD also achieved an uplink rate to the Moon 5,000 times that of radio technology. Flown aboard NASA's Lunar Atmosphere and Dust Environment Explorer spacecraft, the LLCD space terminal demonstrated not only the longest lasercom link ever created but also the most reliable lasercom link to ever bring data down through the atmosphere. The LLCD system's ability to rapidly and reliably transmit enormous amounts of information will significantly transform the objectives, design, and operation of future scientific space missions. NASA is using some of the LLCD designs, such as the space telescope and the pointing module, in the system for its upcoming long-duration Laser Communications Relay Demonstration, which is designed to help advance lasercom capabilities for future deep-space science missions.



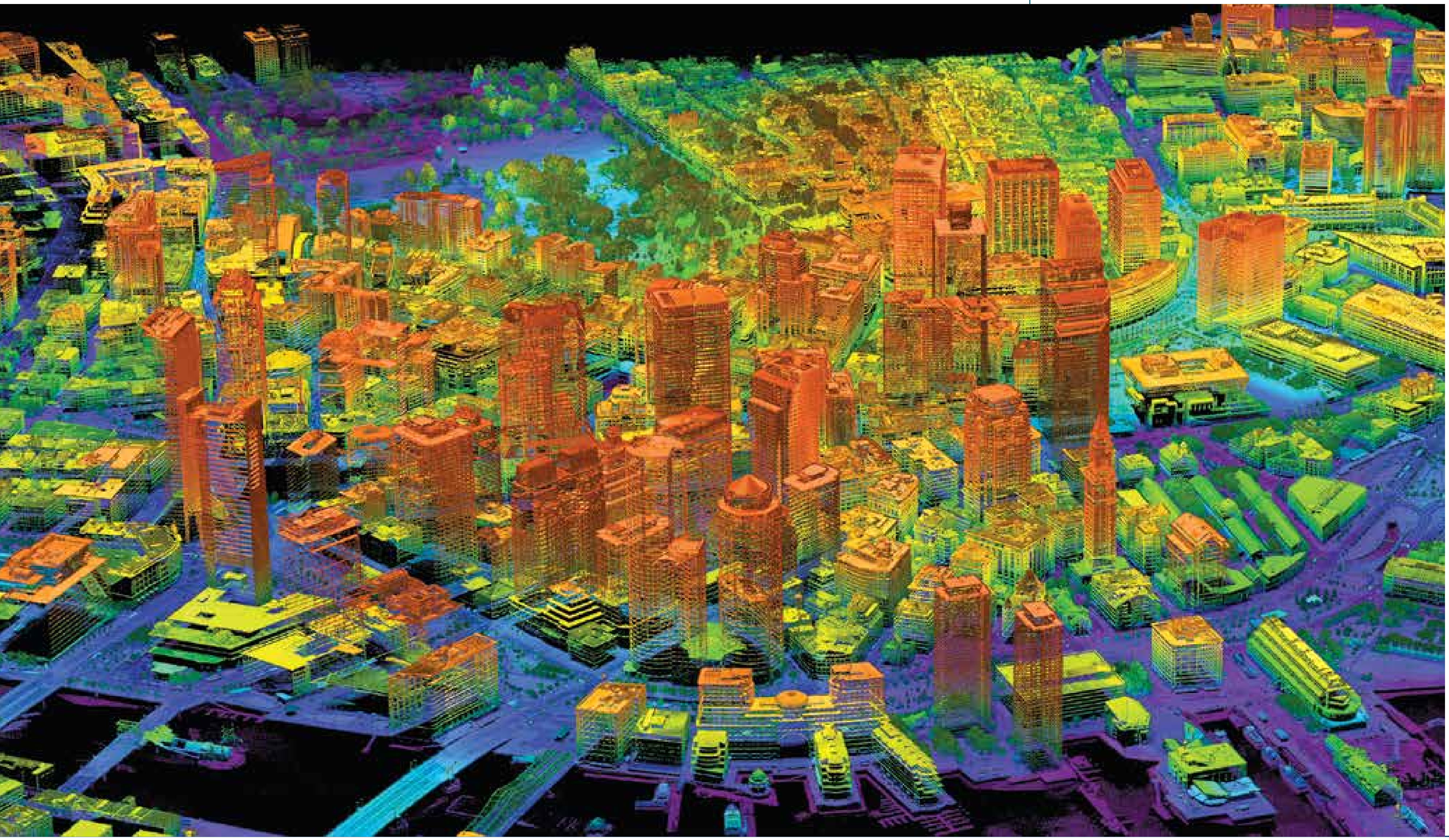
2014

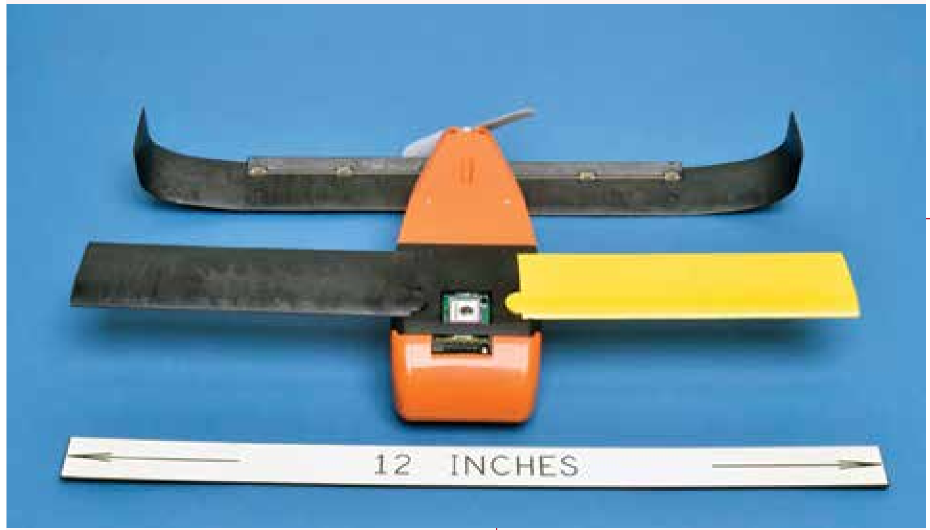
Haystack Ultrawideband Satellite Imaging Radar

The Haystack Ultrawideband Satellite Imaging Radar (HUSIR) was originally the X-band Haystack sensor, but in 2013 Lincoln Laboratory completed the transformation of this single-band system into a dual-band radar, and in January 2014 HUSIR successfully completed the operational trial period and was accepted as a U.S. Space Surveillance Network contributing sensor. HUSIR is now the highest-resolution, long-range sensor in the world, simultaneously generating X- and W-band images that help U.S. researchers better determine the size, shape, orientation, and motion of objects orbiting Earth. This upgrade to W-band operation required the development and construction of a new 120-foot-diameter antenna. HUSIR can characterize individual components of large, complex objects and can distinguish small objects from each other. These advanced capabilities can supply data valuable for improving space situational awareness.

Multi-look Airborne Collector for Human Encampment and Terrain Extraction

2015 Capable of collecting 3D imagery from an altitude of 25 kft and at an incredible area coverage rate (400 km^2/hr at 25 cm resolution), the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) is a ladar system designed to uncover hidden activity in heavily foliated areas. The airborne platform sends down high-energy, narrow laser pulses, some of which travel to the ground through openings in the tree canopy and reflect back toward the system; this light is collected by a receiver telescope and focused onto two 16-kilopixel Geiger-mode avalanche photodiode detector arrays. A timing circuit measures the arrival time of the returning pulses; these times are correlated with measurements of MACHETE's altitude and pointing angle to produce a geolocated 3D point-cloud image of the area below. This image can then be digitally "defoliated" to reveal the structures underneath. MACHETE has been used in hundreds of sorties overseas.





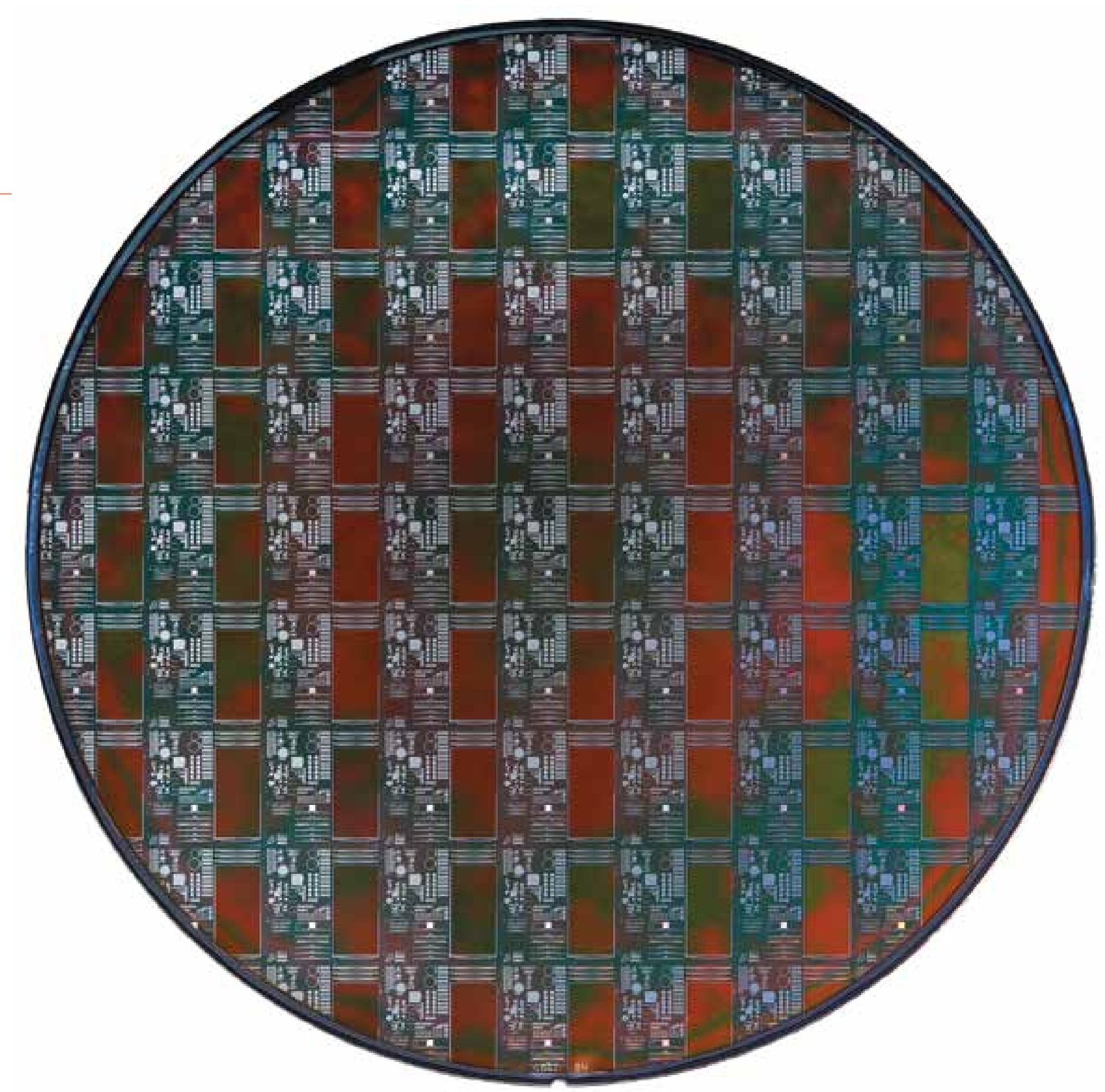
Perdix

2016 Perdix is an expendable miniature unmanned aerial vehicle (micro-UAV) that can be dispensed in large numbers from tactical aircraft, self-navigate, and autonomously collaborate to perform a variety of missions, such as surveillance. The initial air vehicle was designed and demonstrated by MIT students as part of a two-semester capstone course led jointly by staff from Lincoln Laboratory and faculty in the MIT Department of Aeronautics and Astronautics. Lincoln Laboratory researchers then improved the design by adding advanced miniature avionics, an air-launched deployment system, communication systems, autonomy algorithms, and modular payloads that can be integrated as required by missions. Data obtained from Perdix flight tests are helping researchers further develop advanced algorithms for coordinated autonomous behavior and transition the system for operational use.

Germanium Charge-Coupled Devices

2017

Lincoln Laboratory demonstrated the world's first germanium charge-coupled device (CCD). Germanium CCDs cover a broader spectral range than traditional silicon CCDs, extending into both the short-wave infrared (SWIR) and hard X-ray bands. These improvements in sensitivity enable germanium CCDs to significantly improve imager performance for night-vision applications. Germanium CCDs also have important applications in astronomy. A germanium CCD can image over the entire X-ray band, enabling observations of deep-space objects that were previously beyond the capabilities of other imagers. The broad sensitivity of germanium across multiple wavebands may also enable new applications in imaging; for example, a single sensor could image in both the visible and SWIR bands, enabling persistent day–night surveillance. While this proof-of-concept germanium CCD was a 32 × 32 pixel array, Lincoln Laboratory plans to scale these devices to larger arrays, eventually making megapixel-class and beyond devices for applications in national defense and basic science.



2018 Embedded Semiconductors and Photodetecting Diodes in Fibers

In a collaborative venture, researchers from the Advanced Functional Fabrics of America, Lincoln Laboratory, Inman Mills, and MIT successfully demonstrated embedding semiconductor light-emitting diodes (LEDs) and photodetecting diodes into fibers produced through a thermal draw process. When voltage is applied to the end of the fibers, the tiny (the size of a grain of sand) diodes light up or detect light. The fibers are flexible and durable enough to be woven into a soft textile, machine washed, and handled day to day.

The fibers can enable an optical communication system that uses pulsed light in a fabric to transmit information from the wearer to a receiver, such as a cell phone camera. The receiver can measure fluctuations in light intensity emitted from a LED fabric that is being worn 10 meters away and convert the pattern of fluctuations into an electrical signal. The fibers could also provide biomedical sensing. For example, these two types of fibers embedded into a knit glove can detect the changes in light intensity reflected off a finger as blood circulates in vessels close to the skin. This signal could then be used to determine the wearer's heart rate.

Airborne Collision Avoidance System for Unmanned Aircraft Systems

2019

The Airborne Collision Avoidance System for Unmanned Aircraft Systems (ACAS Xu) is the only technology that will allow unmanned air systems (UAS) to meet U.S. law and international regulations requiring all air vehicles to see and avoid other air traffic. Because unmanned aircraft lack a pilot on board to meet this requirement, a technical solution is needed to allow unrestricted UAS operations in civil airspace. The ACAS Xu is being developed to give UAS the capability to detect and track nearby aircraft and to provide ground operators with alerts that allow them to direct UAS to maintain separation from other air traffic and avoid potential mid-air collisions with manned aircraft and other UAS. This system is sensor agnostic and tunable for effective collision avoidance advisories across the range of UAS vehicle and surveillance system performance characteristics. Additionally, ACAS Xu is designed to coordinate maneuvers and interoperate with collision avoidance systems on all other manned and unmanned aircraft.

2020

Private Automated Contact Tracing

Contact tracing is key to controlling the spread of an infectious disease. Lincoln Laboratory partnered with MIT researchers in developing the Private Automated Contact Tracing (PACT) system to augment the manual COVID-19 tracing efforts of public health officials. The system relies on short-range, anonymized Bluetooth signals emitted by and picked up by people's smartphones. People who test positive for COVID-19 can upload the signals their phone has put out in the past 14 days to a database, and other people can then scan the database to see if any of those signals match ones picked up by their phones. If there's a match, a notification will inform those who may have been exposed to the virus. The PACT framework was integrated into Apple and Google's jointly created Exposure Notifications System, which is available on most Apple or Google devices. The system has been formally adopted into contact-tracing efforts in several states, including Pennsylvania, Delaware, New York, and New Jersey.

2021

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

Lincoln Laboratory developed a small radiometer for NASA's Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats, or TROPICS, mission that will deploy an array of small satellites to collect data on the temperature, humidity, and precipitation within tropical storm systems. These measurements made by the miniaturized microwave radiometers aboard the satellites (known as CubeSats) will enable scientists to study the dynamic processes that occur in the inner core of a storm. A prototype of the radiometer-equipped CubeSat will be launched for a trial flight in 2021. The future launch of a constellation of up to four CubeSats in each of three low-Earth orbital planes will allow new measurements to be collected over an area every 30 minutes, an unprecedented frequency of data refresh.

INDEX BY TECHNOLOGY CATEGORY

SPIN-OFF COMPANIES

1956–present: Spin-off Companies

One direct measure of the Laboratory's contribution to the nation's economy is its success in transferring technology to spin-off companies. More than 100 spin-off companies have been started by Lincoln Laboratory staff since 1956. While some of the companies, such as Digital Equipment Corporation, may no longer exist, each of these spin-off companies has had or continues to have a significant impact on the national economy through the creation of jobs and new technologies. This list of spin-off companies illustrates the range of industrial activities that have been generated and supported by ideas and techniques developed at the Laboratory.

3DEO
Air Traffic Software Architecture
Allthenticate
American Aviation
American Power Conversion Corporation
Amtron Corporation
Applicon
Arcon Corporation
Ascension Technology
Atlantic Aerospace Electronics
Axsun Technologies
Broadcloud Communications
Butterfly Network
Carl Blake Associates
Catalyst
Centocor
Clark Rockoff and Associates
Composable Analytics
Computer Corporation of America
Copious Imaging
Corporate-Tech Planning
Delta Sciences
Digital Computer Controls
Digital Equipment Corporation
Dimensional Photonics
Electronic Space Systems Corporation
Electro-Optical Technology
F.W.S. Engineering
Genometrix Genomics
Gulf Coast Audio Design
Hermes Electronics
Heuristics Lab
HH Controls Company
HighPoint Systems
Information International
Integrated Computing Engines
Janis Research Company
JETCOOL Technologies
Jumpjot
Kenet
KODA Technologies
Kolodzy Consulting
Kopin Corporation
Kulite Semiconductor Products
Laser Analytics
Lasertron
Liberty Defense
LightLab Imaging, LLC
Louis Sutro Associates
Mann VLSI Research
M.D. Field Company
Meeks Associates
Message Secure Corporation
Metric Systems Corporation
Micracor
Micrilor
MicroBit Corporation
MicroGlyph Systems
MIT Francis Bitter Magnet Laboratory
MITRE Corporation
Morris Consulting
NanoSemi
Netexpress
Nichols Research Corporation
(Wakefield Branch)
nou Systems
Novalux
Object Systems
Okena
Optim Microwave
Photon
PhotonEx
Pugh-Roberts Associates
QEI
RN Communications
Sandial Systems
Saperix
Saxenian Hrand Associates
Schwartz Electro-Optics,
Research Division
Sensors Signal Systems
Signatron
SimSpace
sound/IMAGE Multimedia
Sparta (Lexington Branch)
Spiral Software Company
Stanford Telecommunications
(Lowell Office)
Sycamore Networks
Sync Computing
Synkinetics
Tau-Tron
Technology Transfer Institute
TeK Associates
Telebyte Technology
Telenet Communications
TeraDiode
Terason Corporation
Teratech Corporation
Torch Concepts
Transducer Products
Tyco Laboratories
U.S. Windpower
UTP
Viewlogic Systems
VVimaging
Wolf Research & Development
XonTech
Zeopower
ZTEK Corporation

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70 YEARS OF TECHNOLOGY FOR NATIONAL SECURITY