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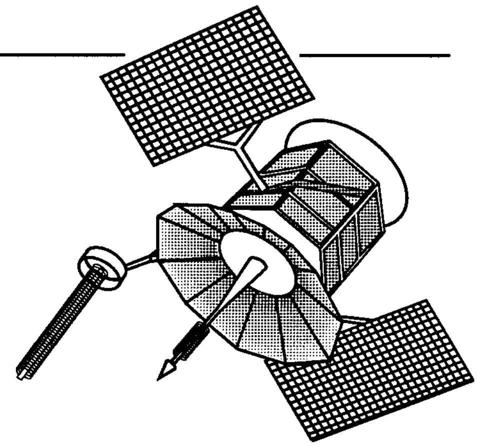
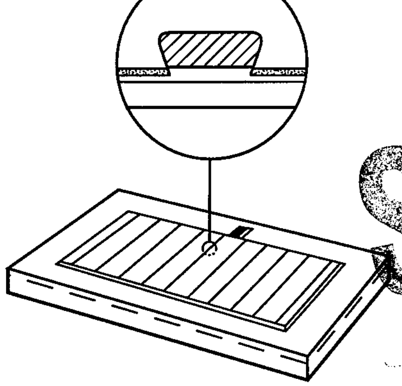
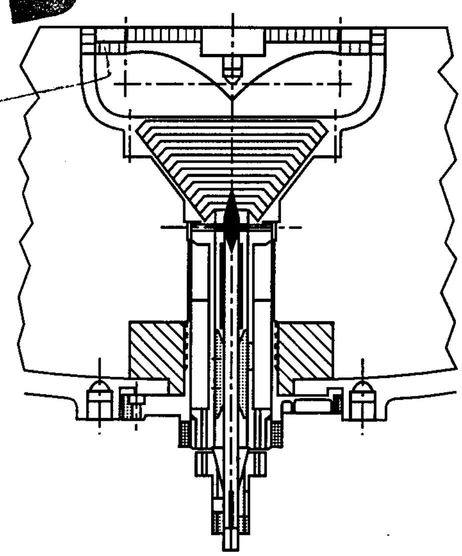
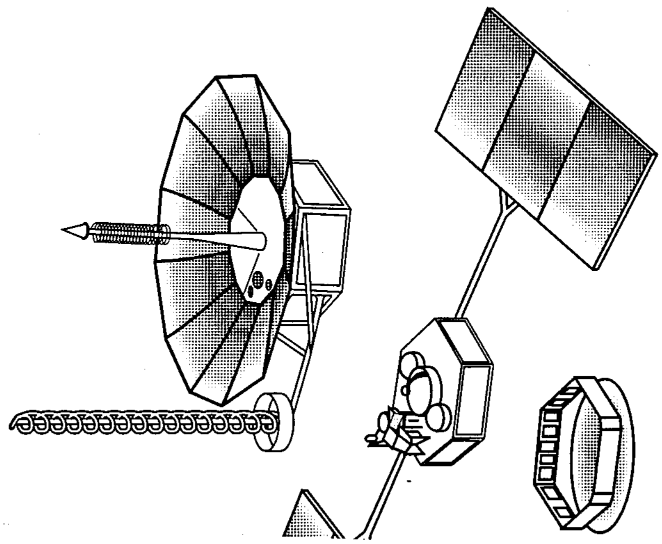
Technology Transfer

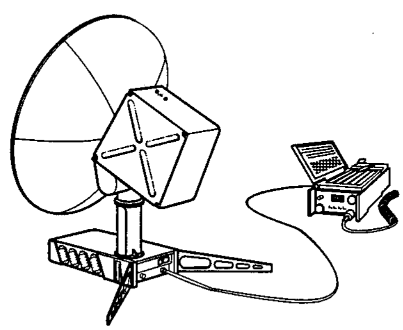
Volume Two
April 1992











Massachusetts Institute of Technology
Lincoln Laboratory

This report is based on studies performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology. The work was sponsored by the Department of the Air Force under Contract F19628-90-C-0002.

FOR THE COMMANDER

Gary Tutungian
Administrative Contracting Officer
Contracted Support Management

Technology Transfer

Volume Two

Massachusetts Institute of Technology
Lincoln Laboratory

Prepared by Group 17
Library and Information Services

Volume Two, 1992

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NOTE: The technology reported here basically covers the period of 1987-1992. Some additional entries report on endeavors before this period that were not included in the first edition. For a thorough report on the technologies transferred before this time period, please refer to **Technology Transfer**, May 1990.

Acknowledgments

The efforts of the Library and Information Services Group, the Publications Group, and all contributing members of the Laboratory's research staff made this publication possible. The efforts of all those who worked on this publication are appreciated.

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Executive Summary

In the course of forty years, Lincoln Laboratory has been a testimony to American ingenuity and daring, advancing technological inventiveness to both the military and commercial sectors. Enlisting the country's top researchers and foreseeing the scientific, economic, social, and educational impact that accelerated technology would bring, management has spearheaded the transition of Lincoln Laboratory from a national institution into a world-class laboratory.

The Massachusetts Institute of Technology's Lincoln Laboratory was established by MIT and the Air Force in 1951 at the request of the Department of Defense. Its mission to conduct research and development in advanced electronics, addressing the problems associated with national defense, vigorously continues today. The Laboratory has developed and transferred to industry important and crucial dual-use technologies in such diverse fields as electronics, computers, communications, aerospace, and medicine. It has spun off more than 60 companies employing 136,000 people and generating over $14 billion in sales; it has been granted 273 patents, 71 of which are licensed.

Technology transfer takes many forms:

- Assisting military procurement personnel in developing specifications and working with industrial contractors to ensure successful transfer of technology.
- Utilizing techniques and hardware developed at Lincoln Laboratory in the design of military systems.
- Hosting frequent technical seminars and workshops to provide a conduit for technology transfer.
- Providing briefings and demonstrations for visitors.
- Publishing classified and unclassified technical reports.
- Publishing seminal texts that have led to the development of new technical fields.
- Publishing books and monographs for general distribution.
- Publishing articles in professional journals.
- Presenting papers at professional meetings.
- Publishing the *Lincoln Laboratory Journal.*
- Patenting, copyrighting, and licensing inventions and software.
- Publishing the annual *Unclassified Publications of Lincoln Laboratory.*

Technology transfer of research and development conducted at Lincoln Laboratory is not a new concept. It has been a key part of the Laboratory's mission since its inception. In the early 1950s, Lincoln Laboratory was directed to study the feasibility of establishing a continental air defense system. This effort led to the development and implementation of many computer systems that paved the way for computer technology today. The Laboratory's researchers developed technology from which the most advanced machines of the time evolved: SAGE, the Semi-Automatic Ground Environment system, utilized the AN/FSQ-7 computer designed by Lincoln Laboratory and built by International Business Machines (IBM). Until the late 1950s, SAGE accounted for nearly half of IBM computer sales. The most notable contribution of this system was the random-access, magnetic-core storage feature, designed by Dr. Jay Forrester, which served as the standard memory device for high-speed digital computers for over two decades.

The technology used by MIT graduate Kenneth H. Olsen and former members of Lincoln Laboratory to design the TX-0 and TX-2 experimental computers was the basis for nearly all subsequent Digital Equipment Corporation (DEC) computer designs. In fact, the first computer developed by DEC, the PDP-1, was greatly influenced by the TX-0 and TX-2 computers designed and constructed by Lincoln Laboratory. Another computer developed by the Laboratory, the LINC (Laboratory Instrument Computer), was the forerunner of the personal computer of today.

The Laboratory developed many useful processing techniques for the fabrication and creation of integrated circuits for computers. X-ray lithography for microelectronic fabrication of computer integrated circuits, invented and demonstrated at Lincoln Laboratory in the early 1970s, has since become an important part of very high speed integrated circuit technology. Diamond etching techniques were developed, patented, and transferred for use by industry in the production of integrated computer circuits. The Laboratory has developed many components, techniques, and algorithms for use in computer systems for applications in diverse areas.

Throughout the 1960s and 1970s, the Laboratory made significant contributions to the development of laser technology. The coherent laser communication system developed for space applications was transferred to domestic telecommunications companies. Wideband radar imaging for satellite identification and status monitoring continues to be used for space surveillance. Semiconductor lasers, carbon dioxide lasers, titanium aluminum oxide lasers, and diode lasers have also been developed by the Laboratory.

In the 1970s the Laboratory designed, constructed, and evaluated residential photovoltaic systems in collaboration with the Solar Energy Research Institute. Residential photovoltaic systems are currently operating in New Mexico, Hawaii, Utah, and Massachusetts.

Over the years, Lincoln Laboratory's expertise and research have been utilized to solve civilian problems or to meet civilian needs. For the last twenty years the Laboratory has been instrumental in solving issues and problems associated with hazardous weather for the Federal Aviation Administration (FAA). The Laboratory's research and development in a moving target indicator radar has many applications, notably in aircraft identification and detection to ensure flight path safety.

Perceiving the nation's future in light of global requirements, and foreseeing that our economic and military securities will depend on technology-driven research, Lincoln Laboratory continues to support high-risk technologies of both defense and commercial value. Research and development in the areas of air traffic control, communications, computer hardware and software, laser technology, medical technology, optics, radar, signal processing, and solid state, which are illustrated in this edition of *Technology Transfer*, demonstrate the Laboratory's endeavors in transferring federally sponsored technologies to the civilian sector.

In air traffic control, for instance, recent Laboratory-conducted tests on the Terminal Doppler Weather Radar (TDWR) system have provided air traffic controllers direct information on aviation weather data at the airport complex. The TDWR is currently installed at two of the forty-seven planned sites nationwide. Additionally, the new Precision Runway Monitor (PRM) system will improve aircraft identification and control by providing more complete aircraft identification data to the air traffic controller.

In communications, a low-cost video telephone for general residential telephone networks has been developed. This technology, which is currently being developed by the Department of Defense in its Secure Voice System, will now be economically feasible to the private sector.

In medical technology, a method to recognize normal or abnormal cells from human cervical Pap smears has been developed. This technology was originally developed to identify military vehicles against natural backgrounds. Now, neural network technology applications have been successfully used in work done in collaboration with pathologists at the Lahey Clinic Medical Center under the Laboratory's Innovative Research Program. These applications are currently under licensing and marketing negotiations with several companies.

In optics research, the binary optics concept has been developed and transferred to the private sector for many applications. For example, diffractive/refractive binary lenses were developed for use by the medical profession to provide bifocal capability in one contact lens. And over the past ten years, the Laboratory has been developing adaptive-optics technology to reduce turbulence-induced distortion in ground-based laser weapon systems. This development can be applied to every astronomical telescope in the world to restore full resolving power.

To the extent that we continue to invigorate civilian industry by transferring new technologies to the commercial sector, Lincoln Laboratory will continue to carry out its mission of "research and development pertinent to national defense with particular emphasis on advanced electronics." As responsible agents of change in a competitively global society, Lincoln Laboratory continues to apply its technical knowledge to solve the nation's problems.

Note — Information used in this section was derived from the following publications:

Bell, C. Gordon, et al. **Computer Engineering: A DEC View of Hardware Systems Design**. Digital Press, 1978.

Bibliography of Patents and Licenses 1951-1990, Third Edition. MIT Lincoln Laboratory, 1991.

Spin-Off Companies from MIT Lincoln Laboratory, Fourth Edition. MIT Lincoln Laboratory, 1991.

Technology Transfer. MIT Lincoln Laboratory, 1990.

Watson, T.J. (Jr.) **Father, Son, & Co**. Bantam Books, 1990.

Air Traffic Control

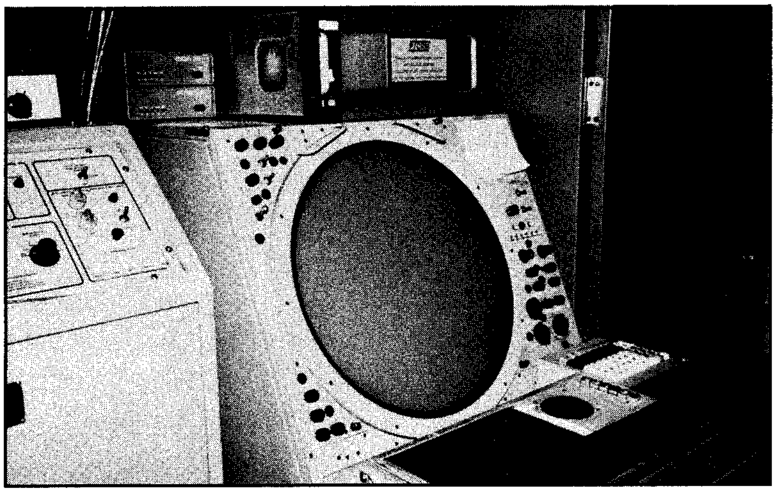
The PRM ARTS Interface

Aircraft arrival rates at closely spaced, parallel runways are significantly affected by periods of reduced visibility. To improve this situation, the Federal Aviation Administration (FAA) has funded Lincoln Laboratory to develop and evaluate new Precision Runway Monitor (PRM) sensors.

An important part of the PRM program is the evaluation of new display formats and automatic blunder detection algorithms for use by air traffic controllers. Aircraft being monitored and controlled are identified by a "tag," which consists of specific information as to the aircraft type, flight number, and runway assignment. This information is contained in the FAA's Automated Radar Terminal System (ARTS) IIIA computer. In order to create a complete aircraft tag in the air traffic controller's display, an interface had to be developed between PRM and ARTS IIIA.

Laboratory researchers Kenneth W. Saunders and Michael J. Hoffman have developed the necessary interface through a combination of hardware and software. The ARTS Interface passively accesses aircraft tag information from the ARTS and combines it with beacon codes from the PRM radar to create a database of aircraft tags that can be queried and displayed by the air traffic controller.

Software licensing agreements have been sent to MSI Services Incorporated and Norden Systems Incorporated. MSI has in turn contracted American Systems Corporation to build copies of the required interface and simulator boxes. Lincoln Laboratory has assisted the transfer of this technology by consulting with both MSI and American Systems. The interface has been tested and evaluated at the Raleigh-Durham Airport in North Carolina and is scheduled to become operational FAA equipment.



ARTS interface placed on the maintenance Data Entry and Display System (DEDS).

Weather Map Compression for Ground to Air Data Links

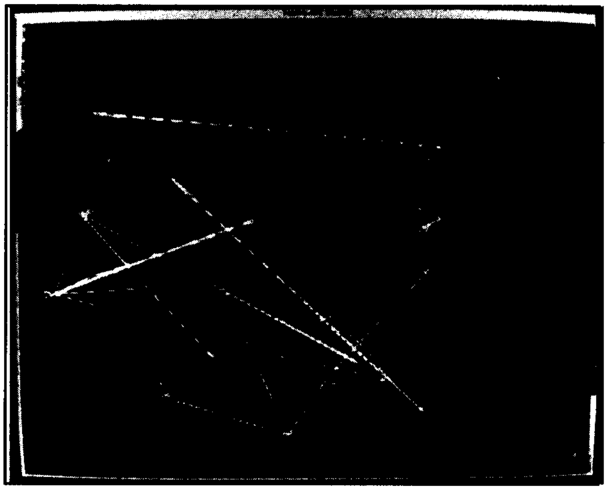
An accurate picture of weather conditions is of crucial importance to a pilot. It would be highly beneficial if the pilot were to have immediate access to the precise weather imagery generated by ground-based radar systems. Even pilots of aircraft with onboard weather radars could benefit by having access to weather images in regions of interest beyond their radar's range. Conveying this data to an aircraft has always been a problem because of the large number of data bits that must be transmitted to exactly specify a weather image.

Jeffrey L. Gertz and Robert D. Grappel of Lincoln Laboratory have developed two compression algorithms for reducing the number of bits required to represent the seven National Weather Service weather levels so that the maps can be transmitted to pilots over bit-limited data links. Both methods gracefully degrade the fidelity of the maps until a prespecified bit limitation is reached. This technology makes possible for the first time the onboard graphical display of weather transmitted from ground computers.

This research was developed under the Weather Map Data Compression program, sponsored by the Federal Aviation Administration (FAA). Software programs for encoding and decoding have been produced.

Traffic Conflict Resolution Based on Self-Organizing Behavior

In modern air traffic control systems, aircraft travel cross-country by navigating from one radio beacon to the next. Air traffic controllers manage this traffic and resolve conflicts by an established set of guidelines. However, technological advances in airborne navigation equipment and techniques enable modern aircraft to fly arbitrary routes that may be more direct, more fuel efficient, and more timely. Unfortunately, techniques do not exist to support air traffic controllers in the management of such a flexible system.


Tracon ATC display.

Lincoln's Martin S. Eby has developed a self-organizing model of air traffic control in which aircraft positions, velocities, and destinations may be processed to provide advance route planning and conflict resolution. Pertinent information is provided to the air traffic controller to use in directing aircraft; ultimately, the routes could be provided directly to the aircraft with controller oversight.

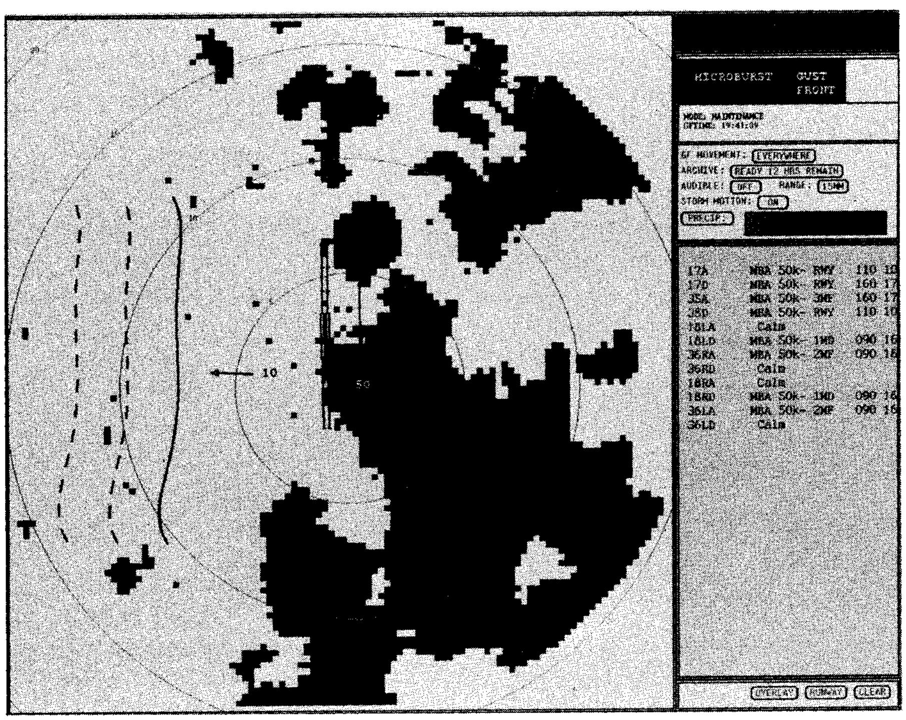
Briefings on this recently completed work have been made to the Federal Aviation Administration and others. It has the potential to greatly increase the capacity and efficiency of the air traffic control system and possible application to all phases of air traffic control from terminal control to en-route operations.

Low-Altitude Wind Shear Detection Using Airport Surveillance Radar

Wind shear is a sudden, unpredictable change in wind direction. During a thunderstorm, intense downdrafts are created that deflect from the ground to produce a brief but strong horizontal wind shear called a microburst. A less intense form of wind shear is generated by the outflow of air from such a storm; called a gust front, the leading edge propagates away from the generating precipitation. Due to their low altitude and unpredictability, microbursts and gust fronts pose significant safety hazards for aircraft during takeoffs and landings.

The Airport Surveillance Radar-9 (ASR-9) system is the Federal Aviation Administration's (FAA) primary radar for the detection and tracking of approaching and departing aircraft. A Lincoln Laboratory team led by Mark E. Weber has developed a "Wind Shear Processor" upgrade to the ASR-9 that can detect microburst generated low-altitude wind shear and gust fronts with a high degree of confidence. This improved weather surveillance capability could be used at airports with low traffic volume or infrequent thunderstorm activity and to enhance the effectiveness of existing systems.

Sponsored by the FAA, this upgrade is being evaluated for retrofitting current ASR-9 radars and is likely to be a built-in capability in the next generation ASR-10s.



ASR-9 Wind shear processor operational test, Orlando, Florida; ATC Supervisor Display.

Communications

A Video Telephone for the General Residential Telephone Network

The picture telephone has long been a common element of science fiction. The combination of picture and sound has been widely understood as the future means of person-to-person communications. In fact, this technology has been available for quite some time, as demonstrated by the increasing popularity of videoconferencing.

One of the impediments to its wider applications, however, has been the cost of both the equipment and the necessary upgrade to existing telephone circuitry. Lincoln Laboratory researchers Robert L. Harvey, Pat R. Hirschler-Marchand, and David J. Cipolle have developed a low-cost system that can be used with existing residential telephone lines. The technology is capable of simultaneous, real-time transmission of black-and-white, low-resolution images. Both high-resolution and color are possible with an enhanced version of this technology for compatible channels.

This videophone technology has been licensed to Coastal Partners Incorporated (CPI); CPI has sublicensed the video technology to Comtech Laboratories Incorporated for the secure video market. Negotiations are also currently underway by CPI with several other companies to manufacture videophones for the commercial market. This technology also is being developed for use by the Department of Defense in its Secure Voice System.

Machine Intelligent Technical Control

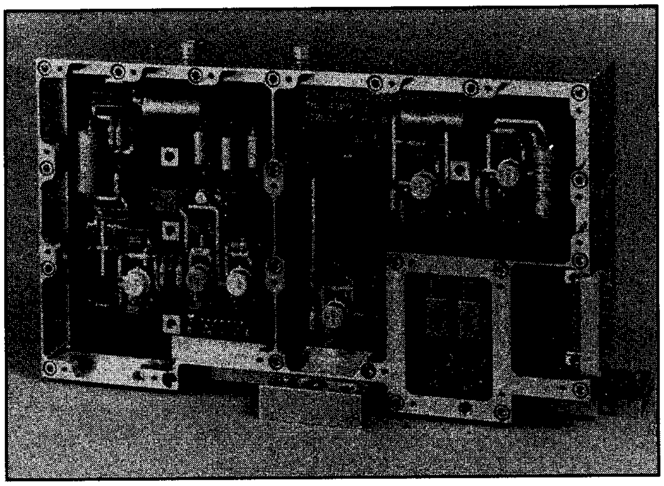
The Department of Defense uses a variety of national and international communications circuits called "long-haul" systems. These systems typically have more stringent performance requirements than normal circuits while handling higher traffic and message densities. Maintaining this circuitry are the Tech Controllers – military communications technicians who perform management, fault isolation, and service restoral tasks.

Harold M. Heggestad, James W. Forgie, Alicia Stevenson Steele, and William Kantrowitz of Lincoln Laboratory have generated a software package called Machine Intelligent Technical Control (MITEC) that encapsulates the skills and knowledge of these Tech Controllers. MITEC automatically performs much of the more routine work of Tech Controllers, boosting their productivity and freeing them to concentrate on the really difficult problems that require human intervention.

This work was sponsored by the Air Force's Rome Air Development Center (RADC) under its Knowledge-Based Systems Analysis and Control program. The Air Force Communications Software Center at Tinker Air Force Base in Oklahoma is collaborating in the software re-implementation of MITEC and will be responsible for its maintenance after its incorporation into the operational Air Force inventory.

Diode-Laser Diagnostics Module for Heterodyne Optical Communications

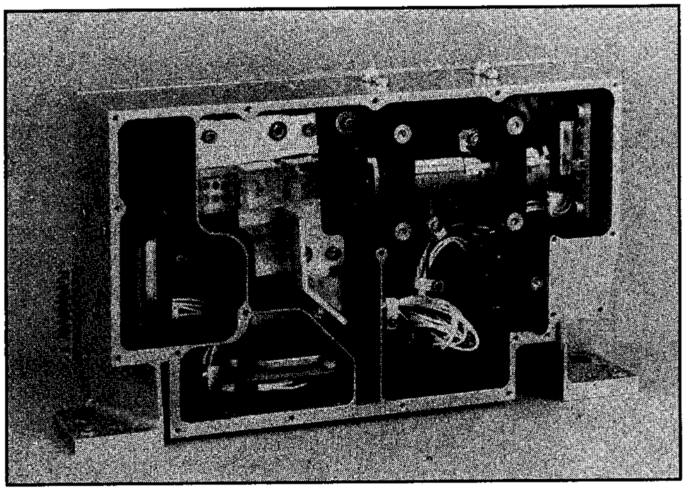
The arrival of space-based diode-laser communications systems has necessitated a space-qualified laser diagnostics module to monitor and adjust the system's operations during its orbital lifetime.



Electronics side of the diagnostics module, shown without cover.

A Laboratory team consisting of Vijay Jayaraman, Emily S. Kintzer, Dominique P. Verly, James G. Garcia, Allen D. Pillsbury, and David F. McDonough developed a computer controlled diagnostics module that provides precise and autonomous setting of the transmitter power, wavelength, and modulation characteristics. The final package weighs only 2.8 pounds, consumes just 1.1 watts of electrical power, and has been space-qualified. This module is essential to the realization of the first flightworthy laser transmitter for high data rate optical communications in space.

Sponsored by the Air Force under the Laser Intersatellite Transmission Experiment (LITE) program, a space-qualified engineering model of the diagnostics module has been produced.



(Left) Optics side of the diagnostics module. The optics cavity cover is not shown.

Sinusoidal Transform System

Modeling speech as a sum of sine-waves with time-varying amplitudes, frequencies, and phases yields a synthetic waveform that preserves the general waveform shape and is essentially indistinguishable from the original speech input. Laboratory researchers Robert J. McAulay and Thomas F. Quatieri have developed the Sinusoidal Transform System (STS), which performs this modeling so accurately that, even in the presence of noise, the characteristics of the speech input are maintained. In fact, high quality reproduction can be maintained with overlapping speech waveforms, music waveforms, speech with musical backgrounds, and certain marine biological sounds.

Sponsored by the Air Force under the Digital Voice Processing program, this development has led to a high-performance voice coder, called the Sinusoidal Transform Coder (STC), that is applicable to secure voice systems at rates of 2400 to 4800 baud per second; this coder has drawn significant interest from other governmental agencies as well as industry. Further work has continued to improve the quality of the synthetic speech and to enable the coder to operate at lower data rates.

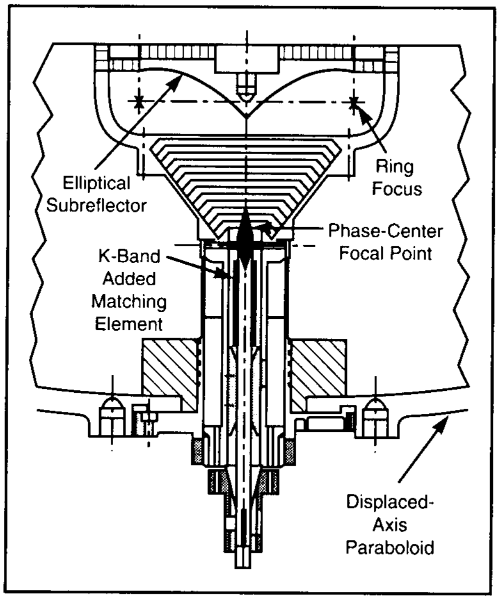
In 1989, a commercial secure voice terminal product was created with the STC algorithm. Lincoln Laboratory has licensed this technology to Cylink Corporation, Aware Incorporated, and Comtech Systems Incorporated. In a cooperative arrangement with Aware, the Laboratory provided training and commercially sponsored research and development to convert software simulation to real-time hardware.

Dual-Band Ring-Focus Feed

Theoretical analysis has been practically applied to only the most elementary antenna feeds. Much more challenging are compact, high-performance, dual-band antenna feeds; such devices require consideration of both dielectric and conducting material boundary conditions and multifrequency band operation. Designing such a feed requires both experience and expertise in electronic circuits, electromagnetics, and antennas.

Lincoln researcher Joseph C. Lee has designed and developed a high performance, circular polarized, compact, dual-band feed with ring focusing that has a higher efficiency than a conventional Cassegrain antenna. The two frequency bands are centered at 44.5 and 20.7 GHz but can be scaled to other frequencies. Such a feed can be applied to lightweight, high efficiency, small aperture antennas for satellite and ground terminal applications.

This technology has been used in the antennas for the Advanced Single Channel Antijam Man Portable (ASCAMP) system and the Military Strategic and Tactical Relay (Milstar) program.



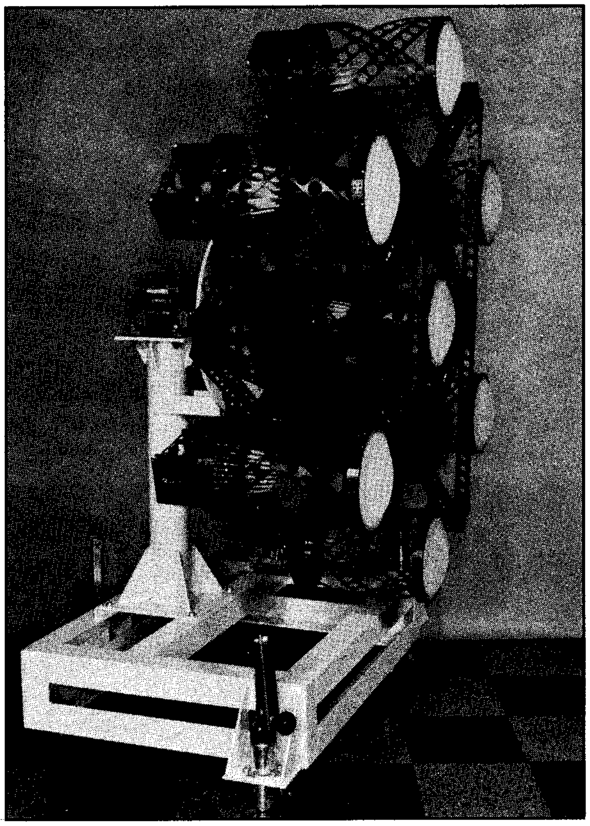
ADE (displaced-axis elliptical) design of the Advanced SCAMP antenna.

Multiple Aperture Multiple Beam Antenna

An exceptionally lightweight, extremely high frequency, multiple beam antenna for simultaneous narrow-beam coverage to two or more arbitrarily located communications systems users has been developed by the Lincoln team of Bing M. Potts, William C. Cummings, Dean P. Kolba, Alan J. Fenn, Frank A. Folino, Joseph C. Lee, Andre R. Dion, and Lawrence W. Rispin. The antenna is designed to provide high resolution nulls on interference sources located as close as 0.1 degree to communicating users. The design embodies both a unique combination of multiple beam and thinned phased array antenna concepts and a monolithic beam switching network concept based on high strength, thin walled electroformed waveguide and ferrite isolator switches.

This work, performed under the Satellite Communications Technology program and sponsored by the Air Force Space Systems Division, is intended for use in connection with a Defense Advanced Research Projects Agency (DARPA) lightweight communications satellite technology demonstration. Lincoln designed and fabricated a brassboard model of the planned configuration using seven apertures to produce 127 beams covering the visible earth as seen from geosynchronous orbit.

Electromagnetic Science Corporation has licensed this technology. They developed the lightweight beam switch network under contract to Lincoln in close cooperation with Lincoln researchers. Electromagnetic Science plans to apply this technology to a number of space communications antennas.



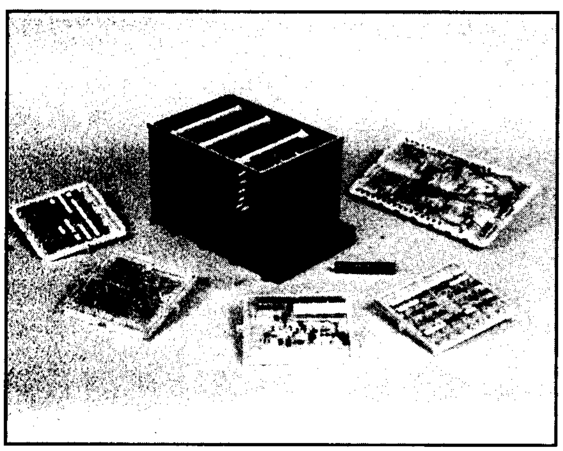
Agile adaptive antenna.

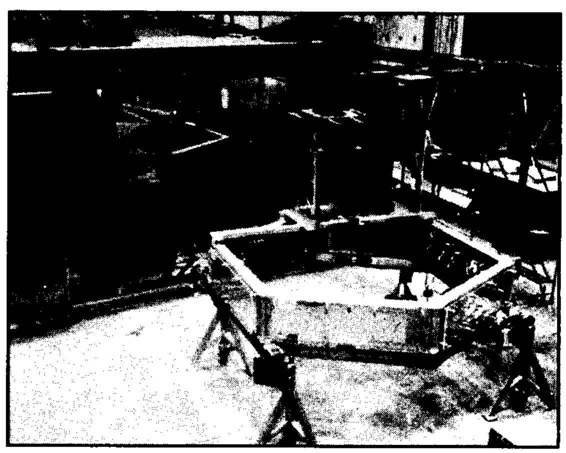
Satellite Based Access/Resource Controller

A vision for the future has been the image of many small and widely dispersed persons and groups able to effectively communicate with each other in real time. Such linkages can be powerfully applied in the military where a tremendous advantage can be gained from a communications network that effectively connects – in real time – diverse, mobile entities, such as ships, aircraft, submarines, tanks, even individual soldiers.

Although satellite-based communications systems offer such connectivity, they are challenged by the requirement to accurately serve many widely dispersed users at the same time. A further limitation of concern to the military is the vulnerability of these systems to jamming. Lincoln researchers Marilyn D. Semprucci, Joseph V. MacPhee, Harriet Garfinkel, Wendy McNaughton, and Ethan Bradford have developed and demonstrated a satellite-based access controller that can, within seconds, dynamically allocate and reconfigure extremely high frequency communications resources in response to requests from user terminals. This "switchboard-in-the-sky" can provide a responsive, efficient means of allocating communications resources for a wide range of user needs and can autonomously preempt these resources, when required, to provide service to higher priority users.

Developed for use as the access controller on the Fleet Satellite Communications System EHF (Extremely High Frequency) Package (commonly referred to as the FLTSATCOM EHF Package or FEP) sponsored by the Navy (through the Milstar Joint Program Office), this technology is also being used by the Air Force in the Milstar Satellite Program and by the Navy in its EHF packages on the UHF (Ultra-High Frequency) Follow-On Communications Satellites. The concept and protocols implemented in the access controller are being utilized by Lockheed, TRW, and Hughes in the development of space hardware and by Raytheon and Magnavox in the development of ground terminals for the Navy's EHF Satellite Program (NESP) and for the Air Force and the Army.

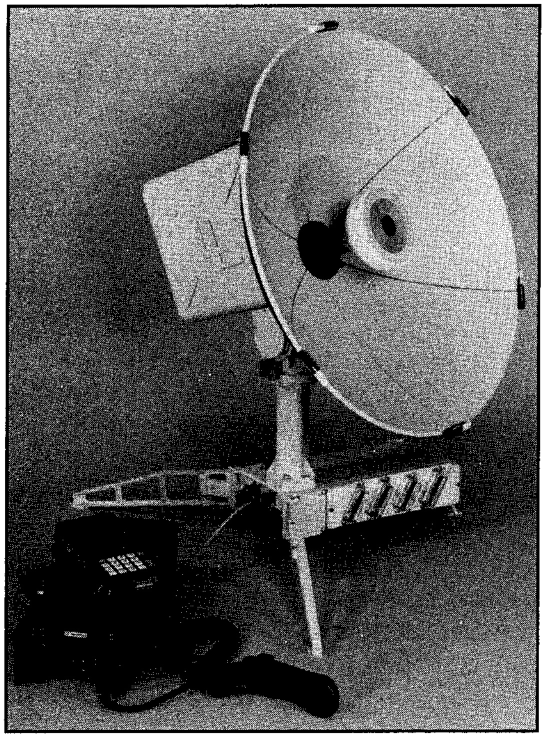




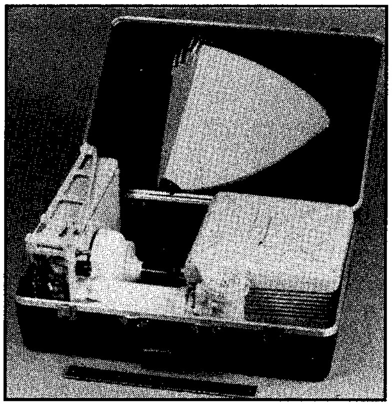
Implementation of FEP. The device includes seven boards, weighs 6 lbs, and draws 6 W. It includes a real-time emulator, real-time Pascal, and 64K of memory.

Single Channel Antijam Milstar Portable Terminal

As an outgrowth of their work on the Army's SCOTT (Single Channel Objective Tactical Terminal) program, a Lincoln research and development team developed the first man-portable, Milstar (Military Strategic and Tactical Relay)-compatible, extremely high frequency satellite communications terminal. The team consisted of Ronald F. Bauer, Clement B. Edgar, Robert J. Figucia, George Gorski-Popiel, Lawrence J. Kushner, Arthur H. Levasseur, John F. Siemasko, Chester E. Small, David M. Snider, Harry M. Wolfson, Joseph C. Lee, and Frank A. Folino. Called SCAMP (Single Channel Antijam Milstar Portable Terminal), the terminal demonstrated how to reduce size, weight, and power by almost two orders-of-magnitude by creating new techniques for radio frequency signal generation, extremely high frequency power amplification, antenna pointing, and novel very large scale integrated (VLSI) baseband processing architectures.



Developed under sponsorship from the Army, the Laboratory completed two working terminals and performed field demonstrations on the utility of the new technology for the government and military services. As a result, all the military services referred to SCAMP as the technical basis and credibility for their specific satellite communications programs including the Air Force's Low Volume Terminal (LVT), the Army's Single Channel Terminal (SCT), and the Man-Portable Milstar Terminal (MMT) used by the Army, Navy, Air Force, and Special Forces.



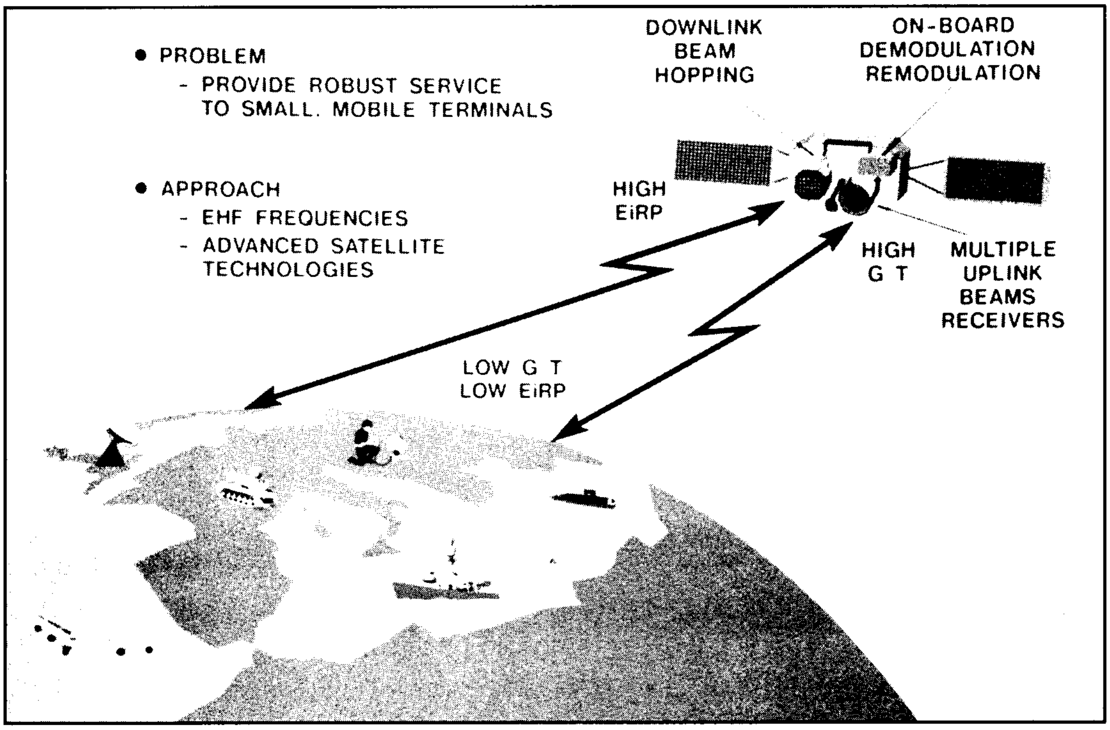
Advanced SCAMP.

In the commercial sector, Lincoln has collaborated with industry to demonstrate the commercial producibility of such components as the antenna and antenna positioner, radio frequency generator (the design of which has been licensed to Stanford Telecommunications), as well as the transmitter and receiver. Through Technical Interchange Meetings held at the Laboratory, our ideas, techniques, and implementations have been copied or formed the starting point for modified designs for the following companies: Harris, GTE, TRW, Raytheon, Magnavox, Lockheed, Hughes, Avantek, E-Systems, General Electric, Rockwell, Bell-Aerospace Textron, and MPC Corporation. To ensure the producibility of the designs, the Laboratory has cooperative agreements with several of these companies to provide funding, technical assistance, consulting, direction, and specific problem solving.

System Concepts for Antijam Communications to Small, Mobile Terminals

A necessary capability of small, mobile, and portable satellite communications terminals is their resistance to intentional interference or jamming; such a capability is of obvious importance in military applications. Lincoln Laboratory's David R. McElroy, William C. Cummings, Marilyn D. Semprucci, Russell R. Rhodes, William L. Greenberg, Dean P. Kolba, Roger C. King, and others have developed the system concepts for providing antijam communications to small, mobile, extremely high frequency terminals. The concepts include the use of advanced antennas, spread-spectrum techniques, and on-board signal processing and control to provide robust communications to these small terminals.

This capability was successfully demonstrated on-orbit by the two FLTSATCOM EHF (Fleet Satellite Communications System - Extremely High Frequency) packages as part of the Milstar Joint Program and sponsored by the Navy. Other Navy applications include the Navy EHF Satellite Program and EHF packages on the UHF (Ultra High Frequency) Follow-On Communications Satellites. The Army's applications include both the SCOTT (Single Channel Objective Tactical Terminal) program, for the development of a transportable terminal, and the SCAMP (Single Channel Antijam Milstar Portable Terminal) program, for the development of a man-portable terminal. In the private sector, Lockheed, TRW, Hughes, Raytheon, and Magnavox are applying these concepts in their development of communications hardware.



Antijam satellite communications.

Computer Hardware

Autosplit - A System for Automatic Bypassing of Defective Subrings Within a Token Passing Network

A token passing ring is a method of interconnecting computer systems. The machines or nodes are connected in series, with the output of one machine feeding the input to the next, creating a network in the form of a unidirectional communications ring. Any node in this ring may originate a message that is then passed from one node to the next until it arrives at its destination node. Normally, if the ring is broken, it goes down and the machines on the ring can no longer communicate with each other. When this happens, the system operator must identify the faulty subring and switch it off the main network. It takes time to recognize that the network is down, locate the malfunctioning subring, and flip the appropriate switch. Since it is not uncommon for jobs to be run overnight or, in some cases, for several days, a communication interruption that causes a job to abort can be very disruptive.

Lincoln researcher A. Gregory Rocco has invented and developed a device he calls "Autosplit," which is designed to automatically recognize a network failure and switch out the faulty subring. This is generally done fast enough to prevent a major disruption in ongoing work, except, of course, for the nodes on the malfunctioning subring.

Developed under the Radar Techniques - Unmanned Aerial Vehicle (UAV) Signal Processor program, the device is currently being used effectively on one of the Laboratory's networks. A patent is pending for this technology, which has wide potential use for protecting local area networks.

Computer Software

LNKnet: Neural Network and Conventional Pattern Classification Software

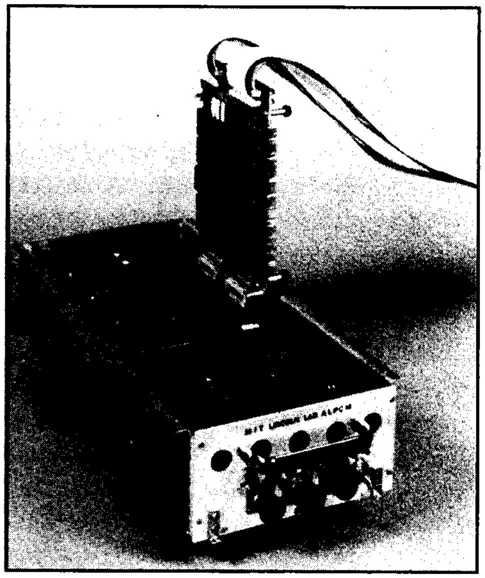
In recent years the promise of neural networks as an improved model for computer processing has generated much excitement. The idea is to design a computer's hardware and pattern its software to resemble the structure and thought processes of biological models (i.e., the brain and nervous system). The benefits are improved processing capabilities, increased efficiency, and the ability to *learn* from the task at hand.

The Laboratory's Linda C. Kukolich and Richard P. Lippmann have devised a software package called LNKnet, which contains thirteen important neural network, statistical, and machine-learning pattern classification algorithms. These algorithms share common input data handling and report generating routines. They can be accessed from shell scripts or from subroutine calls in an application program, using a window-based, mouse-driven interface under Sun's Openlook Window System.

The Air Force's Rome Air Development Center (RADC) and the Federal Bureau of Investigation have sponsored this work under the Neural Network Software Development program. Potential uses include process control, fault analysis, speech recognition, fingerprint classification, optical character recognition, and other pattern classification tasks.

High-Performance 2400 Baud Per Second Voice Coding Algorithm

Aircraft voice communications are essential for the coordination and control necessary to a successful mission. Reliable and coherent voice communications are especially challenged by the combat environment. The military prefers narrowband speech transmission in these environments because it is more secure and resistant to jamming. However, the signal processing involved to encode the analog voice signal into the digitized data stream is susceptible to audio distortion present in the intercom system and noise from the power source, as well as various forms of acoustic noise in the environments of both the talker and the listener.



Flexible speech processor.

Lincoln Laboratory's Elliot Singer, Edward M. Hofstetter, and Joseph Tierney have developed a high-performance voice coding and transmission algorithm that produces speech with higher intelligibility in noisy aircraft environments. The algorithm is based on the linear predictive coding of speech producing a 2400 baud per second data stream.

The Air Force sponsored this work under its Joint Tactical Information Distribution System (JTIDS) program. The high-performance algorithm was coded and ran in a special purpose speech coding hardware called the Advanced Linear Predictive Coding Microprocessor (ALPCM). Twelve of these units were built at Lincoln Laboratory for use in air trials held at Eglin Air Force Base in Florida.

In the commercial sector, GEC and Kearfott have used the algorithm in a follow-on voice-coder board for airborne use in the JTIDS system. The software and algorithm have also been licensed to the Defense Communications Division of ITT.

Data Link Applications Coding

The most efficient and effective means of transmission when using limited-bandwidth channels is to compress the transmitted data. Lincoln researchers Robert D. Grappel and Vincent A. Orlando have developed a data compression algorithm to be used in aviation datalinks. Called Data Link Application Coding (DLAC), the algorithm provides a highly flexible coding for message transfer achieving significant compression efficiency that incorporates dictionaries of fixed words and "fill-in-the-blanks" phrases.

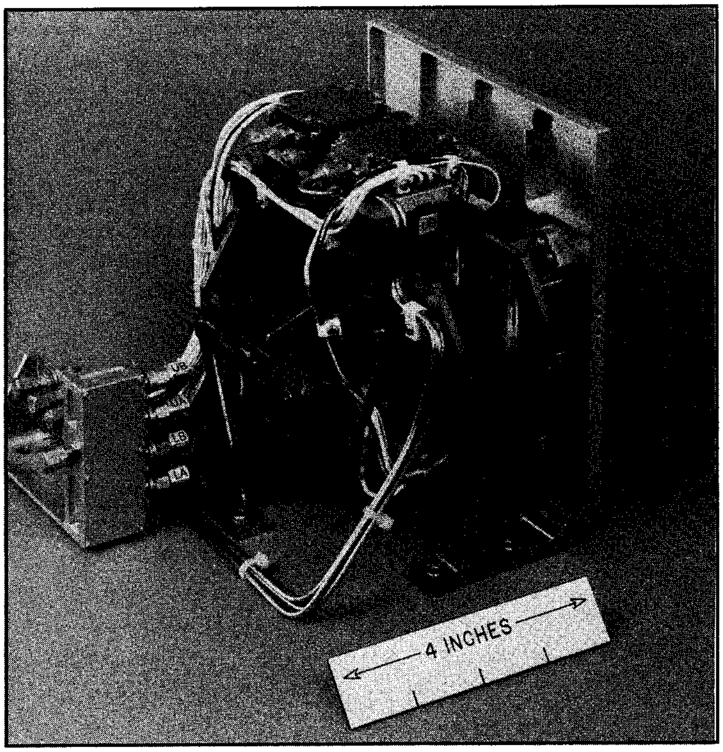
Sponsored by the Federal Aviation Administration (FAA), software and documentation for DLAC encoding and decoding have been developed as well as a draft for an international standard document. Boeing, Honeywell, ARINC Research Corporation, and MITRE are all evaluating DLAC and incorporating it into their datalink testbeds.

Laser Technology

Diode-Laser Transmitter for Satellite Optical Communications

For certain applications in space communications, optical systems offer distinct advantages over conventional radio-frequency links. An optical system can provide space communications at very high data rates with a narrow beam that is resistant to jamming and interception. Also, because such systems are relatively light and small, they are good choices for spaceborne platforms. The combination of small size and narrow beamwidth could also prove important for applications such as communications from deep space.

Developments toward a spaceborne optical communications system have been pursued for nearly three decades. Early laser systems were successful in the laboratory, but their bulk or fragility made them unacceptable for space applications. Lincoln researchers John A. Taylor and Allen D. Pillsbury have developed an optical transmitter based on a diode laser that is small, robust, and highly efficient. It is the first such transmitter to have successfully passed an extensive battery of environmental testing, including random vibration and thermal cycling.



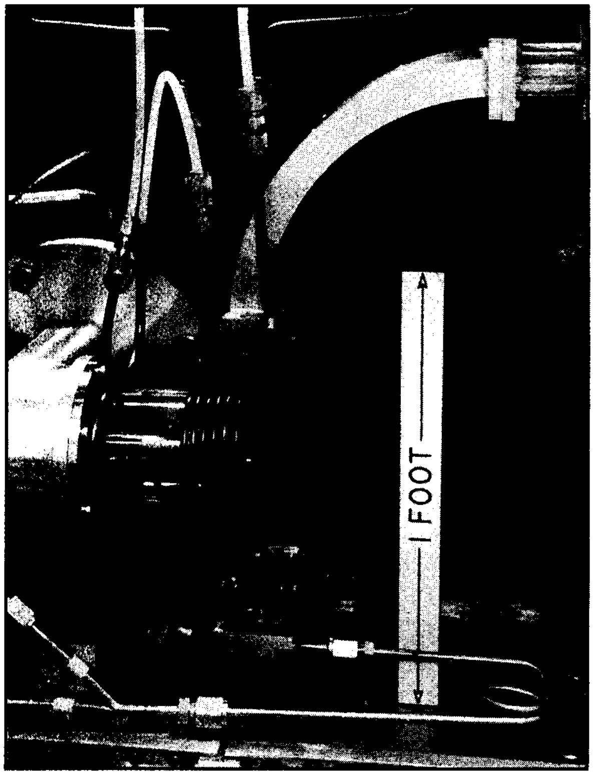
MIT-LL Lasercom transmitter.

This development was sponsored by the Air Force under the Laboratory's Laser Intersatellite Transmission Experiment (LITE) program and was scheduled to be used on NASA's Advanced Communications Technology Satellite (ACTS). Key elements of this design could be incorporated into future satellite or laboratory systems. Several companies have expressed interest in developing this technology.

Growth Tube for Organometallic Vapor Phase Epitaxy

Although much progress has been made in the crucial field of epitaxial crystal layer growth, the complex manner in which these thin films are produced presents a constant set of challenges. The Lincoln team of Steven H. Groves, Susan C. Palmateer, James W. Caunt, and David L. Hovey has made a significant contribution to these efforts by developing a tube for epitaxial growth at atmospheric pressure. Used for organometallic vapor phase epitaxy (OMVPE), the design utilizes a chimney geometry with upward flow to eliminate thermal convection cells. An attached sidearm permits susceptor rotation and fully mechanized substrate loading. The utility of the growth tube has been demonstrated for growth of gallium indium arsenide phosphide (GaInAsP) alloys on gallium arsenide (GaAs) and indium phosphide (InP) substrates.

Developed in the GaAs Lasers Fabricated with Mass-Transport Technology program sponsored by the Air Force and the Laboratory's Innovative Research Program, state-of-the-art quantum well lasers have been made from the GaAs-based structures. Besides being used in various research and development activities at the Laboratory, this technology is also being evaluated for production by a laser manufacturer.

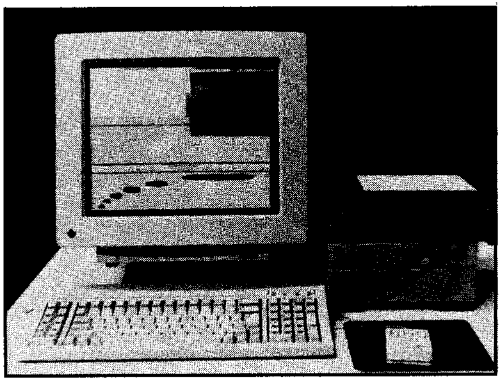


OMVPE chimney-type growth tube with attached sidearm.

Medical Technology

Cochlear Implant Signal Processor

Deafness is often caused by nerve or sensory damage in the cochlea, a snail-shaped organ in the inner ear that contains the essential organs of hearing. One corrective procedure for this problem is to surgically implant nerve exciting electrodes in the cochlea; these cochlear implants can be combined with a specially adjusted hearing aid to improve or restore hearing.



The SPARC station-based clinical instrument used at Massachusetts Eye and Ear Infirmary.

Sponsored by the Laboratory's Innovative Research Program, researchers Joseph Tierney and Marc A. Zissman have developed a programmable, workstation-based, signal processing instrument to simulate a range of special hearing aids. Working with clinicians and patients at the Massachusetts Eye and Ear Infirmary, they determined that the instrument has potential application for interactive testing and adjustment of cochlear implant hearing aids for newly implanted patients.

Based on the Sun SPARC workstation, the clinical instrument contains a digital signal processor board that converts analog speech to digital cochlear implant signals. Still to be developed is a portable aid that could be adjusted based on a program downloaded from the test instrument.

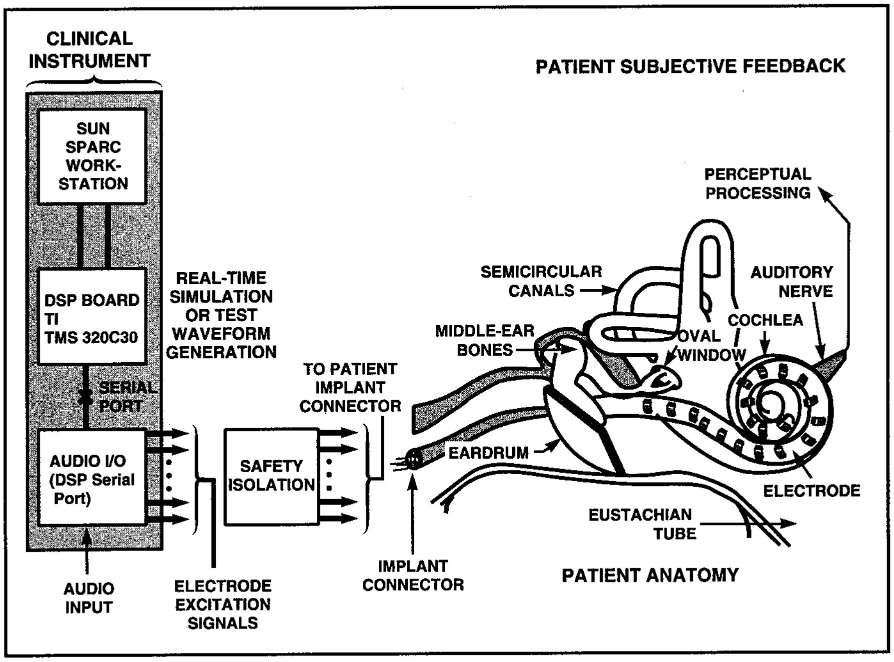
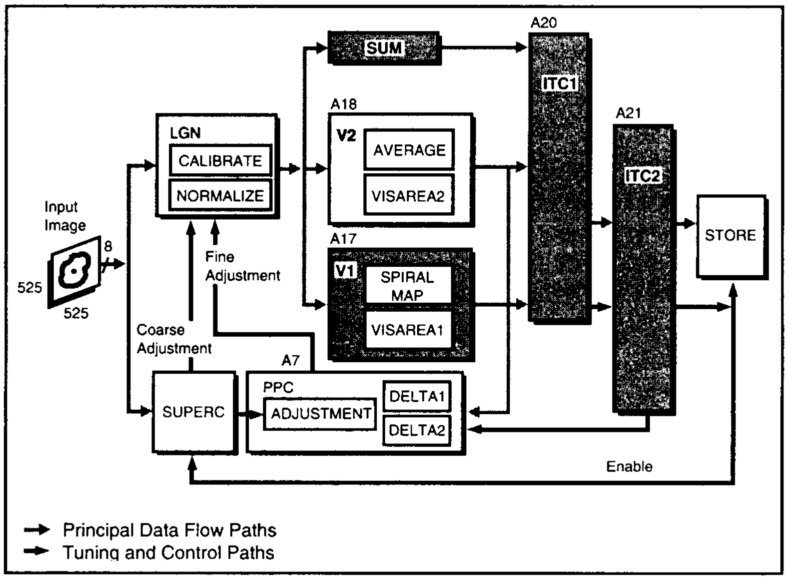


Diagram for the cochlear implant processor.

Neural Network for General Pattern Recognition

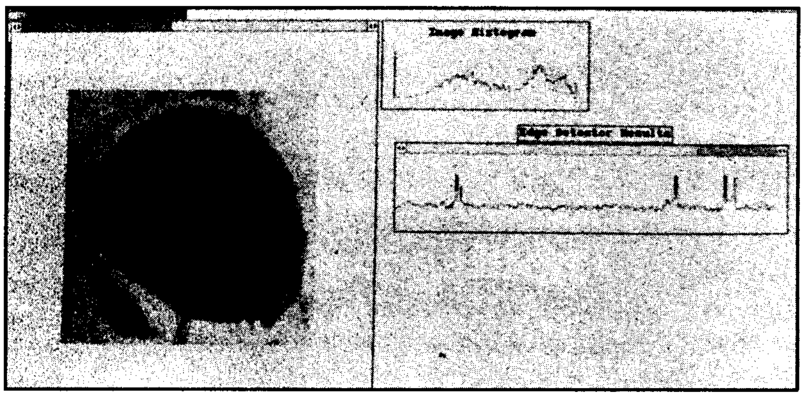
The ability of a machine to sense and identify various patterns such as figures, characters, shapes, and forms without active human intervention is important for a range of applications. Laboratory researchers Robert L. Harvey, Paul N. DiCaprio, and Karl G. Heinemann have devised a method for constructing a machine, using neural network technology, that is capable of recognizing diverse objects in natural backgrounds. The machine is able to learn from its experience and develop its own criteria for classification through the use of two interconnected channels: a location channel and a classification channel.

The resulting system has proven quite accurate in recognizing military vehicles such as tanks, howitzers, and armored personnel carriers against natural background scenes. Additionally, it is being applied to recognize images from radar, laser, infrared, and visible sensors for Lincoln sponsors.



Block diagram of the neural network architecture.

A most intriguing application has been its use in recognizing human cells. Working with pathologists from the Lahey Clinic Medical Center, our researchers collaborated in a cytology study in which the system was trained to recognize images from human cervical Pap smears. The results have been quite promising: the system has not only recognized the cells accurately, but has been able to correctly classify them as normal or abnormal (i.e., precancerous).



Sun workstation display of a Pap-smear cell, its histogram, and its feature vector.

Negotiations are underway with several companies to license and market this technology developed under the Laboratory's Innovative Research Program. A license has also been granted to Lahey for the transfer of Lincoln software and for limited technical support for developing medical applications.

Optics

Optical Square Wave Generator

There are a variety of significant and promising uses for high bandwidth optical square-wave sources in optical communications and high-speed signal processing. Because these sources are not susceptible to capacitive effects that restrict the rise time of electronic signals in a transmission line, optical signals of extremely high bandwidth can be generated and propagated.

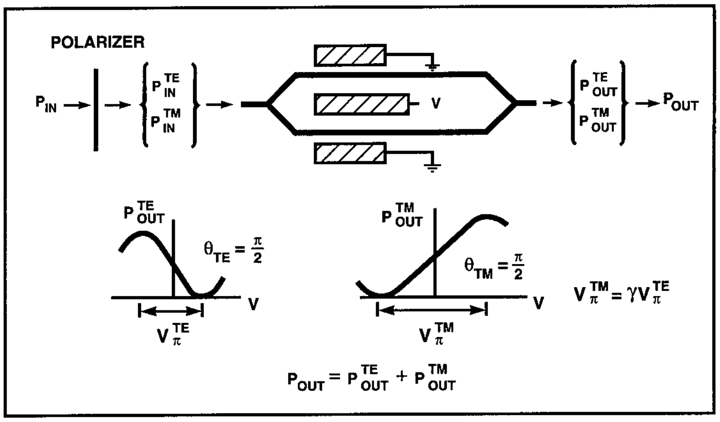
Lincoln researchers Lily Y. Pang, Emily S. Kintzer, and James G. Fujimoto have developed a new passive technique for optical square-wave generation that uses a semiconductor laser array in a folded, noncollinear external cavity. Square-wave generation takes place by a process called directional switching and produces an optical output with a fifty percent duty cycle square wave intensity modulation with fast rise time and high contrast ratio. Repetition rates as fast as 800 MHz and rise times as fast as 200 picoseconds have been demonstrated.

Sponsored by the Air Force, this research and development was conducted under the Optical Communications Technology program. By utilizing fiber optics or integrated-optical waveguides in place of a free space cavity, this technique could be developed into a compact optical oscillator.

Linearized Integrated Optical Modulator

High-linearity optical intensity modulators are required for accurately transmitting analog signals with low distortion on low-loss optical fibers. Analog optical links utilizing external integrated-optical intensity modulators and constant-power optical sources can be applied to such uses as cable television distribution and microwave signal transmission.

Lincoln Laboratory's Leonard M. Johnson has developed a technique for reducing the nonlinearities of integrated-optical modulators that involves a cancellation scheme based on operating the device in two polarization states simultaneously. Using this technique, linear optical modulation at frequencies up to tens of gigahertz can be obtained. The technique can be adapted for many different types of electro-optic modulators.

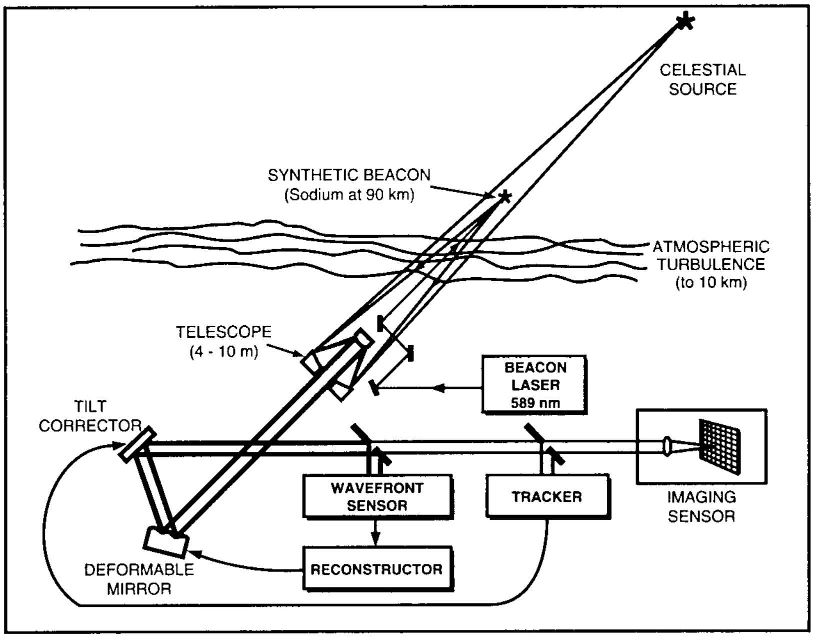


Polarization-mixing linearization technique.

Sponsored by Air Force funding, this technology has been licensed to a domestic firm engaged in fiber optic cable television systems; Lincoln's role included a technology assistance program, which involved the fabrication of prototype devices for the company's evaluation.

Adaptive Optics for Astronomy

Large ground-based telescopes (four to ten meters) have impressive light-gathering capabilities, but their resolution capability is limited to no better than that from a small backyard telescope because of atmospheric turbulence (the phenomenon that makes stars twinkle and dance). The Hubble Telescope was developed to orbit the Earth above the atmosphere and give astronomers, for the first time, clear pictures of objects in space. The Hubble's flawed optics have only increased the frustration astronomers have felt in realizing this dream.



Astonomical applications of adaptive optics with synthetic beacons.

Over the past ten years, a Lincoln Laboratory team headed by Charles A. Primmerman has been involved in classified research to develop adaptive-optics systems to correct for the effects of turbulence-induced distortion in ground-based laser weapon systems. Recently, this adaptive-optics technology has been declassified and made available to astronomers.

To compensate for turbulence using adaptive optics, we first generate a synthetic beacon (or laser guidestar) by atmospheric backscatter from a ground-based laser. Light from this beacon is used in a wavefront sensor to measure the turbulence-induced optical aberrations and a deformable mirror corrects them in real time. By this atmospheric compensation we can restore the full resolving power of the telescope.

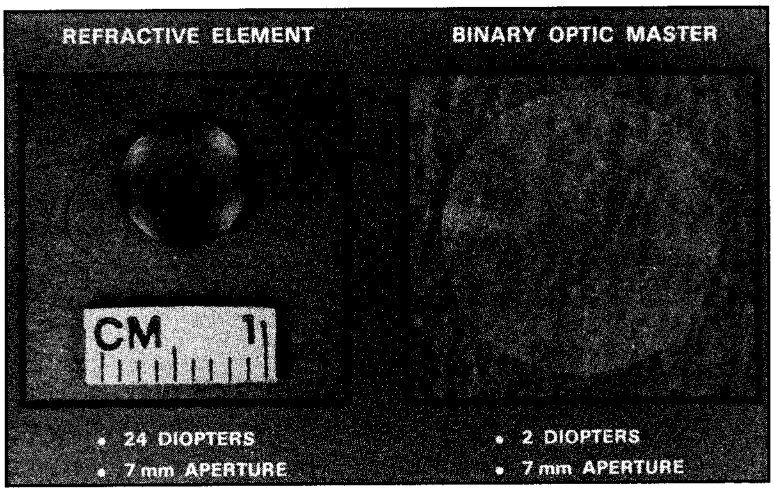
Developed with funding from the Defense Advanced Research Projects Agency (DARPA) and the Strategic Defense Initiative Organization (SDIO), this technology could be applied to every astronomical telescope in the world. The Laboratory is currently discussing with the National Science Foundation ways to speed its transfer to the ground-based astronomy community.

Refractive/Diffractive Intraocular Lens Implant

Light is diffracted when it breaks up or scatters while passing objects in its path. Refraction is the bending of light as it passes from one medium into another. Human eye lens implants are usually refractive and only correct the focus on distant objects. Combining diffraction and refraction in one lens would result in a bifocal lens capable of focusing on objects both near and far.

Laboratory researcher Gary J. Swanson has developed a nonrotationally symmetric diffractive optical structure placed on a refractive lens that provides bifocal capability. Bifocality is achieved by covering the surface of the lens with a series of stepped ridges or notches. The advantage of this design over other diffractive/refractive designs is an increase in image clarity and a reduction in false image coloration.

Developed under the Binary Optics program sponsored by the Defense Advanced Research Projects Agency (DARPA), this development would make possible a bifocal lens implant that could replace the eye's natural lens and provide corrected vision for both near and far vision. Lincoln has licensed this technology to a medical company that is providing funding for the design and fabrication of prototype molds for implantable binary lenses.



A refractive lens implant (left) will contain the diffractive structure (right) on one of its surfaces.

Radar

Radar Signal Processing for Long-Range Satellite Detection

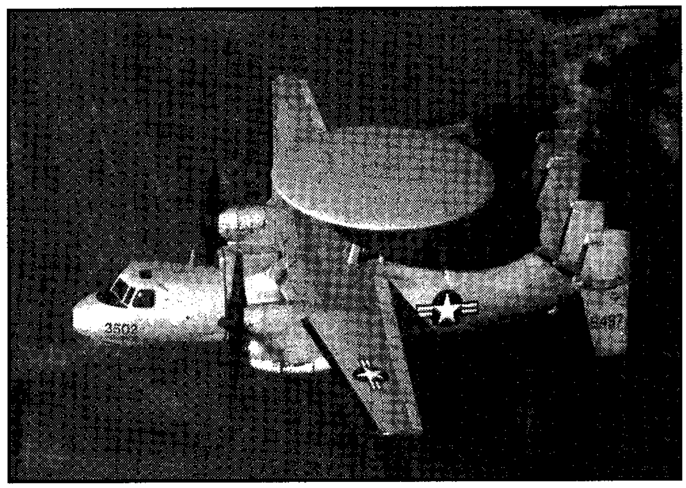
Most artificial satellites orbit the Earth at distances of several hundred miles; such objects can be easily detected and tracked by ground-based radar systems. However, another class of satellites orbits at much greater distances; these long-range satellites typically orbit the Earth at distances well over 5,000 miles. Special techniques and provisions are required to detect such distant objects.

Thomas E. Clark and Gary R. Krumpholz have addressed this problem by creating special signal processing software to detect and track long-range satellites. Working at the Laboratory's Millstone Radar Site in Westford, Massachusetts, they have developed and tested an effective method for the multiple pulse coherent and non-coherent integration of returns from conventional pulsed radar. In order to achieve optimal processing of the satellite's back-scattered signal, their technique includes the effects of polarization as well as the dynamics of the satellite.

The product was developed and tested by Lincoln Laboratory with funding from the Air Force Space Command's Satellite Tracking Program. Under Laboratory supervision, the prototype software has been transferred to the Space Command's Twentieth Surveillance Squadron for use on their FPS-85 radar located at Eglin Air Force Base.

Time Averaged Clutter Coherent Airborne Radar

The Navy has used the Grumman E-2C aircraft extensively for several decades to support carrier operations by providing surveillance and warning as well as assistance in command and control. It is currently being used to safeguard naval forces, defend the borders of our allies, and assist in drug interdiction. The E-2C is able to accomplish these missions due to its long-range, high-power radar.


Grumman E-2C Hawkeye early warning and control aircraft.

Because such aircraft-mounted radars provide high altitude platforms, very long line-of-sight ranges can be achieved. The problem is that this increased range results in a critical level of unwanted radar returns or clutter. Efforts to reject this clutter are complicated by the fact that the platform itself is moving.

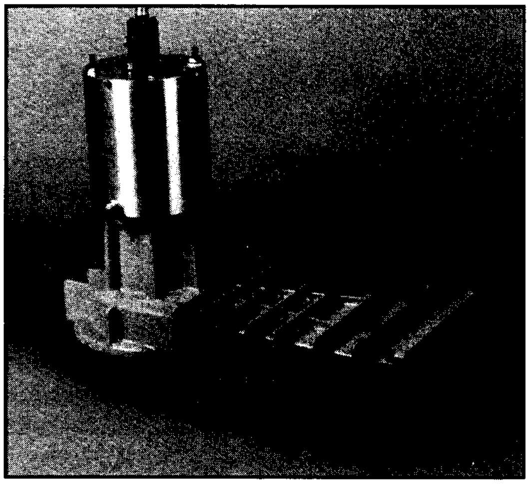
Some time ago, Lincoln Laboratory's Melvin Labitt was instrumental in solving this formidable problem. Under the sponsorship of the Navy, he developed a technique that became known as Time Averaged Clutter Coherent Airborne Radar (TACCAR), which compensates for platform motion along the beam axis in a coherent radar. This technique was incorporated into the APS-111, the forerunner of the current APS-120 series of radars. An evolved version of TACCAR has been used in the Joint Surveillance Target Attack Radar System (JSTARS), which was used in Desert Storm to detect both fixed and mobile targets.

In 1991, Melvin was awarded the prestigious Pioneer Award by the Institute of Electrical and Electronics Engineers (IEEE) for "his contributions to improved airborne moving target radar systems."

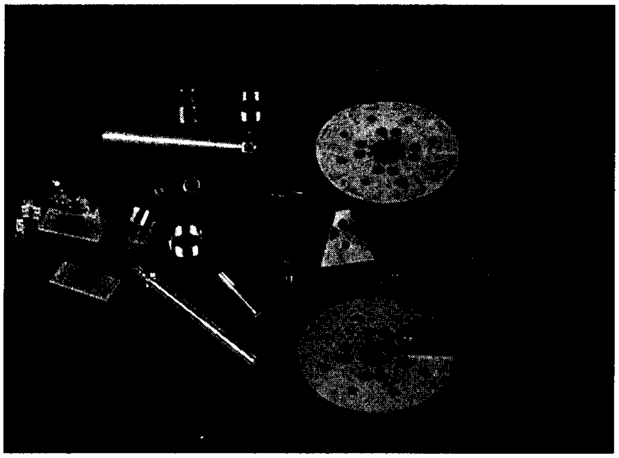
Extremely High Average Power Radar Duplexers Using Pin Diodes

Since the early 1960s, Lincoln Laboratory has had a major involvement with the PRESS (Pacific Range Electromagnetic Signature Studies) Project. Based on Kwajalein Atoll in the South Pacific, the PRESS mission is to analyze and track reentry vehicles. As the Scientific Director for PRESS, Lincoln has developed several major sensor and data processing systems for it.

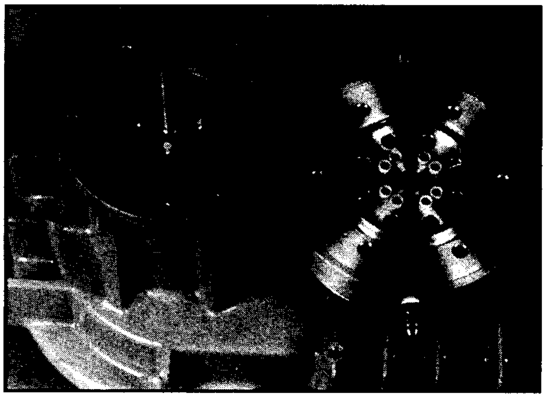
One of the earliest of these systems is the TRADEX (Target Resolution and Discrimination Experiment) radar. First used in 1962, TRADEX is still a vital part of our reentry vehicle sensing proficiency. Recently, Laboratory researcher Guy Huse continued to improve the TRADEX L-band radar using pin diodes to double its average power to 300 kilowatts while upgrading it to a long pulse (565 microseconds) capability. Guy was able to do this through innovative connection, cooling, and microwave circuit elements concepts.



(Above) Complete assembly including pressurization cover.

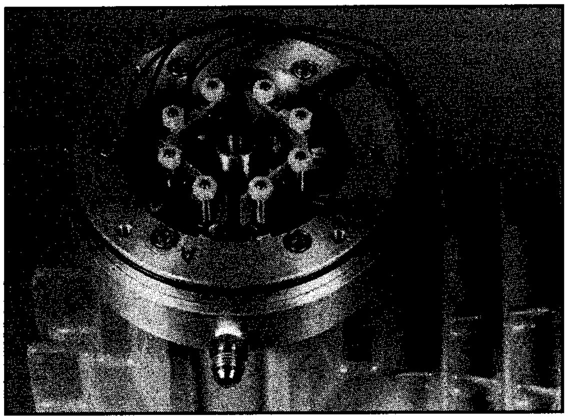


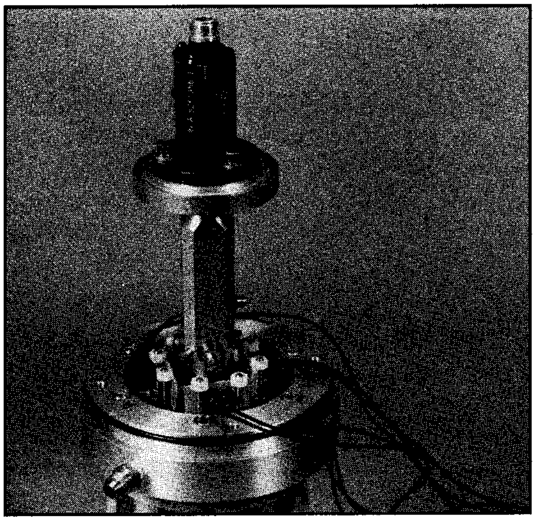
Piece parts including bypass plates, dielectric, contacts, inductors, and output center conductor.



First stage interior showing diodes, inductors, and upper body contacts.

The Laboratory has fabricated, with funding from the Army TRADEX program, modification kits for the existing units. Discussions are currently under way with a vendor to use these upgrades for a proposed European ionospheric scattering experiment.





(Above) First stage assembled on waveguide transition. (Right) Assembly with top section, water jacket, and output connection.

Sensor Metric Calibration

A major portion of the Laboratory's work over the years has been in the area of space surveillance using both radar and electrooptical sensors. For a variety of reasons, it is very important to have the capacity to detect, track, and identify objects in space such as satellites, rocket bodies, and debris. Maintaining the element sets necessary to do this requires precise metric data, network tasking, orbital computation, and analysis.

Lincoln Laboratory's Edward M. Gaposchkin has developed techniques for ensuring that the data gathered is as accurate as possible. His system works by monitoring and adjusting the data calibration in near real-time.

Sponsored by the Air Force Space Command, and developed at the Laboratory's Millstone Radar Site in Westford, Massachusetts, these techniques have already been transferred to some of the other sensors in the Command's space surveillance network. Potentially, any satellite tracking and some missile tracking sensors could be calibrated with this system.

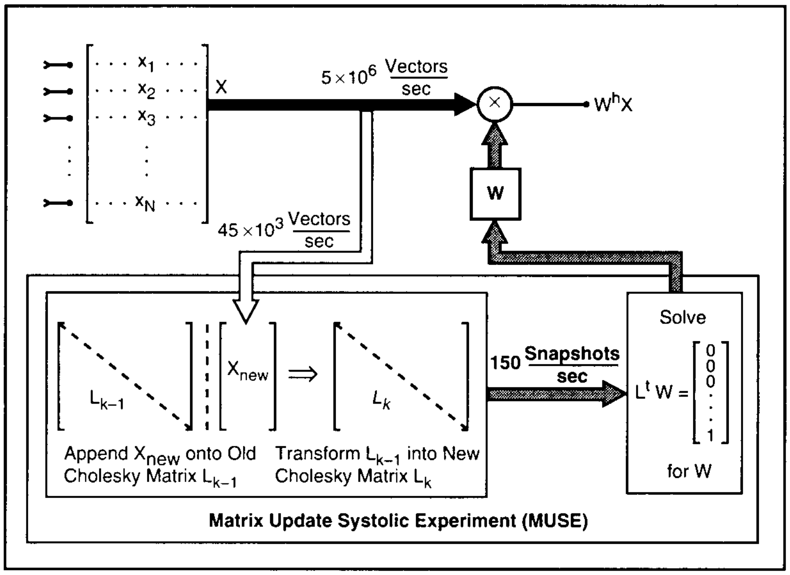
Signal Processing

Wafer Scale Adaptive Nulling Processor

Antenna arrays are subjected to unwanted co-channel interference such as jamming. This interference can be reduced (nulled) relative to the power in a desired signal by forming, as a system output, the weighted sum of the waveforms observed on all the array's elements. Because the nature of the interference changes over time, the determination of all these weights must be performed repetitively in real time.

For a satellite-mounted antenna array, nulling weights must be recomputed at a rate determined by the satellite's motion. But the number of antenna elements that can be used in a nulling system is quickly limited by the computational cost of adaptive weight determination. Increasing the computational resources devoted to the nulling processor is one way to compute weights for a larger number of antenna elements; however, this is not a practical way to handle a large antenna array — particularly when size and power constraints are critical.

In collaboration with colleagues, Lincoln researchers Charles M. Rader and Paul M. Davis have developed a specialized adaptive nulling processor for use on satellites that is capable of continuously determining the weights of sixty-four array elements. Called the Matrix Update Systolic Experiment (MUSE), the wafer-scale system is four inches square yet provides the equivalent of three billion operations per second at a power cost of only ten watts. The MUSE design concept can be applied to similar processors for antenna arrays with a variety of elements.



A diagram of a typical adaptive nulling system.

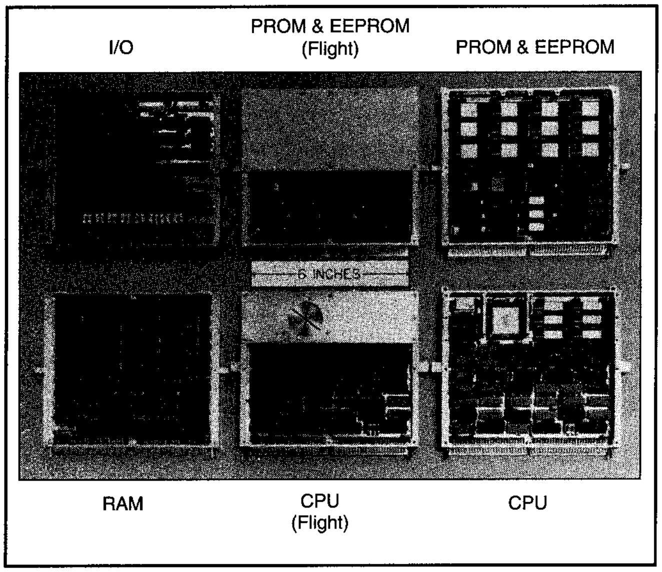
MUSE was developed through funding provided by the Naval Research Laboratory's Spacecraft Technology Center and is planned for use in their DSP-3 processor developed by Bell Laboratories.

Space Qualified Signal Processor

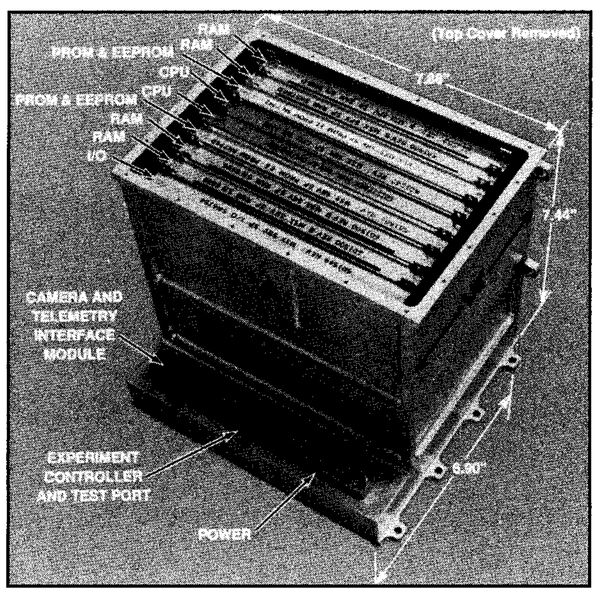
In 1994, the Strategic Defense Initiative Organization (SDIO) will orbit a satellite called the Midcourse Space Experiment (MSX). As a passive optical system, the MSX will gather data on targets of interest and observe backgrounds in wavebands ranging from the infrared to the ultraviolet. A significant element of the MSX is a small, visible-band sensor experiment developed by Lincoln Laboratory called Space-Based Visible (SBV).

The Lincoln team of James C. Anderson, Paul M. Davis, George S. Downs, Anthony E. Filip, and Pierre C. Trepagnier has developed a key part of the SBV, its signal processor. This device places a high degree of processing power into a satellite environment. Using a programmable digital signal processing chip controlling a series of software modules, the processor is designed to accept raw data from a Lincoln-designed charge-coupled device and generate a series of target reports. A striking compression of data is available from the SBV due to this equipment. The processor supports an instruction rate of ten million instructions per second at a cost of ten watts for each of its two channels. The total weight is under five kilograms.

The SDIO and the Air Force's Space Systems Division sponsored this research and development.



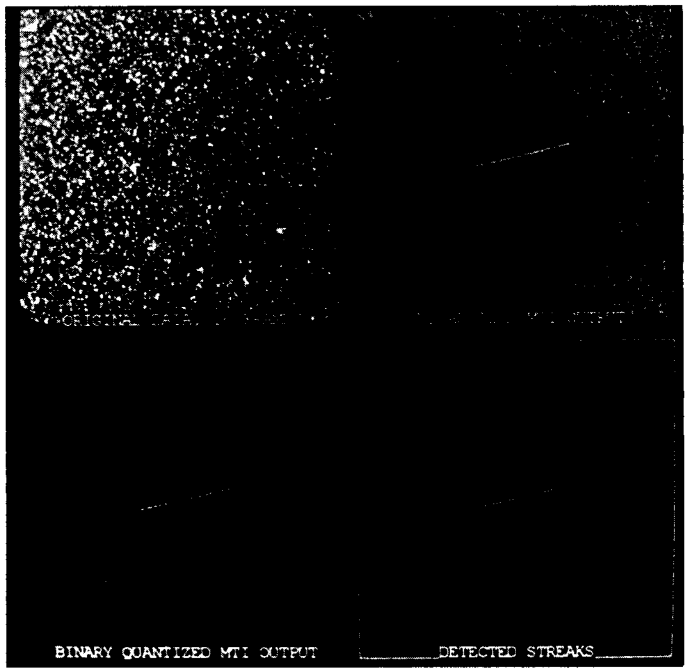
SBV Signal Processor Cards.



(Right) SBV Signal Processor.

Efficient Streak Detection Algorithm

The detection of objects moving through the heavens has historically been accomplished by some variety of visible band sensing, most recently by solid state sensors. Applications include the optical detection of satellites and the infrared detection of dim moving targets. This kind of detection is particularly challenging because of the enormous volume of optical information available in the sky, such as stars and other satellites that are not of interest and only "clutter" the detection process. In this kind of detection scheme there is often too much data to process and too many signal patterns to effectively consider. Therefore, some efficient means must be used to determine the targets of interest while identifying and subtracting the unwanted clutter.



Detection in clutter: Telstar II against the Milky Way.

Laboratory researchers Peter L. Chu, Anthony E. Filip, and Pierre C. Trepagnier have developed an algorithm that can be used with visible-band, charge-coupled devices in the focal plane of a telescope. The concept of projection is used to represent a set of samples by a single sample. The algorithm reduces the computational burden while still preserving most of the sensitivity required for reliable detection. It has been tested with real data derived from both staring and scanning sensors and has proven effective against both stellar and ground clutter.

Sponsored by the Strategic Defense Initiative Organization (SDIO) and the Air Force's Space Systems Division, this technology was developed for use on the Space-Based Visible (SBV) experiment to be orbited in 1994. Licensing agreements have been arranged with Perkin-Elmer, Hughes, Aerojet, and TRW.

Genetic Algorithm Technique for Designing Neural Networks

One of the keys to realizing the promise of neural networking is to be able to design and implement network interconnections that are reliable and versatile. Laboratory researcher Robert L. Harvey has designed an algorithm for creating neural networks with fixed interconnections. Working in the Laboratory's Innovative Research Program, Harvey has devised a method that allows for multiple outputs without constraining the choice in type of interconnection. A neural network fashioned in this manner will be part of a system for recognizing images from radar, laser, infrared, and visible sensors. As for other applications, such a network could be part of a preprocessing module of a larger system, such as signal processing machines used in robotics, automatic screening systems, or a variety of military systems.

This technology has been used by the Defense Advanced Research Projects Agency (DARPA) and negotiations are ongoing with two companies to license it for eventual marketing.

Sinusoidal Time-Scale Modification

For a number of significant applications, it is desirable to transform a speech waveform to a signal that is in a more useful form than the original. For example, degraded speech may be better comprehended when the rate of articulation is slowed down. Conversely, in order to quickly scan a passage or compress an utterance into a certain time frame, the speech rate must be accelerated.

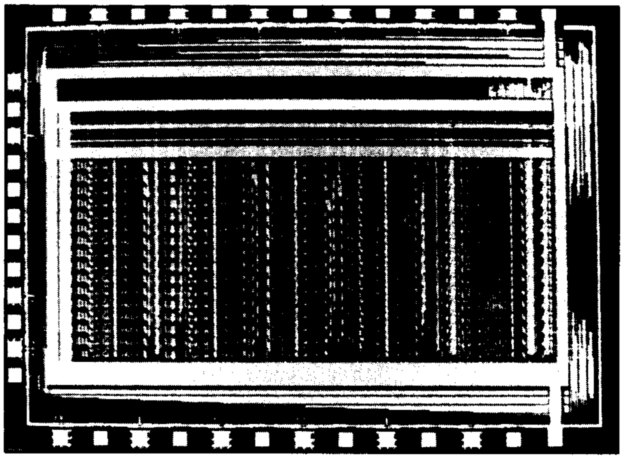
The Lincoln team of Thomas F. Quatieri and Robert J. McAulay has developed a novel method, based on sinusoidal analysis/synthesis, for modifying the time scale of a large class of signals. The technique is capable of changing the rate of articulation of recorded speech, i.e., creating the effect of a speaker talking faster or slower than his/her normal rate. The method can also change the generation rate of non-speech signals such as music (changing the speed of the bow against the violin string, for example). Biological signals, such as dolphin whistles, can also be stretched or compressed in time. An important feature of the system is its capability to continuously change the time scale of signals while simultaneously altering other characteristics of the signal, such as pitch or bandwidth.

The Air Force sponsored this development under the Digital Voice Processing program. The technology has been successfully transferred to Audiofile Incorporated, which uses it within one of its software packages. Discussions with other companies are also taking place.

Digital In-Phase Quadrature Separation

A significant problem for radar, sonar, and some communications systems is to develop baseband samples of the in-phase and one-quarter phase difference (or "quadrature") components of a given band-limited radio frequency waveform. Because it is often difficult to match the gains, phases, and frequency responses of the circuitry that produce these two components, a simpler technique was needed.

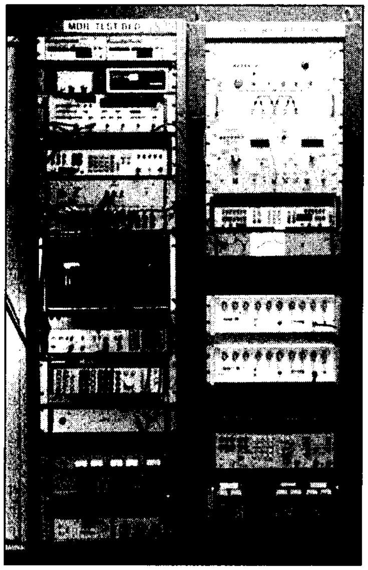
The Laboratory's Charles M. Rader has devised a superb approximation of the desired result by an attractive blend of mixing, sampling, and digital filtering, which was developed under the Space Based Radar program. A patent was obtained and an integrated microcircuit was produced. McDonnell-Douglas has utilized this idea for military radar applications.



Single chip design for high precision I.F. to digital baseband conversion.

Extremely High Frequency Medium Data Rate Waveforms

Initial waveforms for higher data rate communications in the next generation of extremely high frequency (EHF) satellite communications systems have been developed by Laboratory researchers David R. McElroy, Russell R. Rhodes, Dean P. Kolba, Roger C. King, David J. Cipolle, Bruce F. McGuffin, and others. Many of these waveform definitions have been selected for inclusion in the Air Force's Restructured Milstar (Military Strategic and Tactical Relay) MDR (Medium Data Rate) Satellite payload development and the Army's SMART-T (Secure Mobile Antijam Reliable Tactical Terminal). These waveforms will also be included in the EHF MDR communications standard MIL-STD-1810, which is being developed by the Defense Information System Agency's MilSatComm Systems Office for the Department of Defense Command, Control, Communications, and Intelligence, and the Joint Chiefs of Staff. This standard will be used for all higher data rate EHF communications in the United States.



MDR test bed.

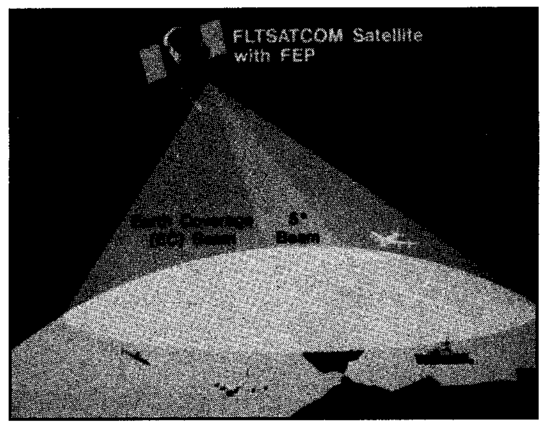
This work came out of the Medium Data Rate Signal Processing Test-Bed program sponsored by the Air Force Defense Satellite Communications Systems Program Office and the Army Communications and Electronics Command's Center for Space Systems. In addition, these waveforms are also being incorporated into the Lightweight EHF Satellite Payload being planned by Lincoln, the Army, and the Defense Advanced Research Projects Agency (DARPA).

Extremely High Frequency Low Data Rate Waveforms

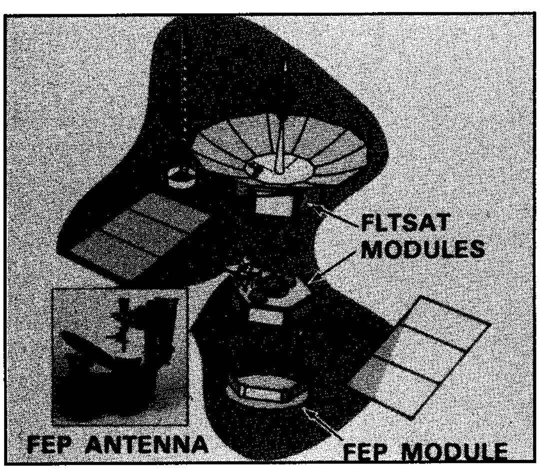
Lincoln Laboratory has also developed the waveforms and protocols that have been selected as the basis of the extremely high frequency (EHF) low data rate (LDR) satellite communications standard, MIL-STD-1582C. Produced by the team of David R. McElroy, Marilyn D. Semprucci, Russell R. Rhodes, William L. Greenberg, Dean P. Kolba, Roger C. King, Pat R. Hirschler-Marchand, and others, this standard is to be utilized for all EHF communications as well as telemetry, tracking, and command systems in the United States. The standard has also been transferred to Canada, Great Britain, and France.

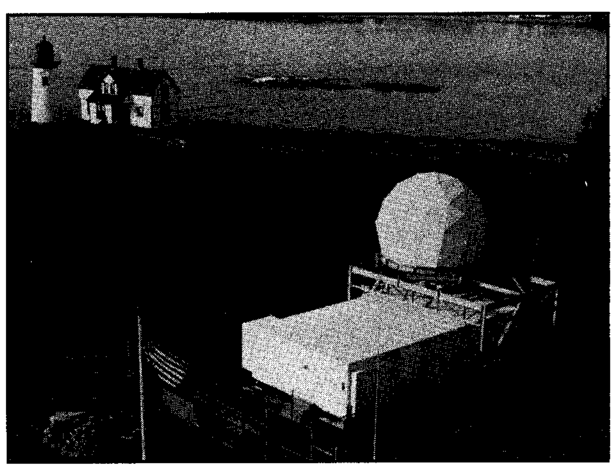
The waveforms and protocols embodied in this communications standard were demonstrated by the Fleet Satellite Communications System - Extremely High Frequency Package (FLTSATCOM EHF Package or FEP) and are being implemented in the Milstar (Military Strategic and Tactical Relay) EHF space segment and EHF terminals, and in the EHF package on the UHF (Ultra-High Frequency) Follow-on Satellite. This work was sponsored by the Air Force's Advanced Technology and Milstar programs, the Army's Single Channel Objective Tactical Terminal (SCOTT) program, and the Navy EHF Satellite Program (NESP), as well as the Defense Information System Agency's MilSatComm Systems Office for the Department of Defense Command, Control, Communications, and Intelligence, and the Joint Chiefs of Staff.

The waveforms and protocols developed are being utilized by Lockheed, TRW, and Hughes in the development of space hardware and by Raytheon and Magnavox for the development of ground terminals.



(Above) FEP coverage. (Below left) FLTSAT/FEP Integration. (Below) FEP operations center.



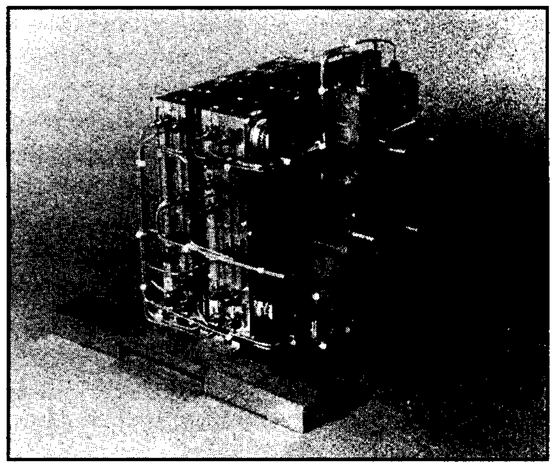


Surface Acoustic Wave Demodulator

Satellite communications systems designed to link many users with frequency-shift-keyed (FSK) modulated signals need a demodulator with hundreds of narrow-band channels. As a spaceborne device, such a demodulator must be compact and highly reliable and have minimal power requirements.

Lincoln researchers David M. Hodsdon, Don M. Boroson, Douglas W. White, and Russell R. Rhodes have developed a space-qualified, FSK demodulator based on surface acoustic wave (SAW) devices that employ fast frequency hopping and other antijam techniques to provide secure communications to small, mobile terrestrial (as well as airborne) terminals. Many of these demodulators are carried by a single satellite; each can provide service to numerous terminals simultaneously through the use of a chirp-Fourier transform.

Developed with funding from the Milstar (Military Strategic and Tactical Relay) Joint Program Office, the Laboratory built and delivered two flight-qualified SAW demodulators which were flown on each of the Fleet Satellite Communications System - Extremely High Frequency Packages (FLTSATCOM EHF Packages or FEP) and remain in service today. In addition, the demodulator design is intended for use in the Milstar space segment now being developed.



Flight qualified SAW demodulator assembly.

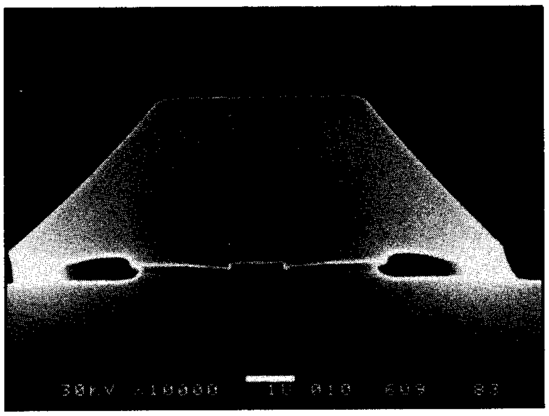
To assure the effective transfer of this technology, Lincoln Laboratory held informative seminars for contractors designated by the Milstar Program Office and has provided technical consultation as needed to both the Milstar Office and its contractors. TRW is currently using the Laboratory's design as the basis for its Milstar demodulator.

Solid State

Buried Stripe Semiconductor Diode Laser

Diode lasers (especially the distributed feedback type) constructed from the compound gallium indium arsenide phosphide over a substrate of the compound indium phosphide (GaInAsP/InP) are important single-frequency light sources for fiber optic communications and integrated optics. However, the fabrication of such devices was quite involved. Lincoln researchers Zong-Long Liau, James N. Walpole, and D. C. Flanders have developed a new material growth technique that has resulted in structures for these single mode, high speed devices, called "buried stripe semiconductor diode lasers."

Starting with a standard heterostructure semiconductor slice or wafer of material, they removed excess material and formed a "mesa" by etching. The GaInAsP or "active layer" of this mesa was then selectively undercut to a narrow width. In a subsequent heat treatment, the active region was buried by the movement or "migration" of wafer material, which was induced by the surface energy stored in the etched structure. This relatively simple procedure has resulted in diode lasers suitable for telecommunications with record low threshold current and high data rate.

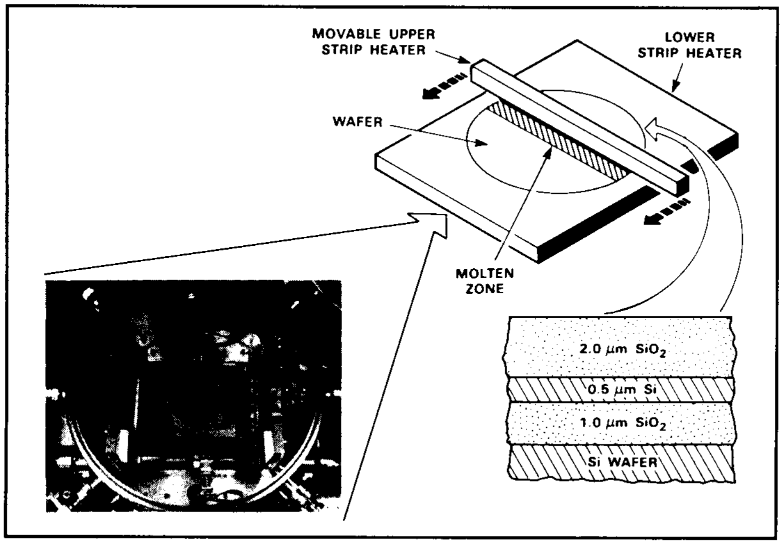


Stained transverse cross section. The micro-wide dark region near the center is the active layer.

This research was sponsored by the Rome Air Development Center (RADC) at Hanscom Air Force Base under the Electrooptical Devices program. Lasertron Incorporated, a "spin-off" company of Lincoln Laboratory, has used this patented process and device structure in the production of laser diodes.

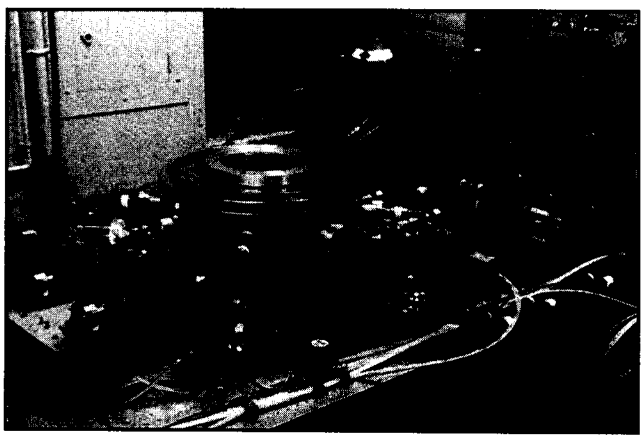
Silicon-on-Insulator Films by Zone Melting Recrystallization

Integrated circuits fabricated in thin silicon films on insulating substrates are attractive because of their potentially higher packing densities, speed, and radiation resistance in comparison to bulk silicon circuits. The Lincoln research team of Chenson K. Chen, Bor-Yeu Tsaur, John C.C. Fan, Michael W. Geis, Ralph Chapman, and James Im have developed a method called zone-melting recrystallization (ZMR) as an effective technique for producing high-quality silicon-on-insulator (SOI) thin films. This technique involves the use of a custom designed and fabricated graphite-strip-heater system to sweep a narrow molten zone through a polycrystalline silicon film deposited on an oxidized silicon wafer. The recrystallized process yields single-crystal films in which high-performance circuits with significantly increased radiation resistance in comparison to bulk silicon circuits have been demonstrated.

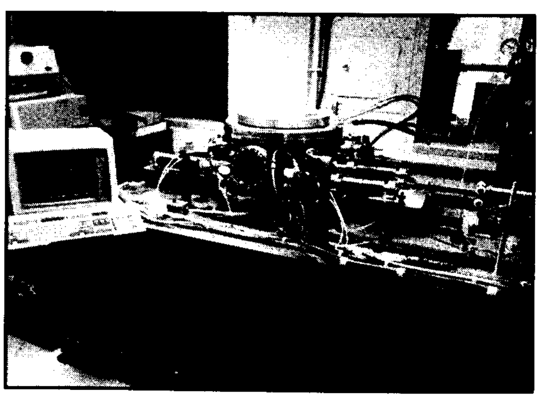


Schematic diagram of a graphite-strip-heater system used for ZMR of SOI films. The left inset provides a top view of the ZMR chamber, and the right inset shows a cross section through a typical sample.

(Below) External view of the ZMR system.



This work was sponsored by Air Force's Rome Air Development Center (RADC) under the Hardened Wafer Scale ICs and Rad-Hard SOI programs. The graphite-strip-heater ZMR technology was licensed to Kopin Corporation and has been utilized to manufacture SOI films for commercial sale. Lincoln Laboratory has also provided detailed design drawings and process information on the ZMR system to Kopin and has conducted on-site visits to assist in the commercial implementation of the ZMR SOI process.



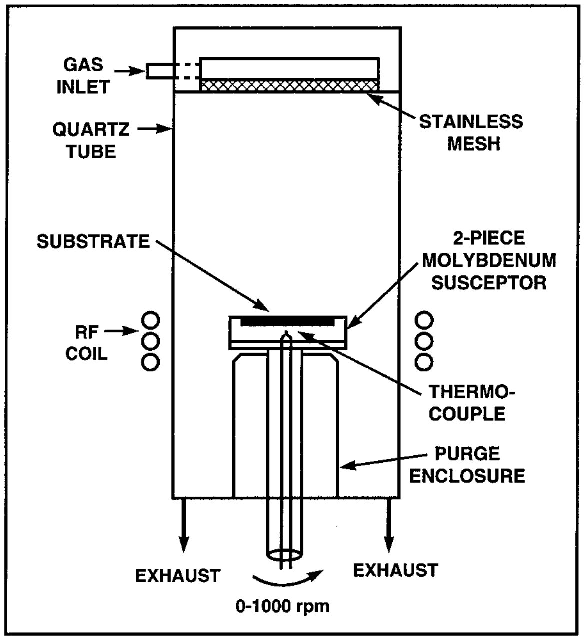
(Right) External view showing the computer automated ZMR system.

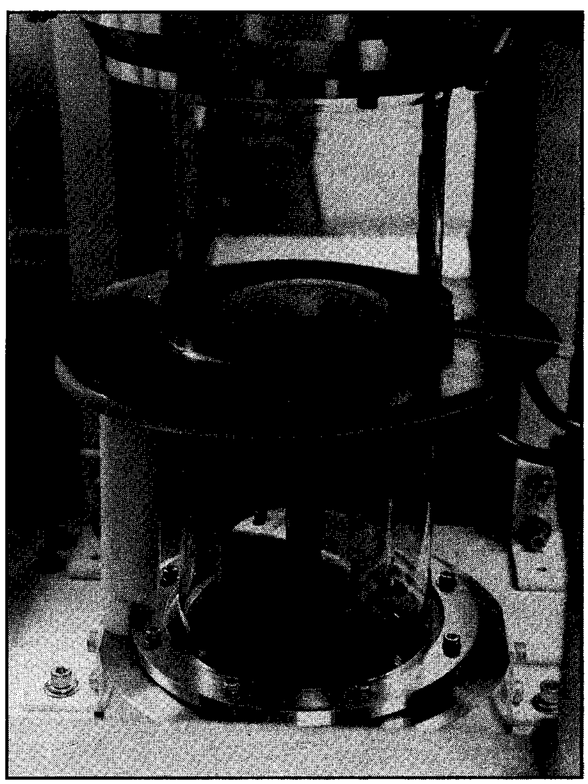
Vapor Phase Reactor for Making Multilayer Structures

Thin film deposition processes are crucial to the development of compound semiconductors for advanced electronic and optoelectronic devices. Such films are composed of single-crystal, epitaxial layers (epilayers) grown on a single-crystal substrate; these films vary in thickness from a few tenths of a nanometer to several micrometers. Applications include high-speed transistors, quantum-well diode lasers, light-emitting diodes, photodetectors, optical modulators, micro- and macro-machining, and various medical applications.

For many applications, the epilayers should be laterally uniform over large areas, and the compositional changes between successive layers should be either abrupt or graded in a controlled manner. Precise control of layer thickness, composition, and doping has been difficult to achieve for the reactors used to deposit these epilayers. Lincoln researchers Christine A. Wang and James W. Caunt have designed, built, and tested a vertical rotating-disk, single-wafer reactor that permits such control of epilayers grown by organometallic vapor phase epitaxy. Thickness uniformity of 1% and AlGaAs (aluminum gallium arsenide) compositional uniformity of 0.1% have been obtained for epilayers grown on five centimeter diameter substrates. Heterostructures have been grown with interfaces as abrupt as those observed in layers grown by molecular beam epitaxy.

This work was sponsored by the Strategic Defense Initiative Organization (SDIO) under the Laboratory's Optical Discrimination Technology program and has been licensed for development by Bell Communications Research (BellCore) and Spire Corporation.



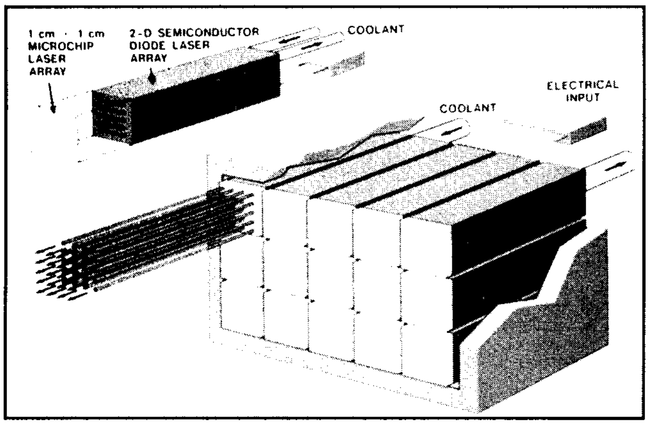


Schematic drawing and picture of Vertical Rotating disk OMVPE Reactor.

Microchip Lasers and External Cavity Semiconductor Lasers

Laboratory researchers Aram Mooradian and John J. Zayhowski have invented and developed a solid state microlaser that is optically pumped by a semiconductor diode laser. This "microchip" laser can operate in a pure single frequency with precision control and generate very short pulses with high intensity. Two-dimensional arrays of such microchip lasers can produce very high average power without the difficulty associated with conventional laser technology. Using semiconductor processing and packaging technology, these lasers can be mass produced at a very low cost for a variety of uses in optical communications, robotic control, laser disc read/write processes, projection display technology (including consumer television), materials processing, and various medical laser uses.

Aram has also developed external cavity semiconductor lasers that operate at linewidths below 4 KHz. This type of diode laser technology can be applied to offset frequency locked operations in coherent communications, as well as applications in spectroscopy, analytical instruments, and various uses in research.



High power, two-dimensional microchip laser array.

These developments were sponsored by the Air Force, Strategic Defense Initiative Organization (SDIO), and the Defense Advanced Research Projects Agency (DARPA). The technology was transferred to the Air Force's Phillips Laboratory and the Charles Stark Draper Laboratory in the form of reports and fabricated devices. It has also been licensed to the Micracor Company; training, consultation, and fabrication have all been provided as part of this licensing arrangement.

Voltage Programmable Link

Gate arrays have become the standard semicustom, mask-configured design approach in advanced integrated circuits technology. A relatively new dimension in gate arrays technology is the possibility to perform the final programming of the device by relying entirely on an electrical (rather than chemical) process. This new development forms one class of what is known as field-programmable gate arrays (FPGAs) technology.

Lincoln Laboratory's Simon S. Cohen has developed a device that allows a permanent connection to be made on a finished integrated circuit by applying a voltage pulse. The metal-to-metal connection has low resistance and the unprogrammed sites have low capacitance, so it can be used for customization of high-speed integrated circuits. This makes possible the building of a new circuit to accomplish a specific function at very low cost and in a matter of minutes.

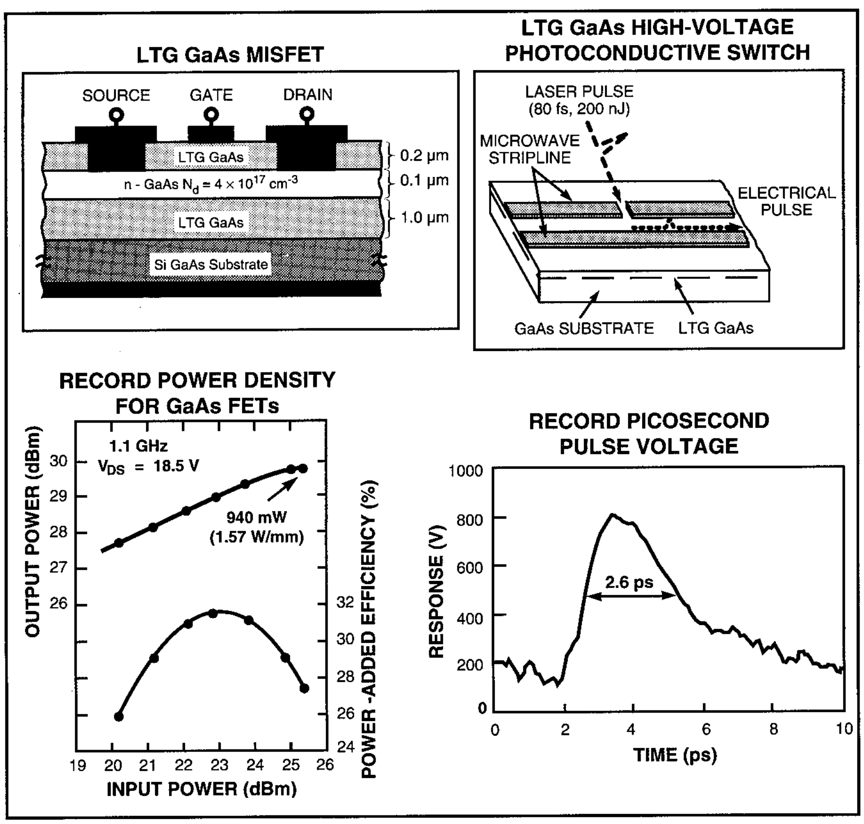
Developed with funding from the Air Force, information and test samples have been produced. Samples have been provided to Actel Corporation, which is interested in incorporating this technology in their field programmable gate arrays.

Low-Temperature-Grown Gallium Arsenide

Using the molecular beam epitaxy (MBE) process at an abnormally low temperature, an electrically insulating layer of gallium arsenide (GaAs) can be formed. Because low-temperature-grown GaAs (LTG GaAs) has the same crystal structure as electrically active GaAs, it is completely compatible with it and can be grown into any GaAs-based circuit. Discovered and developed by Lincoln researchers Arthur R. Calawa and Frank W. Smith, LTG GaAs provides an insulating GaAs layer that eliminates sidegating of GaAs transistors from adjacent devices and thereby allows a higher packing density of devices on GaAs integrated circuits. Developed under the sponsorship of the Air Force, LTG GaAs has been transferred to industry and is now used by Hewlett-Packard, General Electric, Hughes, and Honeywell for such applications as isolation, passivation of field effect transistors (FET), and gate insulators for metal-insulator-semiconductor FETs (MISFETs).

Because LTG GaAs is highly responsive as a light-sensing compound, it has been effectively applied to ultrafast and high-power optical switching. This light detecting capability is truly astonishing: LTG GaAs responds to light in less than one picosecond (one trillionth part of a second), which is over six times faster than commercial photodetectors. Recently, Yi Chen of AT&T Bell Laboratories and Steven Williamson of the University of Michigan paired LTG GaAs with inter-digitated electrodes to produce the fastest and most versatile photodetection yet achieved.

Some of the potential applications of this technology are fiber-optic communications networks that are several hundred times faster than present systems, compact three-dimensional imaging systems used to inspect machined parts as they come off the assembly line, advanced medical imaging techniques, and vehicle collision avoidance systems.



High performance devices utilizing low-temperature-grown (LTG) GaAs.

Charge Domain Block Matching Processor

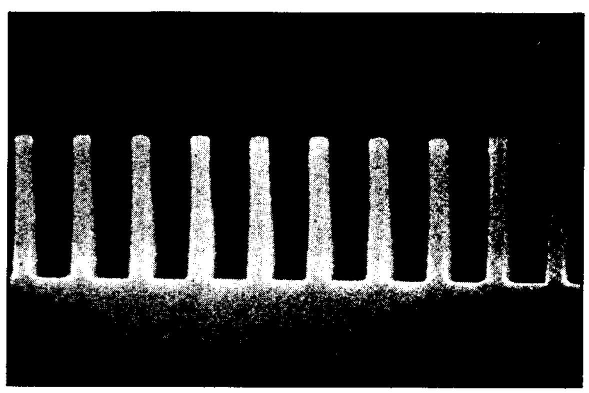
The need to transmit image data through low data-rate channels has been the impetus for developing video compression techniques. For interframe compression, some form of predictive coding based on information from previous frames is used to remove redundancy between frames and reduce transmission bit-rates. Motion estimation and compensation techniques have been demonstrated as an effective means of performing such interframe coding.

Lincoln's Alice M. Chiang has developed a very large scale integration (VLSI) implementation of a motion detection and estimation video processor that predicts the displacement of objects in the direction of motion from one frame to the next with a much lower error rate than the standard interframe prediction process. The reduced transmission bit-rates that result from this processor are particularly important to high definition television (HDTV) systems, which currently require prediction computation rates near the upper limit of present digital technology and would otherwise need highly complex and costly equipment.

Another important application of this technology is automatic focusing of thirty-five millimeter, single reflex cameras. Using the two directional correlation search capability made possible by the charge-domain block matching processor, much better resolutions in range finding can be realized in a compact, low-power, and low-cost autofocusing system that uses images generated from a charge-coupled device with grid-pattern sensors. Discussions are currently underway with Fuji Photo Film Company and Canon Incorporated to implement this technology.

193-Nanometer Lithography Resists Using Silylation

Silylation is the selective incorporation of silicon into a polymer structure. In optical lithography, surface-imaging techniques such as silylation are being extensively investigated as a way of further extending the resolution limits for microelectronic circuits to the range below 0.5 micrometers. Lincoln Laboratory's Mark A. Hartney has developed a prototype process for advanced semiconductor manufacturing that uses radiation induced crosslinking, caused by a 193-nanometer argon-fluorine laser, to permit silylation in a selected pattern. Because of the shorter wavelength used, new photosensitive materials and processes are required to utilize this equipment. With this process, pattern features as small as 0.2 micrometers can be printed.

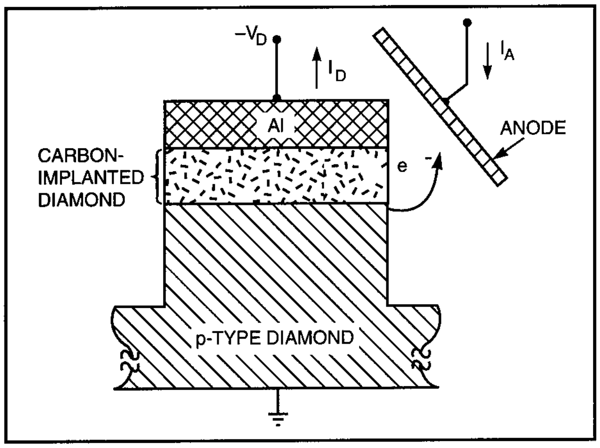


193-nm exposure-0.2 μm resolution.

This work was performed under the Excimer Direct Processing Program sponsored by the Defense Advanced Research Projects Agency (DARPA). Collaborative agreements have been arranged with several manufacturers and a technology license is being negotiated. One patent has been allowed and a second is pending regarding this procedure. The technology could be transferred to the Semiconductor Manufacturing Technology (SEMATECH) consortium and could potentially be used by any semiconductor manufacturer pursuing 193-nanometer lithography.

Diamond Cold Cathodes

If a robust, high-current-density cathode could be made, it would have wide applications in high-power, high-frequency devices. Several potential solutions to this challenge have been advanced, but each has technical problems that would be difficult to overcome. Diamond shows great promise in this regard because the energy of its conduction band electrons is above the energy of electrons in a vacuum.



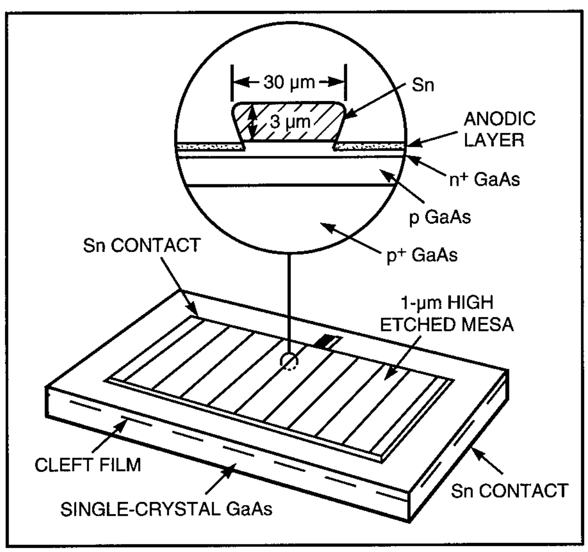
Schematic drawing of the mesa-etched cold cathode diode.

Researchers in the Laboratory's Submicrometer Technology Group have fabricated and characterized cold cathodes made of diamond; for this application, the diamond has been doped to give it semiconductor properties. Developed under the Diamond Transistor Technology program sponsored by the Strategic Defense Initiative Organization (SDIO) and the Office of Naval Research, potential applications for this technology include flat panel displays, power high frequency or traveling wave tubes (TWT), and micro-vacuum tubes. A patent is pending on this technology and discussions are currently taking place with several companies regarding its licensing.

Thin Homojunction Solar Cells

Solar cells use the sun's radiation to produce usable electric current. Panels of these cells are often used to provide the power for satellites and spacecraft. The standard conversion efficiency of such devices is about fifteen percent. Lincoln Laboratory's Carl O. Bozler developed a fabrication technique for single crystal gallium arsenide (GaAs) solar cells with an efficiency as high as twenty-two percent. The fabrication of these cells is much simpler because it does not require any vacuum processing steps. The cell's junction is formed during the epitaxial (thin crystal layer) growth process, and none of the more sophisticated heterojunction layers are required. After crystal growth, all that is required is an antireflective coating, and contact metal deposition and patterning.

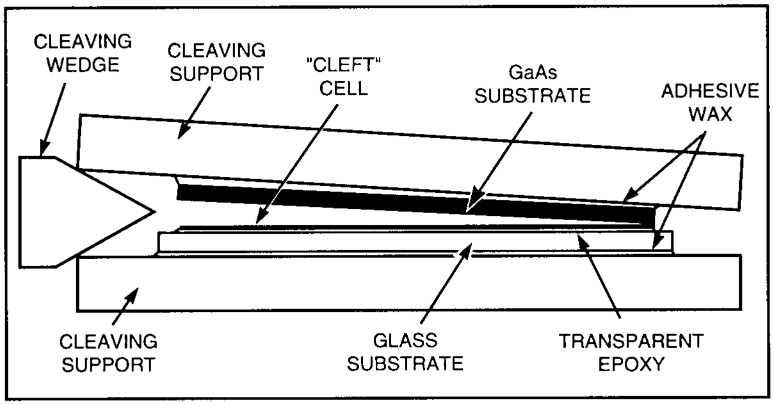
Carl developed this technology under the sponsorship of the Air Force and the Solar Energy Research Institute. Kopin Corporation licensed this technology to produce high efficiency solar cells, the initial application of which is for satellite power generation.



Thin homojunction solar cell.

The CLEFT Process

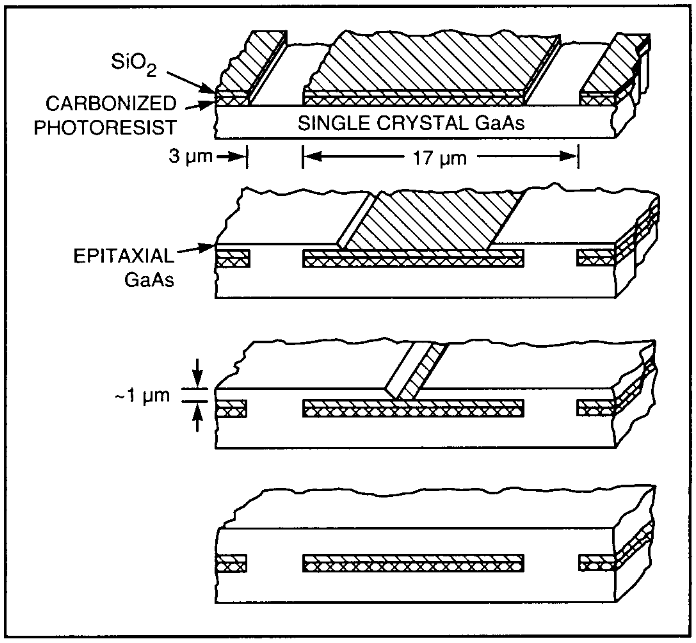
Semiconductor devices are most often constructed in a layer of material a few micrometers thick on the surface of a single crystal wafer. The rest of the wafer serves mostly as a substrate for supporting the devices on it. When used for such applications as gallium arsenide (GaAs) solar cells, so much inactive single crystal material can be prohibitively costly. Device performance can be improved in other applications if another material with more preferred properties is substituted for the original substrate.



Cleaving apparatus for removing CLEFT film from substrate.

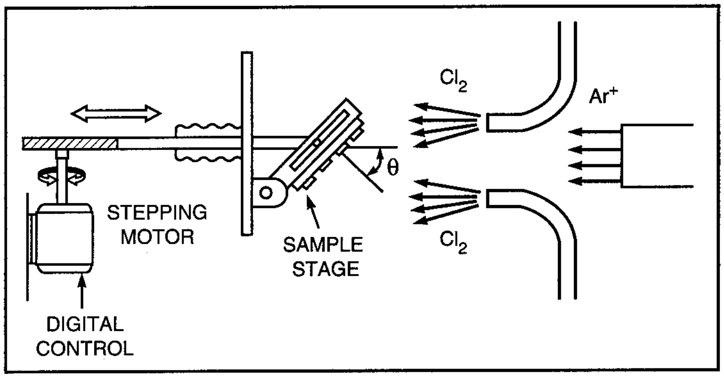
Lincoln researcher Carl O. Bozler has devised a process by which semiconductor thin films can be grown on a reusable GaAs single-crystal substrate and transferred to almost any amorphous or polycrystalline substrate. Called the CLEFT (Cleavage of Lateral Epitaxial Film for Transfer) Process, it makes possible the use of less expensive substrates with more suitable electrical and optical properties.

Developed with funding from the Air Force and the Solar Energy Research Institute, this technology has been licensed to the Kopin Corporation, which is using it to make ultra-light and ultra-thin solar cells for satellite power supplies. Kopin is also using this process to develop low cost light emitting diodes for automobile tail lights and flat panel displays.



(Right) Preparation of a single crystal CLEFT film.

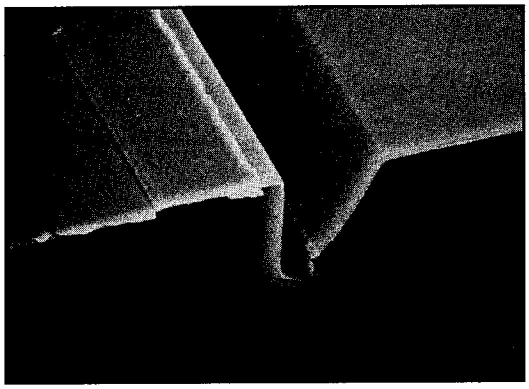
Micromachining Technology Using Chlorine Ion Beam Assisted Etching



Schematic of chlorine ion beam assisted etching system.

In the development of microelectronic devices and components, it is quite useful to be able to sculpt or otherwise alter the semiconductor material to achieve design objectives. The Laboratory's William D. Goodhue and Joseph P. Donnelly have developed a process that uses a computer-controlled angled stage to micromachine curved or angled surfaces in semiconductor materials. This technology is useful for the fabrication of laser facets and micron-sized optical elements in gallium arsenide (GaAs) and aluminum gallium arsenide (AlGaAs) materials.

There is much interest in arrays of semiconductor diode lasers for applications that require higher power levels than single devices can achieve. With this process, monolithic two-dimensional horizontal cavity surface-emitting arrays were constructed in the GaAs/AlGaAs materials system. These arrays are able to produce a significant amount of optical power and are useful as pumps for a variety of solid state laser materials.



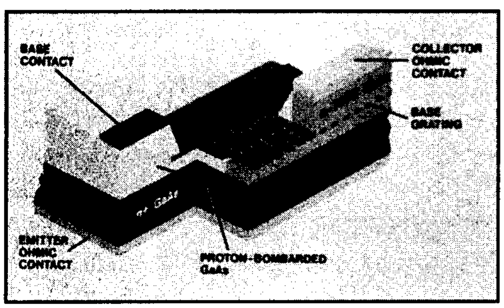
Scanning electron micrograph showing a laser facet profile and a parabolic deflecting mirror from a portion of a two-dimensional surface-emitting laser array. Both were micromachined with chlorine ion beam assisted etching.

This work was sponsored by the Navy for its Optical Discrimination Technology Program and by the Air Force. A number of companies and universities have visited the Laboratory and are currently using the technology, including IBM Zurich, TRW, McDonnell-Douglas, Cornell University, and several Japanese firms. Assistance has also been provided to the University of Maryland, the University of Lowell, and United Technologies in the fabrication of devices using this technology.

Permeable Base Transistor

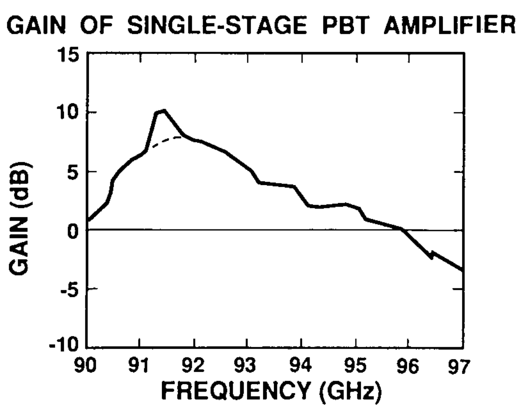
There is a large demand in communications and radar applications for devices that can generate and amplify electrical signals at microwave and millimeter-wave frequencies with the highest possible efficiency. Lincoln Laboratory researcher Carl O. Bozler and his colleagues have developed a device that promises high-frequency and high-power operations exceeding what has been possible with established processes. Called the permeable-base transistor (PBT), it is designed for speed and has set some records for efficiency and gain in the frequency range of 1 to 100 gigahertz. The key element of the device is a metal grating or grid, embedded in a single crystal semiconductor, where the grid lines are only 1600 angstroms wide. When this transistor is placed in a carefully designed circuit, a small amount of power applied to the grid (referred to as the "base" of the transistor) will control a large amount of power delivered by the device.

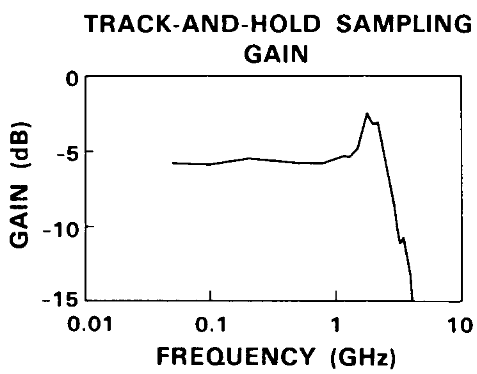
Developed with funding from the Defense Advanced Research Projects Agency (DARPA) and the Air Force, PBTs are useful for efficient generation of microwave power, fast microwave switching, and high gain amplification of some microwave frequencies. Currently, the PBT is being fabricated by M/A-COM under a licensing and technology transfer arrangement for use in cellular radios, satellite communications, and other similar applications. Westinghouse is exploring its development for military radar and communications.



POWER DATA

FREQUENCY (GHz)	1.3	1.3	22	22
POWER (W)	0.1	1.0	0.075	0.5
POWER-ADDED EFFICIENCY (%)	66	35	53	30
CLASS OF OPERATION	AB	A	AB	AB





GaAs permeable base transistor.

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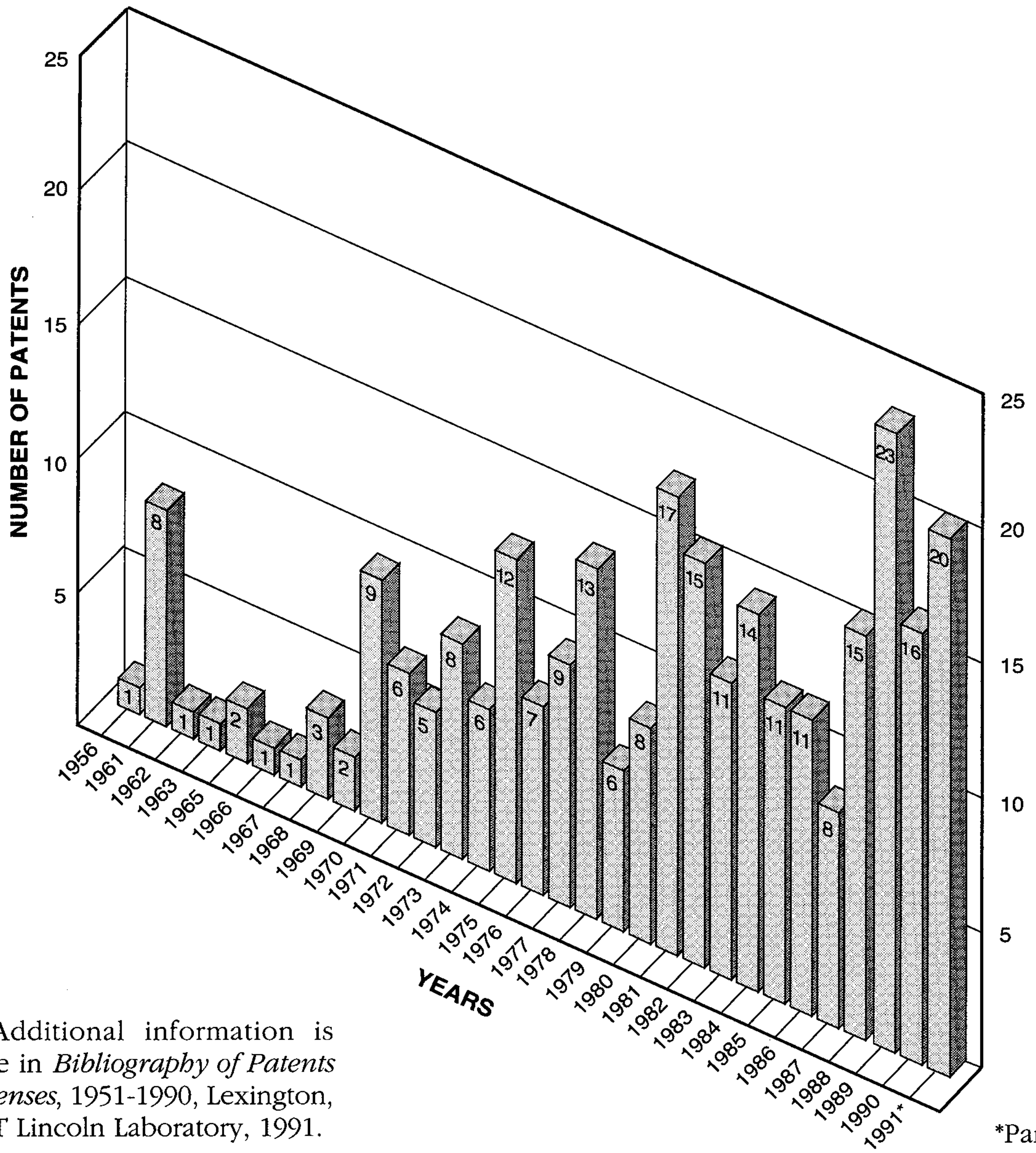
By Subject Area

Appendices

Patents Issued to MIT Lincoln Laboratory



Note: Additional information is available in *Bibliography of Patents and Licenses*, 1951-1990, Lexington, MA. MIT Lincoln Laboratory, 1991.

*Partial Results

Visitors to MIT Lincoln Laboratory

	1989	1990	1991
Classified Visits			
Industry	2,413	2,453	1,924
University	50	39	13
U.S. Air Force	596	519	314
U.S. Army	138	93	68
U.S. Navy	134	95	73
Government	1,246	1,086	1,430
Non-Profit	0	0	0
Consultant	0	2	0
Foreign	10	27	83
Subtotal	**4,587**	**4,314**	**3,905**
Unclassified Visits			
Industry	8,094	11,096	9,189
University	1,667	1,759	1,336
U.S. Air Force	816	841	922
U.S. Army	72	103	76
U.S. Navy	59	41	41
Government	857	866	289
Non-Profit	95	89	87
Consultant	146	642	54
Foreign	542	100	498
Subtotal	**12,348**	**15,537**	**12,492**
TOTAL	**16,935**	**19,851**	**16,397**

Spin-Off Companies from MIT Lincoln Laboratory*

ADVANCED COMPUTER TECHNIQUES CORPORATION
Date Founded: 1962
Products and Services: Computer systems software development services, data processing services, and consulting services to specialty-care health institutions

AMERICAN POWER CONVERSION CORPORATION
Date Founded: 1981
Products and Services: Designs and manufactures electronic uninterruptable power supply products for computers and communications devices

AMTRON CORPORATION
Date Founded: 1956
Products and Services:Manufactures electronic communications equipment

APPLICON, INC.
(Now a CAD/CAM division of Schlumberger Technology Corp.)
Date Founded: 1969
Products and Services: Software design

ARCON CORPORATION
Date Founded: 1960
Products and Services: Performs statistical and computer analytical studies; research and engineering

ASCENSION TECHNOLOGY, INC.
Date Founded: 1986
Products and Services: Consulting, research, development, and sales in electric power systems and distributed photovoltaic systems

ATLANTIC AEROSPACE ELECTRONICS CORPORATION
Date Founded: 1984
Products and Services: Performs research and development in defense electronic hardware and reconnaissance surveillance and counter-surveillance systems

CATALYST, INC.
Date Founded: 1989
Products and Services: Develops statistical software to assist engineering and production processes

CENTOCOR, INC.
Date Founded: 1979
Products and Services: Develops, manufactures, and markets human health care products

CHRONAR TRISOLAR, INC.
(Now a subsidiary of Chronar Corp.)
Date Founded: 1980
Products and Services: Performs research and development in photovoltaic panels

CLARK ROCKOFF AND ASSOCIATES
Date Founded: 1985
Products and Services: Consulting in systems design and patents

COMPUTER CORPORATION OF AMERICA
(Now a subsidiary of Crown Life Insurance, Toronto, Ontario, Canada)
Date Founded: 1965
Products and Services: Develops and markets database management software, applications development software, and other systems software, such as Comet Electronic Mail System

*Additional information is available in *Spin-Off Companies from MIT Lincoln Laboratory*, Lexington, MA, MIT Lincoln Laboratory (May 1991)

CORPORATE-TECH PLANNING, INC.
Date Founded: 1969
Products and Services: Operates as a management consulting firm, develops database software systems, systems design, and implementation

DIGITAL COMPUTER CONTROLS, INC. (Acquired by Data General Corporation in 1976)
Date Founded: 1969
Products and Services: Computer controls

DIGITAL EQUIPMENT CORPORATION
Date Founded: 1957
Products and Services: Designs and manufactures network computer systems and provides peripheral devices, software, and maintenance services

ELECTRO-OPTICAL TECHNOLOGY, INC.
(Merged with IL Med in 1988)
Date Founded: 1985
Products and Services: Laser components and systems

ELECTRONIC SPACE STRUCTURES, INC. [Now Electronic Space Systems Corporation (ESSCO)]
Date Founded: 1961
Products and Services: Manufactures precision antenna systems and space frame and composite radomes

EVANS & SUTHERLAND COMPUTER CORPORATION
Date Founded: 1968
Products and Services: Manufactures interactive computer graphics display systems and subsystems; provides related application software

FRONTIER TECHNOLOGY, INC.
Date Founded: 1985
Products and Services: Performs research and development in computer hardware, software, silicon compilers, and digital signal processing; conducts technical seminars

F.W.S. ENGINEERING
Date Founded: 1982
Products and Services: Consulting in electronic and communication instruments and power systems for harsh environments

HERMES ELECTRONICS, INC. (Acquired by Itek Corporation in 1960)
Date Founded: 1956
Products and Services: Electronics

HH CONTROLS CO., INC.
Date Founded: 1963
Products and Services: Manufactures electro-optical equipment, such as the electro-optical shaft encoder

HRAND SAXENIAN ASSOCIATES
Date Founded: 1961
Products and Services: Performs research and consults on individual effectiveness through MODULAR h2 Practices (TM); assists industry, education, and government in simplifying and strengthening innovation, production, and operations

INFORMATION INTERNATIONAL, INC.
Date Founded: 1962
Products and Services: Manufactures computer-based electronic optical systems that generate finished pages containing text, drawings, and photographs

INTEGRATED SYSTEMS, INC.
Date Founded: 1991
Products and Services: Software applications to model architectural environmental effects, such as acoustic and electromagnetic performance

INTERACTIVE DATA CORPORATION (Now a subsidiary of Dun & Bradstreet Corp.)
Date Founded: 1968
Products and Services: Engages in computer time-sharing

JANIS RESEARCH COMPANY, INC.
Date Founded: 1960
Products and Services: Cryogenic laboratory apparatus

JOHN ACKLEY CONSULTANTS
Date Founded: 1976
Products and Services: Consulting in computer-related products and services; implementing computer systems

KOPIN CORPORATION
Date Founded: 1984
Products and Services: Manufactures semiconducting materials, including thin film circuits

KULITE SEMICONDUCTOR PRODUCTS, INC.
Date Founded: 1959
Products and Services: Manufactures pressure transducers, accelerometers, and solid state strain gauges

LASER ANALYTICS, INC. (Now Analytical Division of Laser Photonics, Inc., formerly Spectra-Physics, Inc.)
Date Founded: 1975
Products and Services: Sells and services lasers used in building construction

LASERTRON, INC.
Date Founded: 1980
Products and Services: Manufactures fiber optic telecommunication systems and components, including transmitters and detectors

L.J. RICARDI, INC. (Now a subsidiary of EMS Inc.)
Date Founded: 1984
Products and Services: Satellite communication analysis and general consulting

LOUIS SUTRO ASSOCIATES
Date Founded: 1982
Products and Services: Consults in engineering design

MAN LABS, INC. (Now a subsidiary of Alcan Aluminum Corporation)
Date Founded: 1960
Products and Services: Performs research, development, and testing in materials science

M.D. FIELD COMPANY
Date Founded: 1960
Products and Services: Consults in systems engineering, requirements analysis, and expert systems

METRIC SYSTEMS CORPORATION
Date Founded: 1989
Products and Services: Develops systems communications for the medical field, such as cardiac telemetry and trauma software

MICRACOR
Date Founded: 1990
Products and Services: Operates as a development stage company; manufactures and sells a new class of miniature laser

MICRILOR, INC.
Date Founded: 1984
Products and Services: Industrial consultant specializing in signal processing technology, circuit and component design, prototyping, systems studies, and defense work

MICRO-BIT CORPORATION (Acquired by Control Data Corporation in 1978)
Date Founded: 1969
Products and Services: Performs research in electron beam memory

MILLSTONE SOFTWARE ASSOCIATES
Date Founded: 1989
Products and Services: Develops real-time system software

MIT FRANCIS BITTER NATIONAL MAGNET LABORATORY
Date Founded: 1960
Products and Services: Operates high magnetic field facilities for research and development in science and engineering involving resistive and superconducting magnets, condensed matter physics, condensed matter chemistry, materials science, and biophysics

MITRE CORPORATION
Date Founded: 1958
Products and Services: Performs research in command systems, space surveillance systems, tactical systems, applications of data processing, radars, and communications

NETEXPRESS, INC. (Includes Net Express Systems, Inc. and Net Express Communications, Inc.)
Date Founded: 1983
Products and Services: Operates as computer consultant for research, development, and manufacture of electronic information, transfer equipment, and technology for next-generation facsimile services; provides telecommunication services and electronic telecommunication document movement

OBJECT SYSTEMS
Date Founded: 1988
Products and Services: Integration software products

PHOTON, INC
Date Founded: 1984
Products and Services: Consults and performs research and development computer-aided design for general business applications, as well as interfacing devices for small computers

PUGH-ROBERTS ASSOCIATES, INC.
Date Founded: 1963
Products and Services: Provides corporate planning, organizational development, and software services to aid corporate planning through computer simulation

QEI, INC.
Date Founded: 1966
Products and Services: Performs research and development in computers and information systems

SCHWARTZ ELECTRO-OPTICS, INC.
(Research Division)
Date Founded: 1985
Products and Services: Designs and manufactures medical, scientific, and military laser equipment

SIGNATRON, INC.
(Subsidiary of Sundstran Corporation)
Date Founded: 1962
Products and Services: Manufactures defense and industrial electronics communication systems and components

SOUND/IMAGE
Date Founded: 1981
Products and Services: Multimedia products and services

SPARTA, INC. (Lexington Branch)
Date Founded: 1980
Products and Services: Engineering services, experimental research in optics and applied physics

SPIRAL SOFTWARE
Date Founded: 1989
Products and Services: Develops scientific and engineering plotting and data analysis products for the IBM PC

TAU-TRON, INC.
(Acquired by General Signal Corp. in 1982)
Date Founded: 1968
Products and Services: Designs and manufactures high-speed digital telecommunication instruments and test equipment

TECHNOLOGY TRANSFER INSTITUTE
Date Founded: 1976
Products and Services: Data processing and telecommunications; seminar service to business executives on computer communications

TELEBYTE TECHNOLOGY, INC.
Date Founded: 1983
Products and Services: Manufactures data communication products such as modems, multiplexers, interface converters, data communication aids, and test and monitoring equipment

TELENET COMMUNICATIONS, INC.
(Now Telenet Communications Corporation, a U.S. Sprint company)
Date Founded: 1973
Products and Services: Data communications products and services

TRANSDUCER PRODUCTS, INC.
Date Founded: 1963
Products and Services: Manufactures electric ceramics and ultrasonic crystals used in underwater exploration and in the medical field

TYCO LABORATORIES, INC.
(Now Mobil Solar Energy Corporation)
Date Founded: 1960
Products and Services: Designs photovoltaic devices

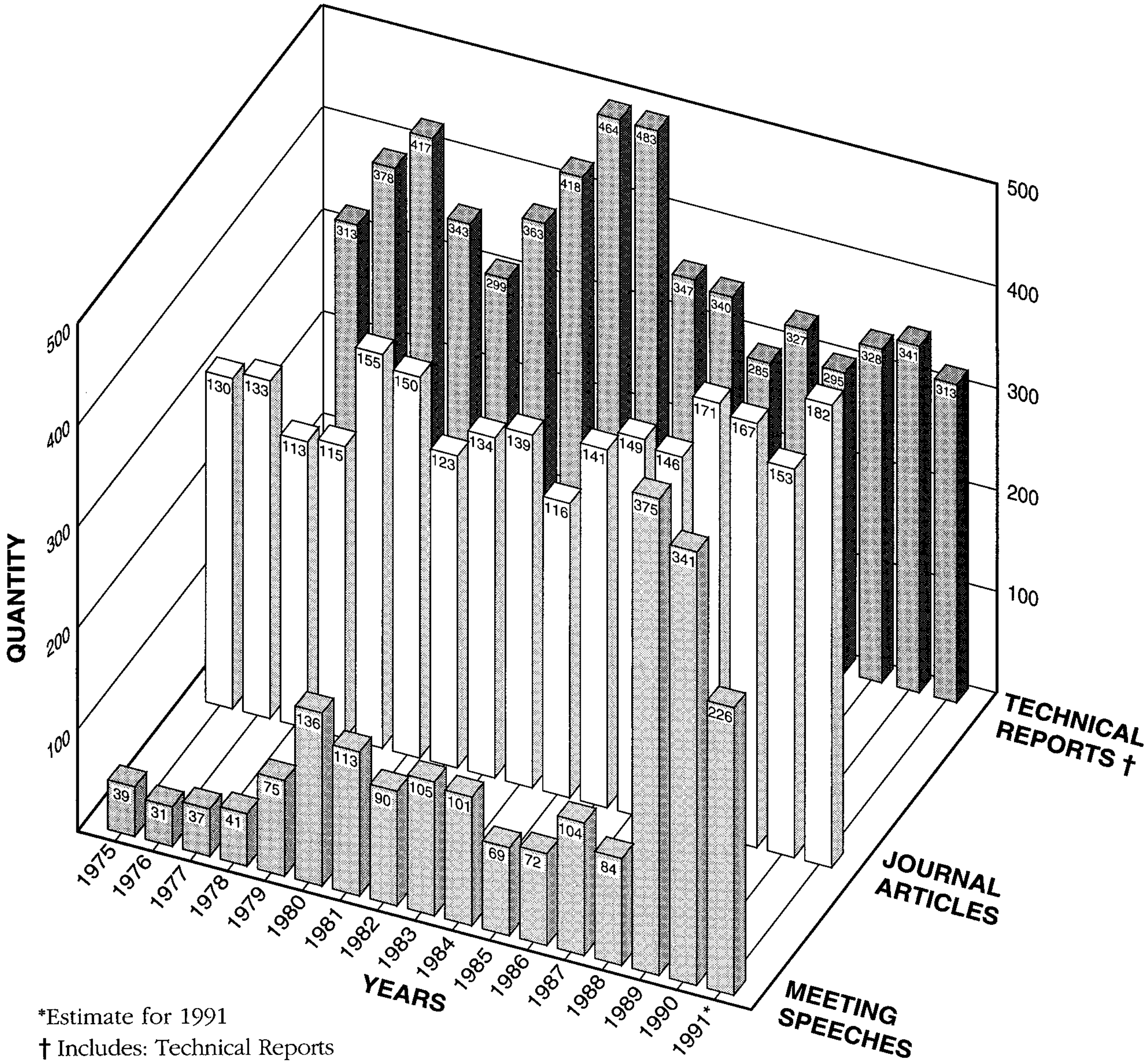
U.S. WINDPOWER, INC.
Date Founded: 1979
Products and Services: Manufactures wind turbine generators, installs electrical generation equipment, and supplies wind generated electricity

WOLF RESEARCH & DEVELOPMENT, INC.
(Acquired by EG&G in 1967)
Date Founded: 1954
Products and Services: Provides digital computer analysis, programs, and associated services for the Army, Navy, Air Force, and NASA

XONTECH, INC.
Date Founded: 1980
Products and Services: Performs research and systems engineering in radar, space, optics, communications, and computer science

ZEOPOWER COMPANY
Date Founded: 1978
Products and Services: Operates as a research and development company, applying zeolite-based technology and prototypes to conventionally fueled commercial space conditioning

Publications of MIT Lincoln Laboratory



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Acronyms

ACTS	Advanced Communications Technology Satellite
AlGaAs	Aluminum Gallium Arsenide
ALPCM	Advanced Linear Predictive Coding Microprocessor
ARTS	Automated Radar Terminal System
ASCAMP	Advanced Single Channel Antijam Man Portable
ASR-9	Airport Surveillance Radar-9
CLEFT	Cleavage of Lateral Epitaxial Film for Transfer
DARPA	Defense Advanced Research Projects Agency
DLAC	Data Link Application Coding
EHF	Extremely High Frequency
FAA	Federal Aviation Administration
FEP	see FLTSATCOM EHF
FET	Field Effect Transistor
FLTSATCOM EHF	Fleet Satellite Communications System, Extremely High Frequency (also called FEP)
FPGA	Field Programmable Gate Arrays
FSK	Frequency Shift Keyed
GaAs	Gallium Arsenide
GaInAsP	Gallium Indium Arsenide Phosphide
HDTV	High Definition Television
IEEE	Institute of Electrical and Electronics Engineers
InP	Indium Phosphide
JSTARS	Joint Surveillance Target Attack Radar System
JTIDS	Joint Tactical Information Distribution System
LDR	Low Data Rate
LITE	Laser Intersatellite Transmission Experiment
LTG GaAs	Low Temperature Grown Gallium Arsenide
LVT	Low Volume Terminal
MBE	Molecular Beam Epitaxy
MDR	Medium Data Rate
Milstar	Military Strategic and Tactical Relay System
MISFET	Metal-Insulator-Semiconductor Field Effect Transistor
MITEC	Machine Intelligent Technical Control
MMT	Man-Portable Milstar Terminal
MSX	Midcourse Space Experiment
MUSE	Matrix Update Systolic Experiment
NESP	Navy EHF Satellite Program
OMVPE	Organometallic Vapor Phase Epitaxy
ONR	Office of Naval Research
PBT	Permeable Base Transistor
PRESS	Pacific Range Electromagnetic Signature Studies

PRM	Precision Runway Monitor
RADC	Rome Air Development Center
SAW	Surface Acoustic Wave
SBV	Space-Based Visible
SCAMP	Single Channel Antijam Milstar Portable Terminal
SCOTT	Single Channel Objective Tactical Terminal
SCT	Single Channel Terminal
SDIO	Strategic Defense Initiative Organization
SEMATECH	Semiconductor Manufacturing Technology (consortium)
SMART-T	Secure Mobile Antijam Reliable Tactical Terminal
SOI	Silicon-On-Insulator
STC	Sinusoidal Transform Coder
STS	Sinusoidal Transform System
STU-III	Secure Telephone Unit - Third Generation
TACCAR	Time Averaged Clutter Coherent Airborne Radar
TRADEX	Target Resolution and Discrimination Experiment
TWT	Traveling Wave Tube
UAV	Unmanned Aerial Vehicle
UHF	Ultra-High Frequency
VLSI	Very Large Scale Integration
ZMR	Zone Melting Recrystallization

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13. ABSTRACT (*Maximum 200 words*)

Perceiving the nation's future in light of global requirements, and foreseeing that our economic and military securities will depend on technology-driven research, Lincoln Laboratory continues to support high-risk technologies of both defense and commercial value. Research and development in the areas of air traffic control, communications, computer hardware and software, laser technology, medical technology, optics, radar, signal processing, and solid state, which are illustrated in this edition of Technology Transfer, demonstrate the Laboratory's endeavors in transferring federally sponsored technologies to the civilian sector.

14. SUBJECT TERMS

technology transfer	communications	lasers	signal processing
dual-use technologies	computers	medical applications	solid state physics
air traffic control	software	optics	radar
astronomy	semiconductors		

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