



RLE

currents

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The Research Laboratory of Electronics at the Massachusetts Institute of Technology

THE MIT RADIATION LABORATORY: RLE's Microwave Heritage

The recent Persian Gulf conflict vividly demonstrated America's high-tech arsenal. Although laser-guided smart weapons and Patriot missiles had not been previously used in actual combat, their superiority on the battlefield was evident. While they may not have single-handedly won the war, they did minimize civilian casualties by accurately pinpointing strategic targets, and may have curtailed hostilities by challenging traditional military tactics.

Fifty years ago, the new technology of that era would also change the nature of warfare. Even as fighting raged on, no effort was spared to develop combat-ready microwave radar equipment that eventually gave the Allies a decisive edge in World War II. The remarkable success of this wartime effort depended not only on the goodwill between the U.S. and Britain, but also on an innovative partnership that was taking shape between academia, industry, and the government; and the new cooperation that was evolving between physicists, engineers, and other scientists from different academic backgrounds. These fledgling bonds would transform scientific research and how it would be carried out in the future.



From left: Professors Julius A. Stratton, Albert G. Hill, and Jerome B. Wiesner have been the inspiring and foresighted builders of the Research Laboratory of Electronics. As both RadLab scientists and RLE directors, all three have emphasized the importance of collaboration between government, industry, and academia in broad-based, fundamental research. (1948 Photo by Benjamin Diver)

Hands Across the Water

Radar, an acronym for radio detection and ranging, had been patented in 1935 by British scientist Sir Robert Watson-

Watt for meteorological applications. Watson-Watt and other scientists believed that radar could also be developed into a system to locate objects

using transmitted and reflected high-frequency radio waves. The range of an

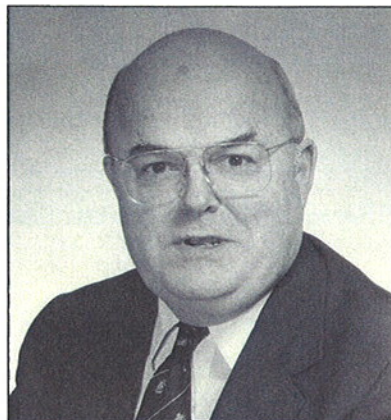
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Director's Message

The fiftieth anniversary of the founding of the MIT Radiation Laboratory (RadLab) is being celebrated this year, and we are especially pleased to devote this issue of *currents* to a remembrance of that lab, its many accomplishments, and its strong leadership. RLE is the natural continuation into peacetime of the RadLab style. The extensive array of equipment amassed in the RadLab formed our initial equipment inventory, and our first three directors were associated with the RadLab.

The wartime experience in the RadLab showed that talented people from several disciplines could effectively focus on a variety of fundamental and applied research projects with outstanding results. Many of these investigators acquired new skills in order to solve these problems, and their achievements showed how effective interdisciplinary research can be.

This was the heritage upon which



*Professor Jonathan Allen, Director
Research Laboratory of Electronics*

RLE was designed and founded, and the wide variety of research presently found in RLE is ample testimony that the interdisciplinary style of research started in the RadLab continues vigorously. We are extremely proud of our roots, and look forward to extending the RadLab style into the exciting future.

MIT RADIATION LABORATORY

(continued)

object in the radio wave's path could be determined by measuring the time it took to transmit and receive the reflected radio waves. This idea had potential for navigation and military applications, especially in determining the distance and altitude of airborne objects.

During the 1920s and '30s, early radar research was being conducted by Germany, France, the United States, and Britain. By the late '30s, the Chain Home network, a ground-based radar network along Britain's east and south coasts, was in operation. Chain Home was a system of antennas that could detect aircraft up to 150 miles away and low-flying planes

as they came over the water. Because it removed the element of surprise, the system was crucial during the London Blitz. British fighter planes were also using radar at one-meter wavelength frequencies. But, in 1940, microwave airborne radar was not yet realized.

With Germany threatening invasion, British scientists aggressively experimented with shorter wavelengths, narrower beams, more compact equipment, and greater power generation to improve their radar capability. Existing radar operated on relatively low frequencies with wavelengths several meters long. The goal was to generate more powerful and narrower beams that operated on shorter wavelengths which could more accurately pinpoint small, airborne targets. The problem

was generating enough high power at these shorter (microwave) wavelengths.

In August 1940, the British government dispatched the top-secret Tizard Mission to the United States to exchange information on radar. The mission's members were Sir Henry Tizard, Chairman of the British Aeronautic Research Committee; Sir John Cockcroft, Director of the British Army Air Defense Research and Development Establishment; and Dr. Edward G. "Taffy" Bowen, a cosmic ray researcher from the University of London. The Tizard Mission arrived first in Canada, and then traveled on to Washington, DC, to meet with the U.S. National Defense Research Committee (NDRC).

The NDRC had been conceived by Dr. Vannevar Bush, Dean of Engineering at MIT and scientific advisor to President Franklin Roosevelt; Dr. James Conant, President of Harvard University; and Dr. Karl Taylor Compton, President of MIT. Established in June 1940 as an indepen-

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The staff of *currents* would like to thank Professor Emeritus Henry J. Zimmermann for his technical guidance during the preparation of this issue.

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RLE

dent federal agency under Vannevar Bush, the NDRC sought to apply civilian scientific ideas in military operations. NDRC's Section D-1, known as the Microwave Committee, consisted of representatives from industry and was charged with investigating radio detection and countermeasures. Dr. Alfred L. Loomis, lawyer-scientist and MIT Corporation member, headed up the Microwave Committee. (Dr. Loomis also hosted a program for MIT students at his Tuxedo Park, New York laboratory on microwave radiation and the detection of moving targets using the Doppler effect.)

In September 1940, the Tizard Mission met with representatives from the

U.S. Navy and Army, the NDRC, and its Microwave Committee to exchange highly sensitive information on radar. The U.S. Naval Research Laboratory disclosed that it had obtained clear, pulsed echoes from aircraft and from those

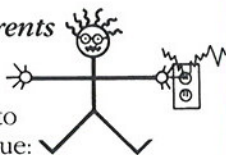
sprouted the idea for the MIT Radiation Laboratory.

Off to a Fast Start

Initially, Bell Telephone Laboratories,

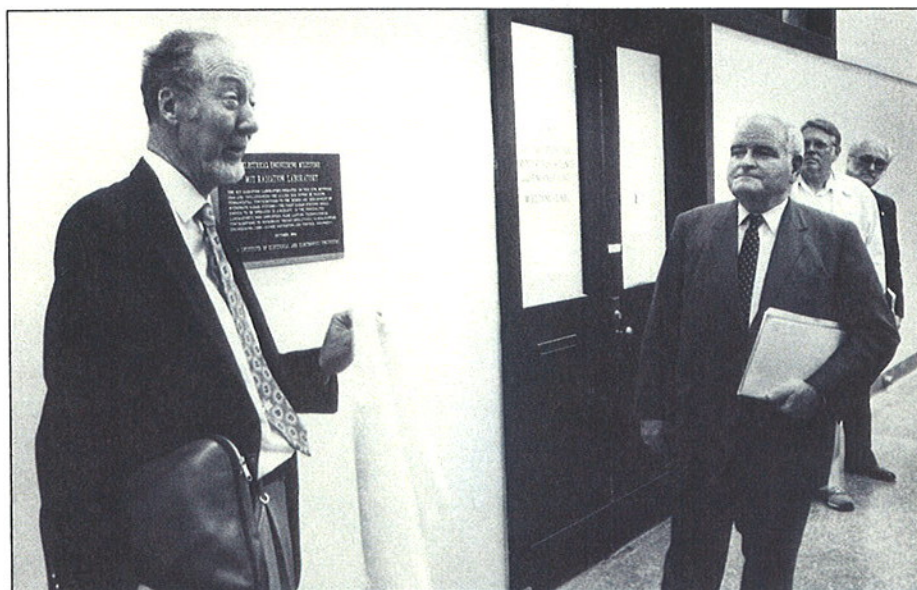
SHORT CIRCUITS

The staff of *currents* would like to note the following corrections to the Fall 1990 issue:



The photo caption on page 18 describing the National Radio Astronomy Observatory in Green Bank, West Virginia, mistakenly identified the 140-foot parabolic antenna. The pictured antenna is the observatory's 300-foot parabola, which collapsed as a result of metal fatigue in a gusset plate near one of its support towers, not snow load as reported. The 140-foot antenna is still intact and operational. Thanks to Charles W. Spann (SB '67) and Professor Gordon H. Pettingill (SB '48) for the correct information.

The photo caption on page 16 of the "Shaggy Dog" microwave radiometer equipment incorrectly described the experiment pictured. The "Shaggy Dog" experiment was conducted in Florida with the apparatus aimed away from the sun. The subjects in the photo are using similar calibrating devices and procedures used for "Shaggy Dog," but are conducting a different experiment. Thanks to Professor Emeritus Robert L. Kyhl (PhD '47) for checking the error.

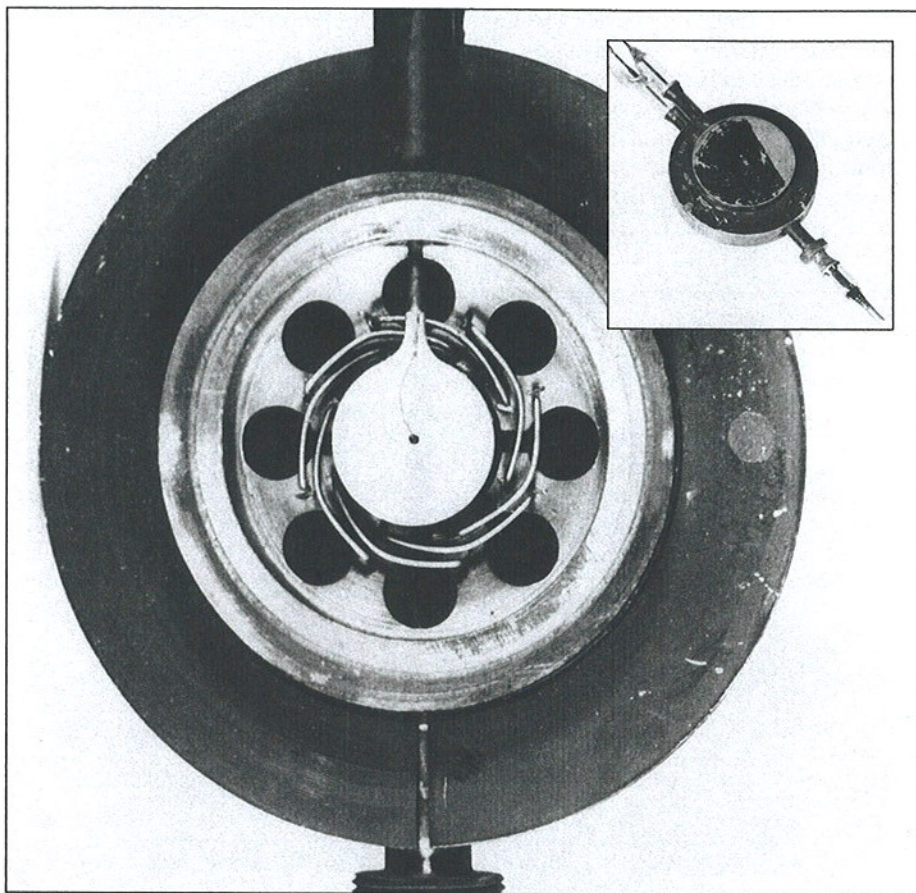


On October 9, 1990, IEEE President Eric E. Sumner (left) presented an Electrical Engineering Milestone commemorative plaque to MIT President Paul E. Gray. The plaque, installed in the corridor outside of MIT room 4-133, RadLab's original office, reads: "The MIT Radiation Laboratory, operated on this site between 1940 and 1945, advanced the Allied war effort by making fundamental contributions to the design and deployment of microwave radar systems—the first radar systems small enough to be operated in aircraft. In the process, the Laboratory's 3900 employees made lasting technological contributions to microwave theory, operational radar, systems engineering, long-range navigation, and control equipment." The IEEE established the Milestones program in 1983 to honor accomplishments in electrical and electronics technology. Through this program, the IEEE hopes to increase the understanding of electrical history among engineers and the public, and to encourage preservation of the historical record of these achievements. The Milestones program is sponsored by the IEEE History Committee and administered by the Center for the History of Electrical Engineering at Rutgers University. (Photo by John F. Cook)

findings had produced shipboard radar. The U.S. Signal Corps had also devised mobile air-warning radar and searchlight-director radar. But, neither country had made substantial progress in airborne radar or high-power transmitters for centimeter wavelengths. In a pivotal meeting with the Microwave Committee, the Tizard Mission revealed the 10-centimeter resonant cavity magnetron invented by British physicists Dr. H.A. Boot and Sir John T. Randall at the University of Birmingham. This magnetron, an efficient, high-power (10-kilowatt) pulsed oscillator that operated at 10-centimeter wavelengths, proved to be the seed that

General Electric, Westinghouse, Sperry, and RCA agreed to quickly supply the magnetrons and other components needed. The NDRC, its Microwave Committee, and the Tizard Mission worked out plans for an independent laboratory that would be staffed by civilian and academic scientists from every discipline. Lee A. DuBridge, a nuclear physicist from the University of Rochester, was hired as the laboratory's director on October 16, 1940. On the following day, MIT was chosen as the site for this still unnamed laboratory. Later that month,

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The resonant cavity magnetron has been described as a "metal ball with protruding glass horns." British physicists Sir John T. Randall and Dr. H.A. Boot, working under Professor M.L. Oliphant at the University of Birmingham, developed the idea of using the klystron's resonant cavity principle in a magnetron. Several production models of this magnetron were manufactured (with different numbers of cavities) by British GEC in 1940, and one accompanied the top-secret Tizard Mission to the United States. Thought to have been a six-cavity magnetron, the Mission accidentally brought one with eight cavities for demonstration. Thus, British models have six resonant cavities, and American models have eight. In this electronic tube, electrons are generated from a heated cathode and move under the combined force of a radial electric field and an axial magnetic field to produce high-energy microwave radiation in the frequency range from 1-40 gigahertz. The magnetrons used for radar applications generate pulsed energy, while magnetrons for microwave ovens generate continuous radiation. (Photos courtesy MIT Museum)

under the guise of an applied nuclear physics conference at MIT, staff members were recruited. Kenneth T. Bainbridge (SB '25 SM '26), a Harvard physicist, was the first to be enlisted, and the laboratory's first meeting took place on Armistice Day 1940 in MIT's Building 4 Room 133. Finally, a name was chosen. To protect the secrecy of its sensitive work, it was called the Radiation Laboratory. The name conjured thoughts of atomic and nuclear physics, a safe and acceptable field of scientific investigation at that time. It also served as a decoy for the laboratory's real work on sophisticated microwave radar.

Fourteen months before the U.S.

entered World War II, RadLab (as it was known) began its investigation of microwave electronics. Six technical working groups were set up to study different components: pulse modulators, transmitter tubes, antennas, receivers, cathode-ray tubes, and klystrons. The first three projects tackled by RadLab were Britain's top priorities:

Project I focused on 10-centimeter airborne intercept microwave radar that could be used by bombers to detect enemy aircraft at night. The first success of Project I came in February 1941, with the detection of buildings in Boston across the Charles River from a two-parabola system on MIT's Building 6. But,

as night bombings of London decreased, attention turned to anti-submarine strategies, since German U-boats threatened to cut Britain off from the sea. The experimental airborne intercept project then shifted to aircraft-to-surface vessel detection. Project I also spawned experiments in shipborne search and land-based harbor defense systems.

Project II, which developed 10-centimeter ground radar for anti-aircraft gun-laying, began in January 1941. The goal was to produce automatic radar tracking to control the aiming and firing at enemy aircraft. Project II resulted in the production of the highly successful SCR-584 gun-laying radar, which is credited with destroying 85% of the V-1 buzz bombs that were dropped on London.

Project III involved long-range radio navigation for ships and aircraft called LORAN. LORAN enabled crafts to locate themselves using radio frequencies. It improved on Britain's Oboe system for bombing Europe and also guided North Atlantic convoys later in the war. By the end of the war, LORAN covered one-third of the Earth's surface.

The Proving Ground

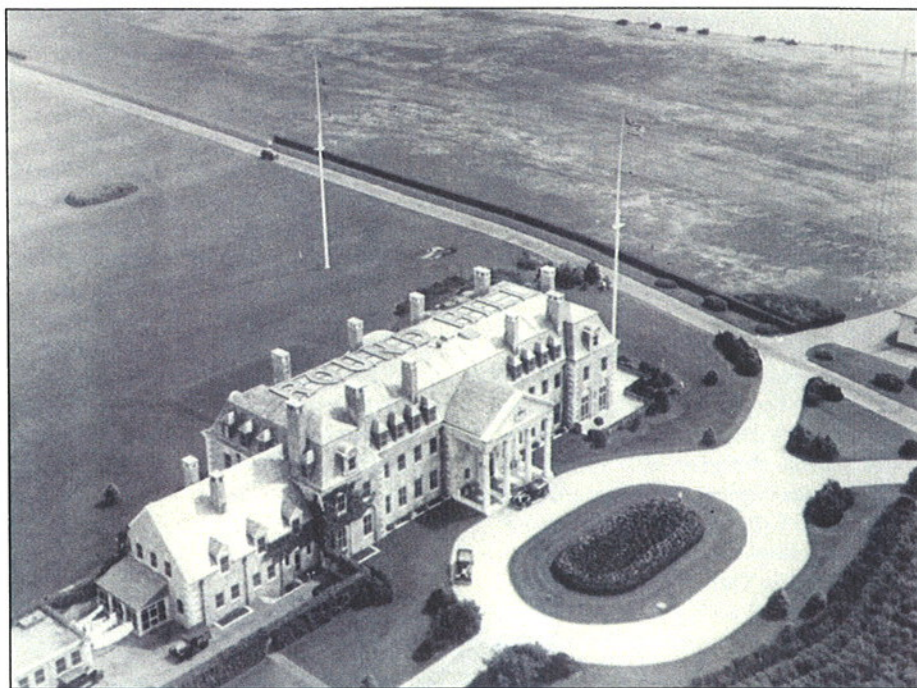
U.S. government and military officials were skeptical of both the civilian scientists and the experimental radar technology. But, on the morning of the Pearl Harbor attack, an Army ground-based long-wavelength radar set at Opana, Oahu, detected Japanese planes as they approached the island. Even though the radar's indications were reported to the officers in command, it was mistakenly believed that the equipment was malfunctioning, and the warnings went unheeded. Consequently, radar gradually gained acceptance as the equipment designed at RadLab proved its accuracy on the battlefields of Europe, Africa, and the Pacific.

In April 1942, Professor Edward L. Bowles was selected as a consultant to Secretary of War Henry Stimson. His first assignment was to assess radar's role in detecting German submarines. Since U-boats would surface at night to attack convoys, they could not then be located by sonar defenses. Professor Bowles persuaded the military to use radar in defense of the Atlantic. Radar was installed on escort ships and, working in tandem with sonar, enabled the Allies to track the U-boats above and below the surface. This proved crucial in winning the Battle of the North Atlantic.

The RadLab was not alone in its mission. Other electronic research centers under NDRC sponsorship studied radar and microwaves. Harvard University's Radiation Research Laboratory worked on countermeasure methods and other aspects of electronic warfare. Columbia University's Radiation Laboratory was established in 1942 and headed by RadLab scientist Isidor I. Rabi. Columbia's Rad Lab investigated microwave components such as the tunable X-band magnetron that operated at frequency ranges above existing devices. Brooklyn Polytechnic Institute's Microwave Research Group worked on measurement techniques and components for microwave systems.

RadLab also contracted with seventy industrial companies to assist in mass producing radar sets. These companies included General Electric, Raytheon, RCA, Westinghouse, Philco, Sperry, and Western Electric. In October 1941, RadLab established its own company, the Research Construction Company (RCC), to manufacture limited quantities of microwave radar systems and components that were not immediately available from industry.

Fire control, airborne radar for blind and precision bombing, ground



MIT's research program at the 277-acre Round Hill estate in South Dartmouth, Massachusetts, started in 1923. Colonel Edward Howland Robinson Green offered the use of his property to MIT, where radio station WMAF broadcasted early network-like programming. Experiments at Round Hill focused on radio communications, the theory and application of microwaves, air navigation, and radio and light propagation through fog. This program was the forerunner of research that was to take place in the MIT Radiation Laboratory. In 1936, the property was given to MIT following Colonel Green's death, and various experiments were carried out there by MIT and Lincoln Laboratory until the estate was sold in 1964. (Photo courtesy MIT Museum)

A Picture of War

"June 5 was a clear beautiful night. It was a bit windy a little after midnight; the moon was up bright and nearly full. The sea was much calmer than previously. After the operation had started it really was a night to set your blood tingling.

"At 2345 something new appeared on the scope; a kind of target I had never seen before. It was a long streak moving directly south. A second group appeared at 2355 looking almost the same; and at 2356 the first streak turned straight east. I had no longer any doubt that something big was on. At 0010 Squadron Leader Cherry Downes told us the Invasion had started, that we were taking part in it and had to do our job as well as possible."

In this way, as reported by the Laboratory's E. C. Pollard, the inva-

sion of France began. Pollard sat in England at a MEW (microwave early warning radar) scope and watched it. He saw armies of planes arise, form and head down towards France. Strings of planes, 20, 40 and 80 miles long were visible at once. Weaving in and out among these, each one separate and distinct, were the roving fighter planes that furnished cover. This whole air fleet performed a slow orbital movement, swinging down over France, dropping the bombs, swinging up over England again and dispersing. It went on all night and continued the next day. It was a picture of war no man had ever seen before. . . .

Reprinted from *Five Years at the Radiation Laboratory*.

imaging, beacon bombing radar, bombing reconnaissance, mobile microwave sets, aircraft and ship search radar, and harbor/coastal surveillance—these are only a few of RadLab's other projects. The microwave early warning system had the greatest range and adaptability of all the microwave ground equipment produced at RadLab, and it played a leading role in D-Day operations, as did the SCR-584 fire-control radar. Supporting the laboratory's hardware production was a group devoted to advanced research on microwave propagation and transmission; the theory of noise, antennas, and waveguides; and signal and design problems with the radar systems. This group was headed up by Isidor I. Rabi, who has been acknowledged by many as RadLab's "scientific heart and soul."

What began as a British-American effort to make microwave radar work, swiftly evolved into a centralized laboratory committed to understanding the theories behind experimental radar

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while solving its engineering problems. From 1940-1945, RadLab designed almost half of the radar deployed in World War II, created over 100 different radar systems, and produced \$1.5 billion of radar equipment. By the end of the war, over a million magnetrons had been produced by the Allies, some operated at millimeter wavelengths and others were capable of one-megawatt of power.

RadLab occupied fifteen acres of MIT space, and its field stations included East Boston (Logan) Airport and Deer Island; Orlando, Florida; and Spraycliff, Rhode Island. Branches also sprung up on several continents, including the British Branch of the Radiation Laboratory at Malvern, England, and the Advanced Service Base in Paris, France. The RadLab switchboard soon became the largest in Cambridge. Almost 4,000 men and women worked for RadLab—nuclear physicists, chemists, mechanical and electrical engineers, mathematicians, biologists, bankers, lawyers, accountants, secretaries, professors, and students. Nine staff members went on to become Nobel laureates, and two became presidential science advisors.

RadLab Ends with a New Beginning

Termination of RadLab was announced on August 14, 1945, and it formally closed on December 31, 1945, leaving behind tons of surplus equipment and a concept for basic research that was to continue in MIT's Research Laboratory of Electronics. The laboratory's technical achievements were recorded in a 28-volume set, the Radiation Laboratory Series, published in 1948 by McGraw-Hill, which is still used today by engineers as a definitive reference on microwave theory and techniques.

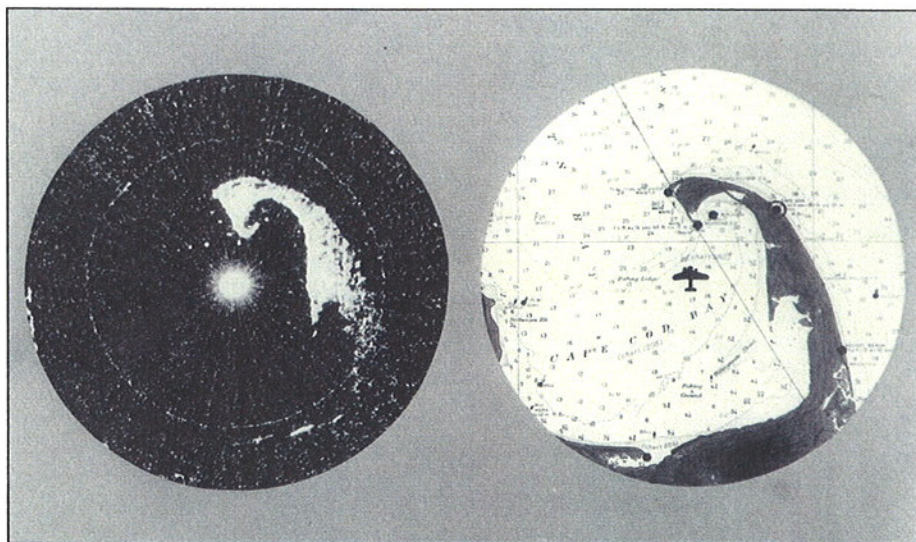
Plans for a peacetime continuation of RadLab had been under consideration since the invasion of Normandy in June 1944. Professor John C. Slater conceived the idea for an electronics laboratory at MIT that would operate jointly under the Department of Physics and the Department of Electrical Engineering. In August 1944, Slater met with MIT President Karl T. Compton, Dean of Science George R. Harrison, and Professors Harold L. Hazen and Julius A. Stratton to discuss these plans. Slater recommended Stratton as director, and in September 1945, Stratton presented a transition plan for the new laboratory. The NRDC

had already voted to provide continued funding under the RadLab contract.

On January 1, 1946, a fragment of RadLab was set up as a transitional organization called the Basic Research Division. Under Director Julius Stratton and Associate Director Albert G. Hill, it continued investigation on problems in physical electronics that involved cathodes, electronic emission, and gaseous conduction. In microwave physics, the electromagnetic properties of matter at microwave frequencies were studied, and modern techniques were applied to both physics and engineering research. Engineering applications were used in

RadLab's Microwave Legacy

The growth of RLE research was boosted by the abundance of microwave components and test equipment left over from the RadLab. Professor George G. Harvey has been credited with inventorying and tagging much of RadLab's surplus equipment, thus ensuring its continued use at RLE. This valuable equipment was coupled with the newly acquired knowledge of microwave measurement techniques plus the backlog of many uninvestigated theoretical and experimental ideas from World War II. RLE scientists and students could now



A plan position indicator scope image of Cape Cod (left), as seen with the experimental airborne search and bombing radar known as X-band ASV developed at RadLab. From this 1942 picture, the exact shape of Cape Cod was known for the first time (compare to map on right). Radar photos such as this one prompted a surprised British RAF dignitary to say, "Gentlemen, this is a turning point in the war." (Photo courtesy MIT Museum)

microwave communication studies.

In March 1946, the Department of Defense set up a committee to oversee the transition: Lieutenant Colonel Harold A. Zahl (Army), Commander Emanuel R. Piore (Navy), and Major John W. Marchetti (Air Force). These three were later joined by Mr. John Keto (Army Air Corps) on a technical advisory committee for what was to become the Joint Services Electronics Program (see related article, page 7).

On July 1, 1946, the Basic Research Division was finally incorporated into the new Research Laboratory of Electronics (RLE) at MIT.

capitalize on shared academic interests, the lab's pooled physical resources, and a new common funding source in the Joint Services Electronics Program.

In 1946, there were five RLE research groups: microwave and physical electronics, microwave physics, communications and related projects, modern electronic techniques applied to physics and engineering, and aids to computation. The microwave studies focused on the generation of powerful radar transmitter pulses, while the activity in electronic circuits and aids to computa-

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The Joint Services Electronics Program at RLE



Participants in a 1963 Joint Services Electronics Program review at RLE (from left): Dr. Arnold Shostak, Office of Naval Research; Lt. Col. William C. Athas, Air Force Office of Scientific Research; MIT President Julius A. Stratton; Dr. Edward M. Reilley, U. S. Army Electronics Research and Development Laboratories; and RLE Director Professor Henry J. Zimmermann. (Photo courtesy MIT Museum)

In June 1941, the Office of Scientific Research and Development (OSRD) was created by the U.S. government to oversee the National Defense Research Committee and the Committee on Medical Research. As a wartime organization, OSRD assigned projects to civilian scientists and engineers from various universities and industrial laboratories. These projects exploited existing scientific theory and technology development essential to the war effort.

A major concern at the end of the war was the suspension of OSRD activity. There was no agency within the federal government that could continue funding for defense-related research. In March 1946, the U.S. government executed a contract with MIT under the sponsorship of a tri-service committee, which consisted of the Army Signal

Corps, the Office of Naval Research, and the Air Materiel Command. The contract awarded RLE its first research funding, in addition to surplus Radiation Laboratory equipment. This tri-service agreement became known as the Joint Services Electronics Program (JSEP). JSEP was essential in maintaining the momentum created by the Radiation Laboratory.

JSEP has funded a broad range of research in basic electronics at RLE. Much of RLE's first research funded by JSEP carried over from the Radiation Laboratory. Initially, there were two main emphases, the first was microwave and physical electronics coupled with the basic study of microwave physics. The second was communication science and information theory. Today, JSEP in RLE focuses on fundamental studies of electrical and optical pro-

cesses. An important emphasis is not only the development of scientific understanding, but also the construction of novel theoretical and experimental tools to produce and observe the phenomena under study. The results under JSEP complement achievements in industry, Department of Defense, and other JSEP-funded academic laboratories.

JSEP at RLE has continued since 1946, making it the oldest sponsored research program at MIT. Likewise, JSEP is the federal government's oldest university-based sponsored research program. By developing continually evolving directions and fostering a high level of cooperation and responsiveness between government and scientific personnel, JSEP has maintained a successful long-term commitment to university-based research.

tion supported work in theoretical design and statistical communication.

Both the microwave and communication interests branched out in many different directions over the years:

Microwave spectroscopy. Professor Malcom W. P. Strandberg studied fundamental atomic resonance phenomena that contributed to the basic knowledge of quantum-mechanical amplifiers. This ultimately led to the invention of devices that could generate coherent radiation by stimulated emission of radiation (the maser and laser).

Research on atomic and molecular beams was another direction that resulted from RLE's initial interest in physical electronics. Professor Jerrold R. Zacharias investigated the resonance phenomena associated with nuclear magnetic moments of elements such as cesium. This work contributed to the first practical demonstration of atomic clocks. Highly accurate standards for time measurement were established using the frequency characteristics of certain atoms, such as cesium, as they were observed in a molecular beam apparatus. The cesium frequency standard is now used commercially and is important in scientific observations and in terrestrial and space navigation systems.

The interest in physical electronics also branched off into solid-state physics, which addressed fundamental problems in condensed matter physics and electronic materials and structures.

Plasma dynamics. Absorption properties of ionized gases in microwave gas discharge experiments conducted by Professor Sanborn C. Brown verified the theory work of Professor William P. Allis and stimulated plasma dynamics research in RLE. There was a special emphasis on radio frequency and microwave gas discharge breakdown and spectroscopy. Initially, the experiments were concerned with low-temperature, low-density plasmas, and progressed to high-temperature, high-density, and fully ionized plasmas. Studies of plasma resonance phenomena led to a better understanding of high-frequency radio wave transmission, since the upper atmosphere contains layers of ionized gas. Later, there were plasma radiation studies and the first quantitative measurements of cyclotron emission and bremsstrahlung by Professor George Bekefi. The phenomena of wave instabilities were also explored, which led to their first classification. In the '60s and

'70s, the generation of coherent electromagnetic radiation and the development of new microwave and millimeter-wave devices also came from this work and ultimately resulted in the building of free-electron lasers. Professor Bruno Coppi later examined the magneto-hydrodynamics of hot fusion plasmas and advanced the theory for the high-field tokamak. In 1980, the evolution of plasma research at RLE contributed to the formation of MIT's Plasma Fusion Center.

Linear accelerator and magnetron phasing. The problem of magnetron phasing was addressed by Professor John C. Slater's construction of a small linear accelerator for electrons. The knowledge acquired in RadLab was the basis for his work, and additional techniques were conceived in RLE. Klystrons or other microwave power sources eventually replaced the magnetron in more modern accelerators, but this work was important in perfecting this type of particle accelerator. In similar studies more closely related to communication and radar applications, Professor Jerome B. Wiesner and graduate student Edward E. David, Jr., (both future Presidential science advisors) investigated transient and steady-state phenomena in phase-locking a magnetron to a more stable source.

Phase-sensitive microwave systems. Missile guidance studies in the late '40s and early '50s included Project Meteor, the code name for a ship-to-air missile research program. Professors Lan Jen Chu, Henry J. Zimmermann, and Campbell L. Searle developed fundamental phase-sensitive microwave systems used in missile guidance. Professor Chu's microwave interferometer used for Project Meteor's homing device led to other studies in phased-array radar systems. Microwave interferometry was also employed in radio astronomy, where very-long baseline interferometers (VLBI) obtain high angular resolution of distant sources. Professors Bernard F. Burke and Alan H. Barrett have used VLBI to correlate radio signals in stellar maser observations. This work received the 1971 Rumford Prize of the American Academy of Arts and Sciences.

Radio astronomy instrumentation. RadLab's interest in minimizing component and cosmic radio noise stimulated RLE studies of high-performance amplifiers. Many early radio astronomy stud-

ies were done with former radar equipment (the dishes used to track targets were now tracking celestial objects with great accuracy), but a variety of new instruments were created as the science evolved. In RLE, Professor Alan H. Barrett used balloon-borne radiometers to measure the oxygen concentration in the atmosphere (OH line), and made microwave observations of Venus in 1962 using radiometers on a NASA Mariner spacecraft. That same year, Professor Louis D. Smullin and Dr. Giorgio Fiocco were the first to bounce a laser beam off the moon's surface.

Optics. Interest in characterizing noise in electronic amplifiers led to the study of optical systems. Although the noise properties of high-speed optical systems are not practical for analog communications, the ability to produce ultrashort optical pulses is important for digital optical communications. Today in RLE, Professors Hermann A. Haus, Erich P. Ippen, and James G. Fujimoto study femtosecond optical phenomena in a variety of materials, and exploit this understanding for high-speed optical switching.

Communication sciences. Statistical communication theory and information and coding theory focused on problems in the generation, transmission, and processing of signals. Studies in statistical communication theory (by Professors Norbert Wiener, Yuk Wing Lee, and Jerome B. Wiesner) gave a better understanding of the communication process in the presence of noise and interference, the optimization of system parameters, and new forms of communication systems. Information theory and coding theory (Professors Claude Shannon, Robert Fano, David Huffman, Peter Elias, Robert Gallager, and John Wozencraft) involved quantitative studies of different noisy channels in terms of the rate of information transmitted. The work was initially concerned with channel capacity, and methods were used that approached the theoretical limit on transmission rate. But, as digital data transmission became more important, the emphasis shifted to error rate and the methods to reduce it by means of error-correcting codes.

The pulsed techniques devised in RadLab were classified information, but in later years they would prove useful in communication technology that used pulses to convey messages. Professor Ernst Guillemin and Dr. Manuel Cerrillo

worked on time-domain network synthesis which led to discrete systems and then to pulse techniques in computers. Guillemin and Cerrillo also worked on electronic circuit theory and the basis for circuit synthesis with graduate student John Linvill, who wrote an important thesis on the gain-bandwidth characteristics of amplifiers.

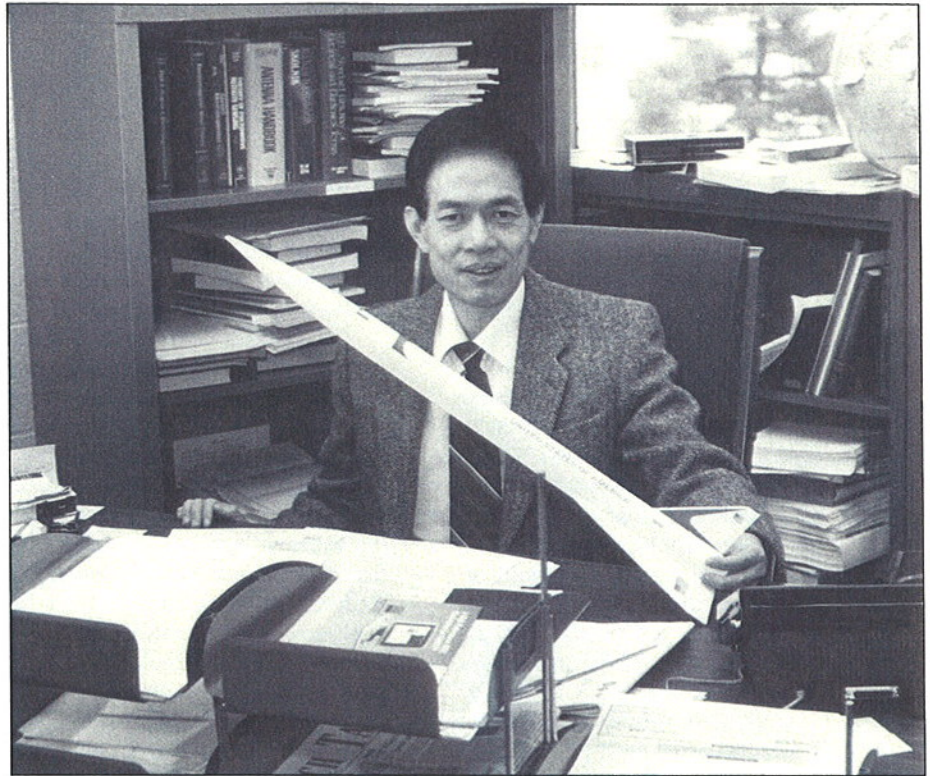
The results from the research projects mentioned above also stimulated MIT's academic program, where new subjects have been introduced in physics, electrical engineering, and other disciplines. Many of these new subjects began as graduate seminars in RLE while the research was in progress.

Riding the Beam from GCA to MLS

Since World War II, radar has been adapted for many purposes, including the navigation of civil aircraft. Highly accurate tracking guidance systems and distance measuring equipment have been used for air traffic control en route or in the airport control area. These systems are especially helpful in bad weather and under heavy traffic conditions.

Early blind-landing systems were studied at MIT's Round Hill program. The RadLab also produced a system for landing airplanes called ground control of approach (GCA). Since most of the GCA equipment was ground-based, the pilot received verbal landing instructions via radio communication. The plane would be detected at a range of 15-20 miles with 10-centimeter search radar, brought on course for landing, and guided down a glide path by the approach controller with a high-precision 3-centimeter system. The first GCA used in combat was at a night-fighter field near Verdun, and was credited with forty landings.

GCA was only one of several airplane navigation systems that was created during the war. Another, the Instrument Landing System (ILS), is still used today as a low-approach guidance system to aid pilots in poor visibility. Although ILS is currently the worldwide standard precision approach guidance system, it has several drawbacks: there must be flat terrain over an extended area for accurate ground reflection patterns, flight patterns must be restricted to a single straight approach path, and there are communication problems with multipath interference. ILS is now over-



Professor Jin Au Kong and his students and colleagues in RLE's Center for Electromagnetic Theory and Applications are evaluating a new airport traffic control system, the Microwave Landing System. Professor Kong displays a model of what may someday be the design for airplanes capable of vertical take-offs and landings using the new landing system. (Photo by John F. Cook)

burdened as large metropolitan areas are faced with airport congestion and channel spacing problems.

Professor Jin Au Kong's group in RLE's Center for Electromagnetic Theory and Applications is investigating possible improvements using a different system, the Microwave Landing System (MLS). MLS offers several advantages over ILS: flat terrain is not required; shorter, curved flight approaches are permitted that can save fuel and reduce noise; and its channel capacity is five times larger than ILS. Professor Kong's group uses a computer simulation tool called EMSALS (Electromagnetic Simulations Applied to Landing Systems) to model and analyze the frequency congestion and electromagnetic interference problems from ten metropolitan U.S. areas. Further details of this research can be found in *RLE Progress Report No. 133*.

RadLab Readings

No single book or document has ever been published on RadLab's history, but

several sources include it as part of a larger work:

A Century of Electrical Engineering and Computer Science at MIT, 1882-1982, by Karl L. Wildes and Nilo A. Lindgren, touches on the lives of the many individuals who were part of RadLab and discusses historically important technological advances within MIT's Department of Electrical Engineering and Computer Science and RLE. (MIT Press, 1985)

Radar Days, by Edward G. Bowen, is an insightful personal history from Dr. Bowen's early involvement in the scientific discoveries of wartime radar in England through the inception and creation of RadLab. Dr. Bowen was a member of the Tizard Mission and RadLab. (Adam Hilger, 1987)

The MIT Radiation Laboratory Series, edited by Louis N. Ridenour, is an extensive technical documentation of RadLab projects in 28 volumes with an index. The series is now out of print, but

(continued on page 10)

A Building with Soul

I am sitting inside MIT's legendary Building 20 with three great minds, one of them encased in plaster.

Institute Professor of Linguistics Morris Halle and neurophysiologist Jerome Lettvin—seated on opposite sides of a bust of German naturalist and explorer Alexander von Humboldt—are rhapsodizing about the rickety wooden barracks that is their professional home.

"Building 20 is an admixture of all the interesting things at MIT," says Lettvin, a jovial mountain of shivering cerebra who is admired inside Building 20 not for his genius but as a man who first uttered a profanity on television, during a 1961 debate with Timothy Leary ("It made the front page of *Variety*," Lettvin insists. "You can look it up.")

What's so special about Building 20? Even the MIT Museum had trouble answering that question in 1980, when it organized an exhibit dedicated to the ramshackle "Plywood Palace," the least descript of all the institute's studiously nonde-

script structures. "Why do we celebrate a building so modest, so meek and indeed so homely in its demeanor?" asked the introduction to the exhibit catalogue.

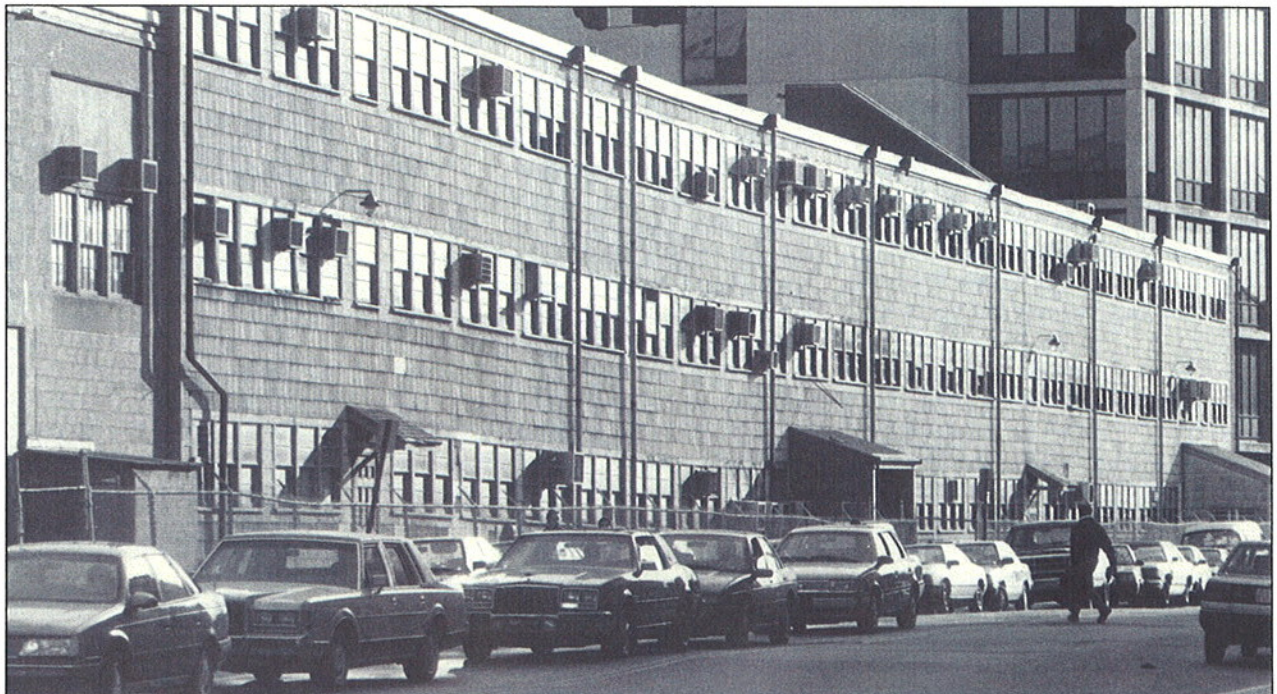
First off, we celebrate its history. One of several temporary structures thrown up on campus during World War II—it took less than an afternoon to design—Building 20 is the only one still standing. Many of MIT's greatest projects, including the wartime radar project and its first interdisciplinary labs started in Building 20, along with many of the institute's leading professors.

Secondly, the building is the kind of academic melting pot that gives university presidents indigestion. Famed linguist and antiwar activist Noam Chomsky works just a few doors away from MIT's ROTC offices, which have decorated one whole wall with a colorful mural of an F-16 fighter.

The music department's piano repair facility—a "computer-free zone," according to a sign on the

wall—shares a floor with the nuclear science lab's shop room. The model railroad club, which houses the most sophisticated toy train in the world, is just a stone's throw away from the chemical engineering department's cell culture lab, where a bulletin board message inquires plaintively: "Did anybody use toxic substances in the small Corning spinner flasks? About half of my cultures died without apparent reason."

After the war many of the heavyweight research projects moved into their own buildings, and Building 20, with its creaky floors and poor ventilation, attracted researchers who couldn't find space elsewhere at MIT. Once they settled in, they fell in love with the place. "It turned out to be absolutely perfect for research," explains Halle, an ebullient bearded scholar who has made Building 20 his home for 37 years. "You can knock down a wall, you can punch out a ceiling, and you could get space. In



academics, space is everything."

In the interests of space, Halle's lab launched an "expansionist" raid against the model railroad club's huge two-room suite. The land grab failed because the club argued that its computerized, 200-switch track layout could not be easily moved. Indeed, a move against the club might have set off a revolt among the building's older tenants, who fondly remember the five-cent Cokes dispensed from the club's specially programmed soft drink machine.

Not surprisingly, Building 20 has its own myths.

"I know someone who can tell you some hair-raising stories about the early days of microwave," Lettvin says, shoving aside piles of unopened mail to dial his phone. Unfortunately, his contact isn't in.

"Remember the phantom?" Lettvin asks. Indeed, Halle does remember the mysterious, homeless botanist who camped out in a Building 20 storeroom and haunted the building's corridors during the 1960s and '70s. No one knows how he supported himself, or who his family was. "He turned down a job at the Field Museum in Chicago in order to remain a phantom in Building 20," Lettvin says.

The professors say MIT tried to evict the squatter and lost their case in a Cambridge court. The phantom hung on until 1980, only to drift into oblivion—and into the history of Building 20.

"A Building with Soul" by Alex Beam originally appeared in *The Boston Globe*, June 29, 1988. It is reprinted with permission of *The Boston Globe*.

A World War II survivor, Building 20 as it looks today, with the Research Laboratory of Electronics (Building 36) towering in the background. (Photo by John F. Cook)

is available at many scientific reference libraries including the RLE Document Room.

Five Years at the Radiation Laboratory was published by MIT after the termination of RadLab. This book is the most comprehensive overview of the laboratory, its work, and the people who were part of this unique experience. Originally published with classified information omitted, a limited number of copies has now been reprinted by the Boston chapter of the IEEE Microwave Committee to commemorate the RadLab's 50th anniversary, with much of the

restricted information reinstated.

Echoes of War is part of the NOVA television series on the Public Broadcasting System. This one-hour program, which was produced in 1989, surveys RadLab's role and the impact of radar in World War II, and includes interviews with several RadLab members. Videotapes of the program are available through the WGBH Public Video Service by calling (800) 248-8311. Transcripts are also available through NOVA Transcripts, Journal Graphics, 267 Broadway, New York, NY 10007.

by Dorothy A. Fleischer

Please Be Seated

When MIT Building 22, previously occupied by the RadLab, was razed in 1954, several stray chairs from the RadLab's conference room found a home in Building 20. Graduate student Abraham Bers had just arrived at MIT and was assigned to room 20B-003, which he shared with the chairs. These wood desk chairs were typical of the World War II period, and were probably considered "executive" models since they had arms. Two chairs displayed name tags stamped with "L.A. DuBridge," MIT's Radiation Laboratory director. Mr. Bers, who was to join the MIT Physics faculty in 1959, learned the historical significance of that name and has taken care of the chairs ever since. One might say that Professor Bers is the "holder of the DuBridge chairs."

The chairs have since moved several times with Professor Bers, who is a principal investigator in RLE's Plasma Physics Group. They are now in the library across from his office in Building 38. "I'm not the only one who received support from these chairs," admits Professor Bers with a smile, referring to the many students he has worked with over the years. "They all sat a lot when they were here."

For now, the chairs will remain in his library. In the future, perhaps someone will offer to care for them as Professor Bers has done. Or, the chairs might

find a home at the Smithsonian, because, in hindsight, didn't radar put an end to flying by the seat of one's pants?

by John F. Cook



Today, Professor Abraham Bers (left) and Professor Emeritus Louis D. Smullin enjoy a moment in the DuBridge chairs. Photograph below shows imprinted tag still in place. (Photos by John F. Cook)



DIRECTORS' PROFILES:

In this issue of *currents*, we have devoted our Profile section to RLE's first four Directors, who shared the experience of working both with the RadLab and RLE.

President Emeritus Julius A. Stratton (EE '23, SM '26)

*RadLab, 1940-42; Expert Consultant to War Department 1942-45
Basic Research Division, 1945-46
RLE Director, 1946-49
MIT Provost, 1949-51
MIT Vice President, 1951-55
MIT Chancellor, 1955-57
MIT Acting President, 1957-59
MIT President, 1959-66*



Professor Emeritus Julius A. Stratton

President Emeritus Julius A. Stratton was born in Seattle, Washington, in 1901. He traveled widely as a boy and, with his strong interest in radio, became a ship's radio operator at the end of World War I. He studied for one year at the University of Washington and transferred to MIT, graduating in 1923. His interest in the humanities prompted him to enroll at the University of Grenoble and the University of Toulouse, but he returned to MIT for graduate study in electrical engineering. He completed his master's

in 1926 and, on an MIT traveling fellowship in mathematics and physics, studied at the Swiss Federal Institute of Technology where he received his ScD in 1928. He returned to MIT as an Assistant Professor of Electrical Engineering, and in 1930 transferred to the Department of Physics where he became Associate Professor in 1935 and full Professor in 1941.

During the '20s, his research at the MIT program at Round Hill involved the propagation of short waves in radio transmission, the forerunner of later efforts for radar development. Professor Stratton was also responsible for the innovative changes made to the Institute's curriculum during the '30s. He became a staff member at the RadLab in 1940, and worked on the development of LORAN in the theory group. In 1942, he went to Washington as Expert Consultant to the Secretary of War and was awarded the Medal for Merit for his services. In 1946, Professor Stratton became the first director of RLE, continuing RadLab's tradition of interdisciplinary research.

Over the years, he has held research and faculty appointments in both Electrical Engineering and Physics, and has been responsible for important academic and research policies in his administrative capacities at the Institute. In addition, he has served on a variety of government boards and committees, and has participated in many professional and scientific organizations, and has also served as a trustee for many educational and cultural institutions. He is the recipient of numerous professional and humanitarian honors.

Professor Stratton's comments are excerpts from his essay "RLE—The Beginning of an Idea" which originally appeared in the commemorative booklet RLE + 20.

Those of us who were here in the '20s and '30s can recall the emergence in those years of an intense and widening interest in the new fields of communications and electromagnetic theory. This started first in the Electrical Engineering Department but soon spread to Physics and Mathematics.

At the outset the progress of communications engineering at the Institute owed most to the initiative and leadership of Edward L. Bowles, who established new laboratories and brought in many young faculty members who were to play a prominent part in later developments. W.L. Barrow, returning from Munich where he had studied with Zenneck and Sommerfeld, began here his work on the transmission of ultra-high frequency electromagnetic waves through hollow tubes, a pioneering contribution to the use of wave guides. At Round Hill, Henry Houghton and W.H. Radford were studying the propagation of millimeter waves and infrared signals through fog and rain. In 1938, Lan Chu presented a brilliant doctoral thesis on the radiation of electromagnetic waves in hollow pipes and horns. In the Insulation Laboratory Arthur von Hippel was investigating the behavior of dielectrics at ultra-high frequencies. And Ernst Guillemin was well on the way to establishing himself as one of the foremost authorities on circuit theory.

In the Physics Department Wayne Nottingham was absorbed with his research on cathode emission and physical electronics. . . . William W. Hansen, who contributed later to the development of the klystron, spent some time with us during this period as a National Research Fellow and proved to be an enormously stimulating influence on our early thinking about microwaves. And Philip Morse and I were occupied with a variety of problems related to the propagation, scattering, and diffraction

DIRECTORS' PROFILES



From left: Professors Julius A. Stratton, Jerome B. Wiesner, and Albert G. Hill practice their slicing form at RLE's 10th anniversary party held at the Woodlawn Golf Club of Brookline in 1956. (Photo by Benjamin Diver)

of electromagnetic waves.

These are but a few highlights of our research interests in the years before the Second World War, but they are sufficient to indicate the extent to which a substantial number of our faculty were preoccupied with a host of practical and theoretical questions ranging from the generation of microwaves and the design of high frequency circuits to the properties of electron gases and the study of electromagnetic radiation and boundary value problems. Out of these interests there grew a remarkable spirit of collaboration between the physicists and the electrical engineers. A whole new field of effort began to emerge, focusing our attention upon a closely knit set of problems which we now identify as electronics. Indeed, in his President's Report for 1939, Karl Compton made special mention of the related research projects which were coalescing "into wide-ranging programs, breaking across departmental boundaries and involving cooperation with outside agencies."

... On Armistice Day in 1940, the first meeting of the Radiation Laboratory took place in Room 4-133. Over the next five years that laboratory drew to our campus physicists, mathematicians, chemists, biologists, engineers, and even architects and historians, from every part of the country. As a pooling of intellectual forces and disciplines for a concentrated attack on a scientific or technical objective, the Radiation Laboratory was to be matched only by the

operations of the Manhattan District.

... as early as 1943 there were speculations about a peacetime sequel to the Radiation Laboratory, whose efforts had not only produced hardware but had also resulted in enormous advances in the entire field of electronics. And with our own background at MIT in these areas of science and engineering, we were presented with a unique opportunity to play a leading role in their further development. To ensure that we would be in a position to move promptly when the occasion arose, the Executive Committee of the Corporation set aside at that time an initial sum of \$50,000.

The stage was thus set; but it was John Slater who brought all our ideas into focus, who clearly defined the concept of a new kind of laboratory, and who took the initiative that led finally to the establishment of RLE. Professor Slater was then Head of the Department of Physics and on leave to Bell Telephone Laboratories. Beginning in August 1944, he set forth through a series of letters and in conferences the main lines of his proposal. ...

On the national scene the decision to liquidate the OSRD was first greeted in 1945 by much criticism, both from the military and in academic circles. In retrospect it appears clearly to have been a wise and statesmanlike move; but at the time it seemed that the country was about to dissipate irreplaceable resources. The war, on the one hand,

had demonstrated in a spectacular manner that henceforth military strength and security would be utterly dependent upon a very advanced, highly sophisticated technology. On the other hand, we had been drawing heavily on the accumulated scientific capital of the pre-war years, and there was now an urgent need for replenishment. The idea of massive federal assistance for basic research began to develop as a new direction in national policy. The approaching dissolution of the OSRD served only to emphasize that wholly new patterns of support would have to be devised for the research efforts of our universities. ...

Fortunately for science, for the universities, and for the country, various agencies of the Armed Services stepped promptly into the breach and undertook the sponsorship of basic research in academic institutions on an unprecedented scale. The Research Laboratory of Electronics in particular owed its first major and continuing support to this foresight and initiative. In March of 1946, a task contract was drawn up providing for joint support by the Army Signal Corps, the Navy, and the Army Air Force. By common accord the Signal Corps was chosen as the administering agency. The task statement itself, our terms of reference, amounted to a very broad interpretation of the word electronics and was designed to ensure the maximum freedom of research. ...

The founding of the new electronics laboratory in 1946 represented a major departure in the organization of academic research at MIT and was destined to influence the development of interdepartmental centers at the Institute over the next two decades. These centers have been designed to supplement rather than replace the traditional departmental structure. They take account of the fact that newly emerging fields of science commonly cut across the conventional disciplinary lines. And they afford a common meeting ground for science and engineering, for the pure and applied aspects of basic research, to the advantage of both. Perhaps more than any other development in recent years they have contributed to the special intellectual character and environment of MIT.



Professor Emeritus Albert G. Hill

RadLab, 1942-45

Basic Research Division, Associate

Director, 1946

RLE Director, 1949-52

Lincoln Laboratory Director, 1952-55

*MIT Vice President for Research,
1970-75*



Professor Emeritus Albert G. Hill

Born in St. Louis, Missouri, in 1910, Dr. Hill received his bachelor's degree from Washington University in 1930. After two years as an engineer at Bell Telephone Laboratories, he returned to Washington University and received his master's degree in 1934. He completed his doctoral studies at the University of Rochester in 1937.

Professor Hill came to MIT as a physics instructor in 1937. He joined the RadLab in 1941, and eventually became the head of the laboratory's largest technical division. In 1946, he became Associate Professor of Physics and the Associate Director of the newly formed RLE. In 1947, he was promoted to Professor, and named RLE's second director in 1949. In 1952, Professor Hill became director of MIT's Lincoln Laboratory. He was responsible for guiding laboratory personnel in the production of air defense systems (Semi-Automatic Ground Environment and Distant Early Warning) using modern electronic devices, computers, and radar. In 1955, he returned to MIT and in the summer estab-

lished the SHAPE Technical Center in The Hague and the NATO Communications Line.

In 1956, he served in Washington as director for the Weapons Systems Evaluation Group, and the Vice President and Director of Research for the Institute for Defense Analyses. He resumed teaching at MIT in 1959. In 1970, he was appointed as MIT's Vice President for Research, and became Chairman of the Board at Charles Stark Draper Laboratories in May of that year.

Professor Hill has served in roles that required both a technical background and administrative experience, and through these he has contributed to the nation's defense-oriented research and development organizations. Professor Hill has received the Presidential Certificate of Merit (1948), and Distinguished Civilian Service Medals from the Air Force (1955), the American Ordnance Association (1956), and the Secretary of Defense (1959).

Professor Hill's comments are taken from his essay "Why the Military?" which originally appeared in the commemorative booklet RLE + 20.

... The need for science had never been apparent in a broad sense to the American people and their government before its use in military development during World War II. The terms of reference of science and the citizen had altered. Science had changed from the proprietary ivory tower interest of the few to the property and concern of the many. Although science *per se* had been neglected during World War II, scientists had not; and the voices of scientists were now, for the first time in peace, sought at the highest government levels.

August 1945 found the Radiation Laboratory a going concern whose death was imminent, and yet this vast scientific capital must somehow be channeled into peacetime use. It was very natural, therefore, for the fall of 1945 to see the metamorphosis of the Division of Basic Research of the Radiation Laboratory into the new Research Laboratory of Electronics at MIT. This change had been foreseen by John Slater as early as 1944 and seemed a very natural thing to those of us who experienced it.

Recognition of the importance of science was not enough. Financial support at a scale many, many times higher than the pre-war scale was a necessity. The Office of Naval Research has justly received a great deal of credit for its actions in the post-war period. Not so well known were the similar ideas in both the Army Signal Corps and the Army Air Corps Communications Command. Although proposed forms of support of research were many and varied in that period, in [Julius] Stratton's mind it was essential that this support be of a long-lasting nature and that it contribute to the academic program of the Institute. (From these initial beginnings came the present tripartite core program support of RLE by the Office of Naval Research, the Army Materiel Command, and the Air Force Systems Command.)

Since peace and peaceful ways were uppermost in the minds of the scientific community, why then military support? First of all, from the simple matter of expediency there was no other support, and science had to come into its own. Secondly, those of us responsible for carrying out this program took the point of view that eternal vigilance was the price of keeping science alive without becoming subservient to military needs. ... the dangers of military support of science in this country were greatly overstressed at the time, but probably the overstressing served to keep both military sponsor and the scientific sponsored aware of the danger.

Nevertheless, there came the time in early 1946 when the [Navy] approached RLE on the possibility of developing a guidance system for the Meteor missile. After much soul-searching, it was recognized that this was, indeed, an advanced engineering project, that both applied research and advanced development were required in its execution, and that it had many attractive features for engineering pedagogy. The assignment was accepted, but only after assurance that minimal security requirements would be placed upon the project. ... it is pleasant to report that the project was much more successful academically than militarily. The Meteor project never came into fruition as a weapons system, but the guidance principles developed in the Research Laboratory of Electronics have been widely

used, and the number of engineering students supported and trained in the broad engineering principles of guidance and control has been great.

China, the events behind the Iron Curtain, and the Berlin blockade soon made it apparent that the world was not the stable place we had dreamed of in August 1945. In this period many of us undoubtedly recalled our relations as scientists to governmental problems, especially military, and I think we all felt that should an emergency arise, we were ready and able to re-attack military problems. . . .

The reaction of the scientific community to the new military situation took two general paths, in both of which RLE participated [summer studies and the air defense of North America]. . . .

The first such [summer] study . . . was Project Lexington, which was conducted by MIT during the summer of 1948 and staffed by scientists from many institutions. Its assigned task . . . was to determine "the technical feasibility of nuclear-powered flight." . . . Unfortunately, as it developed, nuclear-powered flight was deemed technically feasible, but its desirability from the point of view of performance and economics has never been proved.


The second well-known summer study was Project Hartwell, conducted at MIT on behalf of the U.S. Navy and including some of the same personnel as Project Lexington. The problem first addressed to MIT was "to find new ways of detecting submarines." . . . an outstanding group was assembled at the MIT Field Station in Lexington for the three summer months of 1950, and from their deliberations came, among many ideas, the following diverse accomplishments: The Mariner class of merchant vessels; the SOSUS submarine detection system; the atomic depth charge; a whole new look at radar, sonar and magnetic detection; and a good deal of research on oceanography. . . .

With the Russian atomic explosion in 1949, the security of the United States on its own shores became threatened for the first time since the early 19th century. Shortly after the Russian atomic explosion, the Scientific Advisory Board of the U.S. Air Force established the Air Defense Systems Engineering Committee (ADSEC). . . . and by the late fall of

1950 had concluded that air defense was both necessary and feasible. Based on this conclusion, [ADSEC] asked that MIT set up a laboratory to develop implementation of certain ADSEC technical proposals. Since this was to be a major undertaking in a major systems field, MIT countered with the suggestion that the establishment of the laboratory be preceded by an *ad hoc* study (later called Project Charles) . . .

Meanwhile the Korean War had begun in June of 1950, and shortly thereafter, while [Project] Hartwell was still meeting and before the air defense project was started at MIT, the three Service sponsors of RLE asked that the Laboratory's program be enlarged because of the Korean situation. . . .

Hence when the Charles study began in February of 1951 and before the formal establishment of the Lincoln Laboratory in August of 1951, a going concern for military problems of importance to continental air defense had been established at RLE. Again in the spring of 1951 MIT requested and the Services agreed to combine the applied group of RLE with the soon-to-be Lincoln Laboratory. This group from RLE became the Communications and Components Division of Lincoln Laboratory, and together with a group from AFCRC working on digital data transmission methods and the MIT Whirlwind Computer Laboratory, formed the nucleus of Lincoln Laboratory's hardware program.

We have seen, in the six-year period from August 1945 to August 1951, a new academic, peacetime laboratory start from the defunct wartime Radiation Laboratory, and in turn the academic laboratory enabled a new applied military laboratory to get off to a running start. From this, all kinds of conclusions can be drawn regarding six-year cycles, military expediency, and the beauties of the *ad hoc* study. I firmly believe, however, that the only verifiable conclusion is that military support of university research can be extraordinarily fruitful for both parties. Certainly there are dangers, but care and mutual respect can obviate most of them. Personally, I feel that basic research can profit from an association with the applied or programmatic research—an association that should be close, but must not be smothering. 

President Emeritus Jerome B. Wiesner

RadLab, 1942-45

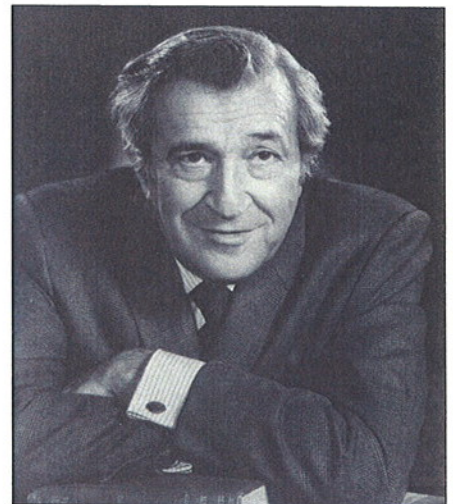
RLE Assistant Director, 1947-49

RLE Associate Director, 1949-52

RLE Director, 1952-61

MIT Provost, 1966-71

MIT President, 1971-80



President Emeritus Jerome B. Wiesner

President Emeritus Jerome B. Wiesner was born in Detroit, Michigan, in 1915, and graduated from the University of Michigan at Ann Arbor (BS '37, MS '38, PhD '50). In 1940, he worked at the Library of Congress where he assisted in developing advanced sound recording facilities and recording regional American folk music. In 1942, Professor Wiesner joined the RadLab staff and became an associate member of the laboratory's steering committee and group leader of Project Cadillac, the forerunner of the AWAC airborne radar system. In 1945, he joined the Los Alamos Laboratory staff, but returned to MIT in 1946 as an Assistant Professor of Electrical Engineering. He became Associate Professor in 1947, and full Professor in 1950.

Professor Wiesner was a frequent consultant and advisor to government agencies on matters relating to science and technology. He served as President John F. Kennedy's Special Assistant for Science and Technology and chaired the President's Science Advisory Committee.

DIRECTORS' PROFILES

He returned to MIT as Dean of the School of Science in 1964 and was appointed Provost in 1966. He became MIT's thirteenth president in 1972. In addition to his research interests, Professor Wiesner is noted for his efforts to use science and engineering in solving humanitarian problems. Among his many professional and public service awards are: President's Certificate of Merit (1948), the IEEE Founder's Medal (1977) and Centennial Medal (1984), and the National Academy of Engineering's Arthur M. Bueche Award (1985).

Professor Wiesner's comments are excerpts from an unpublished essay titled "Remembering RLE."

... It would take a book to only outline the many developments of the Rad Lab that included ground, shipborne and airborne radars, an aircraft landing system, and countless pieces of test equipment needed to keep them all running. In fact, the last organized act of the Rad Lab was to author a set of twenty-seven books describing for posterity what had been learned. As I write this, I see in my mind's eye the 584 air defense radar that was so important to the European ground war, the various shipborne and airborne fighter systems, including my own project Cadillac, which literally saved the American fleet in the Pacific, and the systems H2S and H2X which made possible massed nighttime flights of allied bombers when they became too vulnerable to fighter aircraft and anti-aircraft on daytime flights. I see clearly too, the hundreds of friends who worked night and day to have these complex and tricky machines ready on the impossible schedules that make all the difference in wars.

It is sometimes said the Rad Lab was the first large interdisciplinary laboratory where people from very different disciplines used their special knowledge to work toward a common goal. I don't agree with that description, for although people with very different backgrounds, mostly scientists and engineers, worked together to develop microwave radar systems, most of them had to learn new disciplines and skills to be effective rather than practicing what they already knew. What the Rad Lab really showed

was that well-trained, very bright individuals could quickly learn new disciplines and new skills. ... In a situation where there were very few "experts" it was easy to get up to speed quickly. In a short time, it was not possible to tell a person's background by the skills that were exhibited in their work. Even before the Rad Lab existed, there were many laboratories in which scientists and engineers with different backgrounds worked toward a common goal, usually an applied goal, but the range of disciplines found in them was usually rather narrow. Two good examples are the Bell Telephone Laboratories and those of the E.I. DuPont Chemical Company. The Naval Research Laboratory had a broader mandate and employed a wide range of scientists and engineers, but it was hardly an interdisciplinary laboratory in the true sense. It was common for interdisciplinary teams to do medical research but they were usually very small. ...

Radiation Lab set a new style of collaboration. As far as I know, this was the first time a large-scale collaboration was undertaken between an academic group, the military, and industry. The undertaking was a great success and it set the pattern for post-war collaborations of a similar nature. The collaboration between academics and the military was facilitated by the fact that many of the military officers were really scientists and engineers who had joined the military for the duration. They were the unsung heroes because most of them had some reserve training before the war, and they understood military requirements. At the same time, they could communicate quite easily with most of the Radiation Lab personnel, who were largely ignorant of military requirements and organization, to say nothing of being scornful of many of them.

As the Rad Lab started, it had much assistance from the researchers at Bell Telephone Laboratories, one of the great laboratories of the world, whose early work on microwave components, radar systems, time measurement techniques, and many other aspects of electronics helped the Rad Lab people get a jump start on their task. With the passage of time, the helping turned into true collaboration. ...

RLE was only one, though the biggest, of a group of university-based research laboratories that the Three Services Committee brought into being. There were eventually nine of them and they were to play a major role in restarting research and higher education in the post-war period. Without this far-sighted venture there would not have been the continuity of research or the rapid reestablishment of education that took place in 1946. ...

At the start the RLE had two quite separate tracks: physics, in which researchers set out to exploit microwave tools in search of information about the physical universe, and the communications option, which primarily involved electrical engineers at the beginning, then quickly broadened to include speech and linguistics, neurophysiology, psychology and several other disciplines. Several joint programs developed, involving the two original sponsoring departments. They might otherwise not have happened. The RLE program in radio astronomy is a good example of this.

Much of the communications work was inspired by Norbert Wiener and his exciting ideas about communications and feedback in man and machines. Wiener's theories, and those of Claude Shannon on information theory, spawned new visions of research for everyone interested in communications, including the neurophysiology, speech, and linguistics investigations. The work was both theoretical and experimental as well as basic and applied. For example, many early ideas about coding were developed in the RLE. So were broadband communications systems and the much earlier work about digital systems, as well as the interesting and exciting new ideas, such as the use of correlation functions to enhance weak signals, random noise as the carrier of signals, and the use of noise to measure system functions. This mix of the exploration of new ideas and their reduction to practice remains the hallmark of the present-day RLE.

In the winter of 1947, Wiener began to speak about holding a seminar that would bring together the scientists and engineers who were doing work on what he called communications. He was

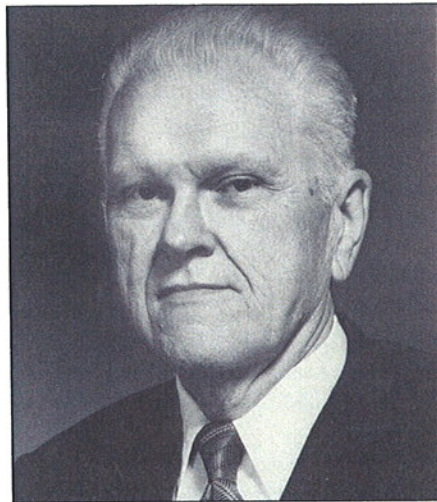
launching his vision of cybernetics in which he regarded signals in any medium, living or artificial, as the same; dependent on their structure and obeying a set of universal laws set out by Shannon. In the spring of 1948, Wiener convened the first of the weekly meetings that was to continue for several years. Wiener believed that good food was an essential ingredient of good conversation, so the dinner meetings were held at Joyce Chen's original restaurant, now the site of an MIT dorm. The first meeting reminded me of the tower of Babel, as engineers, psychologists, acousticians, doctors, mathematicians, neurophysiologists, philosophers, and other interested people tried to have their say. After the first meeting, one of us would take the lead each time, giving a brief summary of their research, usually accompanied by a running commentary by Wiener, to set the stage for the evening's discussion. As time went on, we came to understand each other's lingo and to understand, and even believe, in Wiener's view of the universal role of communications in the universe. For most of us, these dinners were a seminal experience which introduced us to both a world of new ideas and new friends, many of whom became collaborators in later years. Wiener's theme was that the organization of symbols, not their physical embodiment, bonded us together, whatever our disciplinary origins. . . .

My overwhelming impression is really an emotional one—what a unique and wonderful experience to spend a major part of my adult life and perhaps the most enjoyable period of it in the MIT atmosphere—a sentiment that I gather is shared by most of my colleagues. Perhaps this is just the normal nostalgia of men grown responsible and proper from the free time of their youth. But I think that it is more, for we shared communication processes in man's universe and the hopefulness of the post-World War II period. Perhaps as seen from our present and wiser perspective, we were over-excited and hoped for too much, but if so, we didn't know it.



**Professor Emeritus
Henry J. Zimmermann
(SM '42)**

*MIT Radar School, 1941-46
RLE Associate Director, 1952-60
RLE Director, 1961-76*



Professor Emeritus Henry J. Zimmerman

Born in St. Louis, Missouri, in 1916, Professor Zimmermann graduated from Washington University (BS '38) and MIT (SM '42). He joined MIT's Department of Electrical Engineering as a research assistant in 1940, and was appointed Assistant Professor in 1946, Associate Professor in 1948, and Professor in 1955. During World War II, he organized and developed radar training courses in MIT's Radar School, first as an instructor (1941-42), then supervisor of Army courses (1942-44), and finally Assistant Director (1944-46). He also co-authored the school's Principles of Radar book. In 1947, he became a staff member of RLE, where he supervised Project Meteor. He was appointed Associate Director of RLE in 1952, and became the laboratory's fourth director in 1961. Professor Zimmermann is known for his technical contributions in microwave systems, nonlinear circuits, and signal processing.

During the '30s, the microwave research conducted at Round Hill in South Dart-

mouth, Massachusetts, had participants from both Physics and Electrical Engineering. That work, together with the research on microwave components at MIT, was probably instrumental in bringing the Radiation Laboratory to MIT.


In the fall of 1940, I was assigned to a short-wave antenna project which involved basic research on microwave components. The goal was to demonstrate the feasibility of automatically tracking a target using the reflected signal of a microwave beam that illuminated the target (the word radar had not yet been coined). By spring 1941, the group of research assistants under Professor William L. Barrow had conducted successful demonstrations, and many new RadLab recruits visited our one-room laboratory in Building 6 to see microwave equipment for the first time. Professor Barrow had become a consultant to the RadLab, and the military implications of an automatic tracking system imposed security restrictions on our work, so the antenna project was discontinued.

One Saturday morning in June 1941, Professor Barrow came by the laboratory to see the basic component research still going on. He asked me to get my colleague W.H. "Bill" Radford, and we walked out to the center of the Great Court—presumably away from prying ears. He informed us that on the following Monday, a group of about 60 Army and Navy officers would arrive to begin a classified training program on electronics, microwave, and radio location equipment (radar). Professor Barrow said that Bill and I had been assigned to the program, and would give introductory lectures on electronic circuits. After a few weeks of introductory lectures, several RadLab staff members gave lectures on microwave radar equipment under development there. This was the first of three classes (each three months long) trained at MIT on the fundamentals of electronics and radar. After the first three classes, the operation expanded and was moved to the Harbor Building (now the Sheraton Building) on Atlantic Avenue in Boston. It was then designated as the MIT Radar School.

I had a RadLab badge so I had ac-

cess to the laboratory and the weekly seminars in order to carry out the mission of the MIT Radar School, but I was never a staff member of RadLab. Contact with the RadLab was essential to keep abreast of new developments, since we were planning curricula and teaching about equipment as it was scheduled to go into field use. A new class of approximately 150 officers arrived each month for a three-month training program. In its five years, the school trained more than 8,800 officers, enlisted men, and civilians in the theory and operation of the microwave radar being developed at the MIT Radiation Laboratory, and in the maintenance of radar equipment.

Activities at the Radar School were winding down in 1946, and in January 1947, I became Assistant Professor of Electrical Engineering and a staff member in RLE. By that time, MIT had undertaken a program called Project Meteor sponsored by the U.S. Navy Bureau of Ordnance. Project Meteor was classified, and its research was to lead to the development of an air-to-air guided missile. Professor Lan Jen Chu, a student of Professor William L. Barrow and a former RadLab staff member, proposed a unique guidance system based on interferometry, and I worked with him in providing faculty supervision for this group. Several MIT departments and laboratories were involved in Project Meteor. The Aeronautics Department did research on air frames, the Combustion Lab studied propulsion systems, the Dynamic Analysis and Control Lab worked on control systems, and RLE investigated radar guidance. Project Meteor continued for six or seven years, and the interferometric guidance system was successfully tested. When Project Meteor ended, the guidance work in RLE led naturally to basic research on phased-array radar.

In recent years, there has been considerable criticism of the government-industry-academic relationship. In my opinion, the cooperation between military, industrial, and academic institutions has not interfered with the others' separate missions and goals. This cooperation was extremely important during World War II, and has continued to strengthen all three parties in the alliance. 

RLE Publications



RLE has recently published the following technical reports:

Signal Enhancement Using Single and Multi-Sensor Measurements, by Ehud Weinstein, Alan V. Oppenheim, and Meir Feder. RLE TR No. 560. 1990. 40 pp. \$8.00.

Fault-Tolerant Round Robin A/D Converter, by Paul E. Beckmann and Bruce R. Musicus. RLE TR No. 561. 1990. 50 pp. \$10.00.

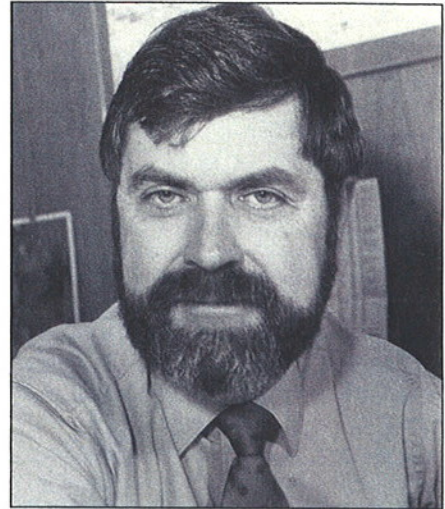
OKI AAP Hardware Description, by Bruce R. Musicus and Srinivasa Prassanna. RLE TR No. 562. 1991. 92 pp. \$14.00.

An Acoustic and Perceptual Study of Vowel Formant Trajectories in American English, by Caroline B. Huang. RLE TR No. 563. 1991. 203 pp. \$16.00.

In addition, ***RLE Progress Report No. 133***, which covers the period January through December 1990, provides extensive information about the work of RLE's research groups. The ***Progress Report*** also lists faculty, staff, and students who participated in research projects and identifies funding sources. Current RLE personnel are also listed. The ***Progress Report*** is available at no cost.

The RLE Communications Group welcomes inquiries regarding RLE research and publications.

Contact:
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Communications Officer
Research Laboratory of Electronics
Room 36-412
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Cambridge, MA 02139
(617) 253-2566

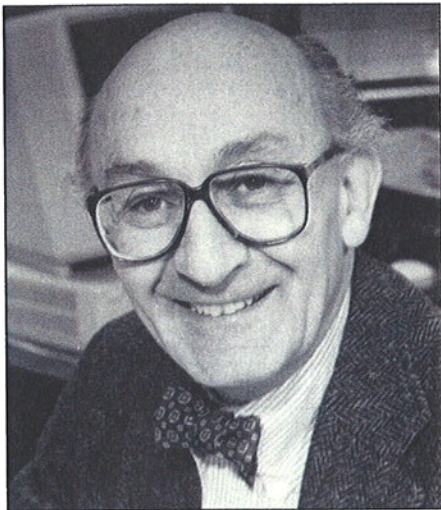


Dr. Arthur B. Baggeroer (EE '65, SM '65, ScD '68) was appointed Ford Professor of Engineering, which recognizes outstanding senior faculty in the School of Engineering for intellectual accomplishment, innovation, and leadership. Since 1973, he has held MIT faculty appointments in both the Department of Electrical Engineering and Computer Science and the Department of Ocean Engineering. Professor Baggeroer's research in RLE's Digital Signal Processing Group involves signal processing for oceanography and ocean acoustics, where a major activity is gathering seismic data from field experiments in the Arctic marginal ice zone. From 1983-88, he was Director of the MIT-Woods Hole Joint Program in Oceanography and Oceanographic Engineering, and collaborated in the development of the first high data-rate digital acoustic telemetry system there. He is a Fellow of the Acoustical Society of America and the Institute of Electrical and Electronic Engineers. (Photo by John F. Cook)

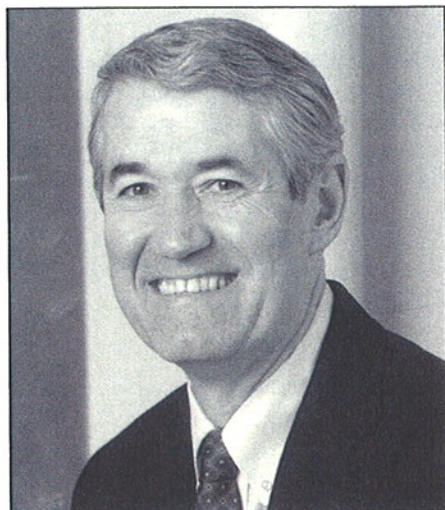
Nine RadLab staff members are Nobel Prize laureates:

Luis W. Alvarez (Physics, 1968)
Hans A. Bethe (Physics, 1967)
Edwin M. McMillan (Chemistry, 1951)
Edward M. Purcell (Physics, 1952)
Isidor I. Rabi (Physics, 1944)
Norman F. Ramsey, Jr. (Physics, 1989)
Paul A. Samuelson (Economics, 1970)
Julian S. Schwinger (Physics, 1965)
Jack Steinberger (Physics, 1988)

-----circuit breakers-----



Dr. Abram Bers (SM '55, ScD '59), Professor of Electrical Engineering and Computer Science, was elected Vice Chairman of the Division of Plasma Physics of the American Physical Society in November 1990. He previously served a one-year term as Vice Chairman Elect of the division. Professor Bers conducts fundamental studies in RLE's Plasma Physics Group aimed at understanding transport in radio-frequency heating, current generation in toroidal plasmas, and related studies of induced stochasticity and chaos. He is President of the University Fusion Association, a member of the American Association for the Advancement of Science, and a Fellow of the American Physical Society. (Photo by John F. Cook)



Dr. Robert J. Birgeneau, Head of MIT's Physics Department and Cecil and Ida

Green Professor of Physics, was appointed Dean of MIT's School of Science, effective July 1, 1991. In 1975, Professor Birgeneau joined the MIT faculty from AT&T Bell Laboratories, and served as Associate Director of RLE from 1983 through 1986. Professor Birgeneau's research in RLE's Surfaces and Interfaces Group is primarily concerned with the phases and phase transition behavior of novel states of matter. He and his colleagues use both neutron and X-ray scattering techniques in their investigations, and have pioneered the use of X-ray synchrotron radiation for high-resolution studies of condensed matter. A graduate of the University of Toronto (BSc '63) and Yale University (PhD '66), Professor Birgeneau has received the American Physical Society's Buckley Prize for Condensed Matter Physics (1987), the U.S. Department of Energy's Materials Science Outstanding Accomplishment Award (1988), and the American Crystallographic Association's Warren Award (1988). He was also named the 48th Richtmyer Memorial Lecturer by the American Association of Physics Teachers (1989). Professor Birgeneau is a Fellow of the American Academy of Arts and Sciences, the American Association for the Advancement of Science, and the American Physical Society. (Photo by John F. Cook)

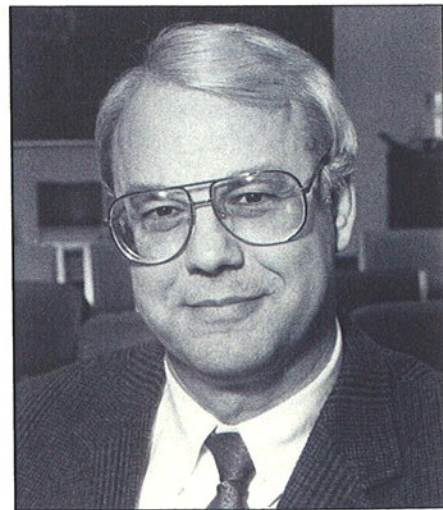


Dr. Hermann A. Haus, Institute Professor (ScD '54), was named recipient of the 1991 Education Medal from the Institute of Electrical and Electronic Engineers. Professor Haus was cited for his

creative contributions to education in electromagnetic fields and waves, and quantum electronics. In November 1990, he also received an honorary degree from the Technical University of Vienna, which he attended as a Guggenheim (1959-60) and Fulbright Fellow (1985). Coincidentally, almost 75 years ago, his grandfather received an honorary doctorate from the same university. Professor Haus is a prolific contributor to emerging technologies in the optics field. Among his many honors, he received the 1987 Charles Hard Townes Award for his analysis of laser noise, the development of the modelocked semiconductor laser, and contributions to the understanding of nonlinear waveguide interactions. Professor Haus also holds degrees from Union College (BS '49 and HScD '90) and Rensselaer Polytechnic Institute (MSEE '51).

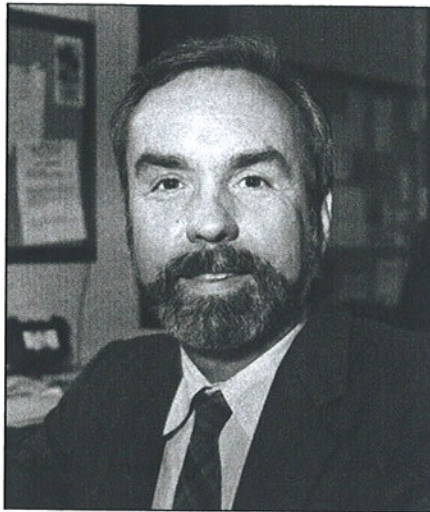


Professor Hermann A. Haus is joined by previous IEEE Education Medal recipients **Professor Emeritus Robert M. Fano** (1977) on the left, and **Professor Alan V. Oppenheim** (1988). (Photos by John F. Cook)

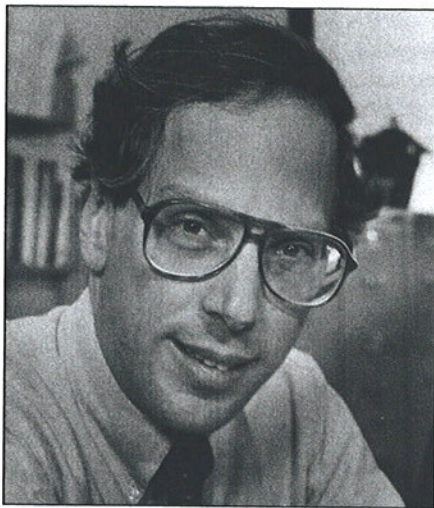


Dr. Miklos Porkolab, Professor of Physics, was appointed Associate Direc-

tor for Plasma Research at MIT's Plasma Fusion Center. Professor Porkolab joined the MIT faculty in 1977, and has made important contributions to the Alcator and Versator tokamak programs. His research in RLE's Plasma Physics Group includes the introduction of techniques for fast-wave current drive, the use of a gyrotron source for electron cyclotron heating and plasma start-up, and studies of the "second stability" regime made for the first time on a tokamak. In his role as Associate Director, Professor Porkolab will oversee the center's Applied Plasma Physics and Coherent Electromagnetic Wave Generation divisions. (Photo by John F. Cook)



Dr. John L. Wyatt, Jr. (SB '68), Professor of Electrical Engineering and Computer Science, was named the first Adler Scholar by the Department of Electrical Engineering and Computer Science. In the fall of 1990, Professor Wyatt relinquished his teaching responsibilities for one term to take a regularly offered MIT subject. Professor Wyatt, a principal investigator in RLE's Circuits and Systems Group, attended a class in machine vision to enhance his research in very large-scale integration microchips. The Adler Scholars Program, named for the late Professor Richard B. Adler, is designed to give Electrical Engineering and Computer Science faculty members an opportunity to enrich their knowledge and technical perspective through continuing education. The program is partly supported by the Richard B. Adler Memorial Fund. (Photo by John F. Cook)

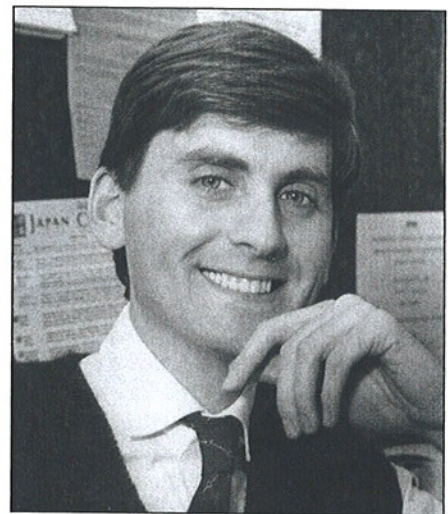


Dr. Jeffrey H. Shapiro (SB '67, SM '68, EE '69, PhD '70), Associate Department Head and Professor of Electrical Engineering and Computer Science, was elected Fellow of the Optical Society of America. At the society's annual meeting in Boston last autumn, Professor Shapiro was cited for his seminal studies on the generation of squeezed light and its use in optical communication systems. Under his guidance, the Optical Communications Group in RLE was the first to generate squeezed-state light in a Doppler-broadened atomic medium. Professor Shapiro also pursues research on atmospheric optical propagation and imaging on coherent laser radars. He is a senior member of the Institute of Electrical and Electronics Engineers and a member of the Society of Photo-Optical Instrumentation Engineers. (Photo by John F. Cook)



Dr. Boris L. Altshuler, Associate Professor of Physics, has joined RLE's Surfaces and Interfaces Group. Professor Alt-

shuler has made important contributions to quantum transport theory in disordered systems, and is a codiscoverer of periodic conductance oscillations of a hollow cylinder as a function of magnetic flux. His current research interest is the theoretical study of microstructure properties including the quantum interference of electron waves and electron-quantum dot interactions. Professor Altshuler is a graduate of Leningrad University (BS '76) and the Leningrad Institute of Nuclear Physics (PhD '79). (Photo by John F. Cook)



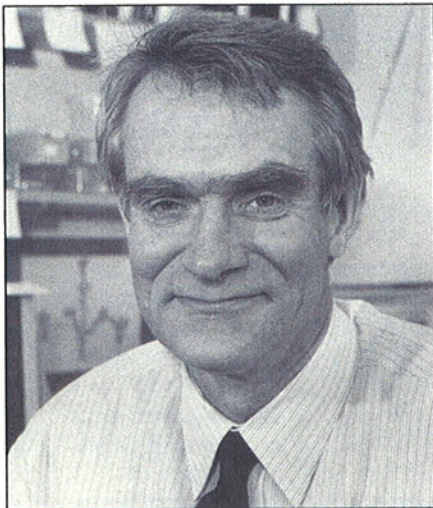
Dr. Jesus A. del Alamo, ITT Career Development Professor, was promoted to Associate Professor without tenure in the Department of Electrical Engineering and Computer Science. Professor del Alamo joined the MIT faculty in 1988, after working at the Nippon Telegraph and Telephone Corporation in Japan. He is a graduate of the Polytechnic University of Madrid ('80) and Stanford University (MS '83, PhD '85). His research in RLE's Materials and Fabrication Group involves high-performance heterostructure field-effect transistors on indium phosphide and gallium arsenide substrates for telecommunications, and the exploration of new quantum-effect electronic devices based on one-dimensional ballistic transport. (Photo by John F. Cook)

Two staff members served as Presidential Science Advisors:

Jerome B. Wiesner under President John F. Kennedy
 Edward E. David, Jr., under President Richard M. Nixon

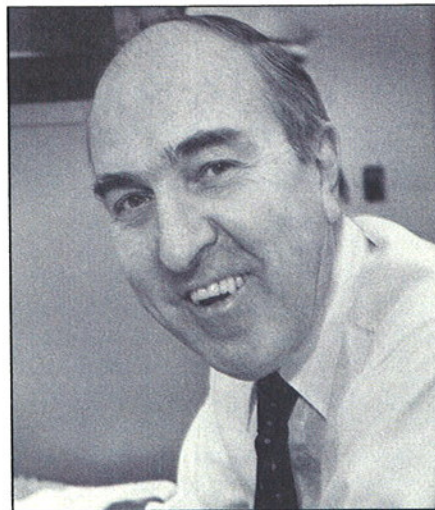


Dr. Jacob K. White (BS '80), Assistant Professor of Electrical Engineering and Computer Science, was promoted to Associate Professor without tenure in that department. Professor White joined the MIT faculty in 1987, and was the recipient of the Analog Devices Career Development Chair (1987-88) and the National Science Foundation Presidential Young Investigator Award in 1988. A graduate of MIT and University of California/Berkeley (MS '83 and PhD '85), his research in RLE's Circuits and Systems Group focuses on numerical techniques for circuit and device simulation, parallel computation, and the interaction between numerical algorithms and computer architecture. He is a member of the Institute for Electrical and Electronic Engineers and the Society for Industrial and Applied Mathematics. (Photo by John F. Cook)



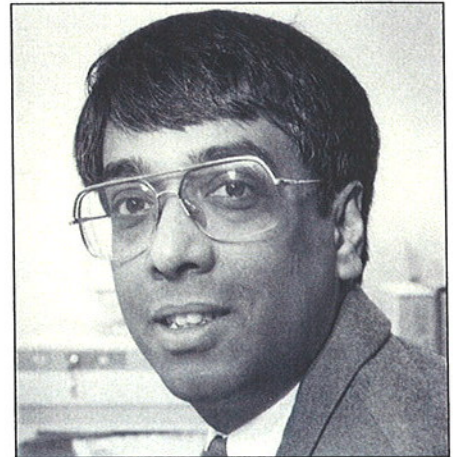
Dr. John Melngailis was promoted from Principal Research Scientist to Senior Research Scientist in RLE's Materials

and Fabrication Group. Dr. Melngailis joined RLE in 1978 from Lincoln Laboratory, where he had been a staff member since 1967. A graduate of Carnegie-Mellon University (BS '60, MS '62, PhD '65), Dr. Melngailis has developed an extensive focused ion beam research in RLE, successfully producing a tunable Gunn diode as well as new charged-couple devices with improved speed. His other achievements include the first demonstration of focused ion beams to make and break connections for circuit repairs, the first ion-induced depositions of gold and of platinum, and the deposition of 50-nanometer gold lines with the lowest resistivity deposits. Dr. Melngailis is a senior member of the Institute for Electrical and Electronic Engineers, and a member of the American Physical Society and the American Vacuum Society. (Photo by John F. Cook)

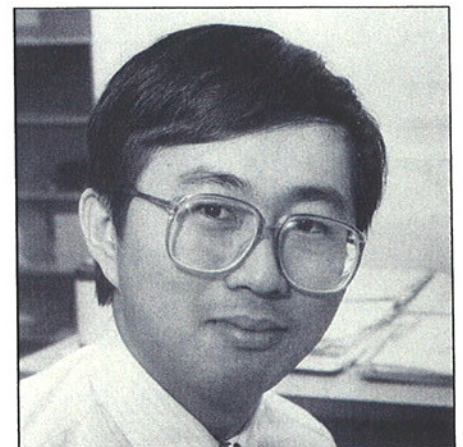


Mr. John W. "Jack" Barrett, a member of the Sponsored Research Technical Staff in RLE's Radio Astronomy Group, has completed forty years of service to the Laboratory. Mr. Barrett has provided engineering and technical support to the Radio Astronomy Group since he joined RLE as a junior electronic technician in May 1951. In 1988, he was named corecipient of the NASA Group Achievement Award for the planning and execution of the Tracking and Data Relay Satellite Very-Long-Baseline Interferometer (VLBI) which produced the world's first astronomical space-ground VLBI observations. Mr. Barrett has also contributed to the group's other projects including a 118-gigahertz aircraft spectrometer and an astrometric optical interferometer at the Mt. Wilson Observatory. In addition, he was selected to represent RLE's research staff at the

1991 inauguration of MIT President Charles M. Vest. (Photo by John F. Cook)



Dr. Santanu Basu was appointed Research Scientist in RLE's Optics and Devices Group in November 1990. Dr. Basu was previously a postdoctoral associate in RLE, and is a graduate of the India Institute of Technology (B. Tech. '78), Case Western Reserve University (MS '79), and Stanford University (MA '81, '84; PhD '88). While attending Stanford, he developed a moving slab laser system suitable for soft x-ray generation at high power. Dr. Basu was also a group leader at Raychem Corporation's Research and Development Division in Menlo Park, California, from 1979-84. As a postdoctoral associate at IBM's T. J. Watson Research Center in 1988, he initiated research on quantum well lasers and modulators on silicon substrates for integration with silicon-based high-speed devices. His current research at RLE involves the development of an electron collisionally excited x-ray laser. (Photo by John F. Cook)



Dr. Ying-Ching Eric Yang (SM '85, PhD '89), Research Scientist in RLE's

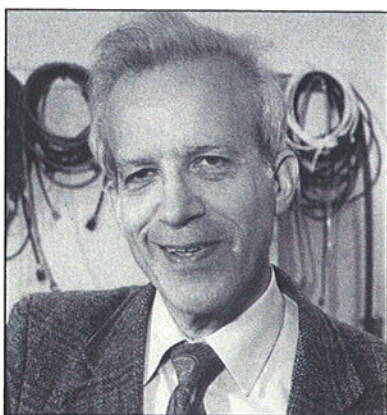
Center for Electromagnetic Theory and Applications, was selected as the 1990 Henry G. Booker Fellow of the International Union of Radio Scientists (URSI). Dr. Yang was cited as a future leader in

the electromagnetic profession and a significant contributor to URSI activities. The fellowship enabled Dr. Yang to attend the URSI general assembly held last August in Prague, Czechoslovakia. Dr.

Yang's research includes millimeter-wave radar image simulation, electromagnetic interference in microelectronic circuits, and airport precision landing systems. (Photo by John F. Cook)

American Physical Society Prize Winners at RLE

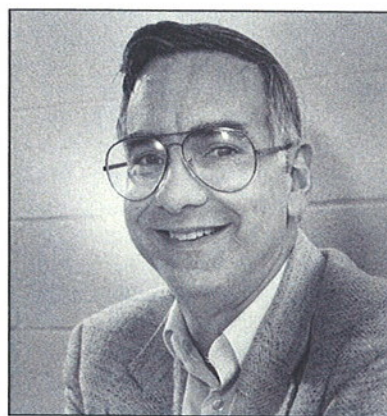
In April 1991, the American Physical Society presented several awards to RLE faculty at a meeting in Washington, DC.



Dr. Daniel Kleppner, Associate Director of RLE and Lester Wolfe Professor of Physics, received the 1991 Julius Edgar Lilienfeld Prize. The prize recognizes outstanding contributions to physics by an individual with exceptional skills in presenting lectures to general audiences. He was also cited for the development of the atomic hydrogen maser and other techniques for precise spectroscopy of neutral atoms, and for clarity in presenting his work. Professor Kleppner also was named recipient of the 1991 William F. Meggers Award presented by the Optical Society of America. The award acknowledges his spectroscopy research including the development of the hydrogen maser, spectroscopy of Rydberg states, and the analysis of atom interactions with electromagnetic fields. Professor Kleppner, a principal investigator in RLE's Atomic, Molecular, and Optical Physics Group, will receive the Meggers Award at the society's annual meeting in San Jose, California, in November 1991. (Photo by John F. Cook)

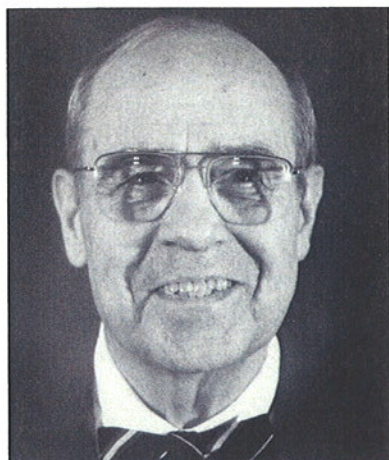


Dr. Patrick A. Lee (SB '66, PhD '70), William and Emma Rogers Professor of Physics, received the 1991 Buckley Prize in Condensed Matter Physics. Professor Lee was honored for his innovative contributions to the theory of electronic properties of solids, particularly strong interacting and disordered materials. In addition, Professor Lee was appointed Rogers Professor of Physics in November 1990, and is the first holder of this five-year professorship. The department cited his distinguished research in condensed matter theory, leadership of the condensed matter theory group, and contributions to graduate education. As a principal investigator in RLE's Surfaces and Interfaces Group, Professor Lee studies the physics of small devices, focusing on conductance fluctuations in disordered metals, the scaling theory of metal-to-insulator transition, and the theory of high-temperature superconductors. (Photo by John F. Cook)



Dr. David E. Pritchard, Professor of Physics, was awarded the 1991 Herbert P. Broida Prize, which recognizes outstanding experimental advancements in the fields of atomic, molecular, or chemical physics. Professor Pritchard was honored for his contributions to atomic, molecular, and optical physics. These include studies of energy transfer in molecular collisions, seminal research on atom wave interferometry and atom optics, studies of light forces on atoms and their application to atom cooling and trapping, and the development of single-ion mass spectroscopy. As a principal investigator in RLE's Atomic, Molecular, and Optical Physics Group, he is currently pursuing experiments in ultraprecision mass spectroscopy of single trapped ions, traps for neutral atoms using light and magnetic forces, and atom interferometry. Professor Pritchard is a member of the American Association for the Advancement of Science, the Optical Society of America, and a Fellow of the American Physical Society. (Photo by John F. Cook)

IN MEMORIAM



Professor Edward L. Bowles, 92, died September 5, 1990. He had suffered from Parkinson's disease for several years. Professor Bowles served as Consulting Professor in the Electrical Engineering Department from 1925-52, and on the faculty of what is now the Sloan School of Management from 1952 until his retirement in 1963.

A native of Westphalia, Missouri, Professor Bowles graduated from Washington University and received his master's degree from MIT in 1922. During the mid-'20s, he helped to establish a new program in communications for MIT's Electrical Engineering Department that included radio engineering and microwaves. Professor Bowles also directed MIT's research program in air navigation, radio and light propagation through fog, and fog dissipation at Round Hill, South Dartmouth, Massachusetts. The research in radar beams and radiation patterns at Round Hill became a foundation for the ensuing MIT Radiation Laboratory and MIT Radar School.

Professor Bowles is perhaps best known for his role as an "ambassador of radar" during World War II, when he served as Expert Consultant to the Secretary of War

and the Commanding General of the Army Air Force. His role helped to foster understanding between the civilian scientists at MIT's Radiation Laboratory and government officials during the development of microwave radar in World War II. He also devised countermeasures to battle German submarines in the North Atlantic, set up a laboratory at Langley Field in Virginia to test airborne radar, and organized a highly successful British defense against German V-1 buzz bombs. In 1945, Professor Bowles received the Distinguished Service Medal for his wartime efforts.

Although he was not affiliated with RLE, Professor Bowles was a consultant to the Raytheon Company for twenty years, and participated on many industrial and government committees. As Consulting Professor at MIT's School of Industrial Management, he lectured on issues of public policy and technology regulation until his retirement in 1963. A memorial service was held in April 1991 at the MIT Museum. (*Photo courtesy MIT Museum*)



Professor James R. Melcher, 54, died January 5, 1991, after suffering from cancer. He was Director of the

Laboratory for Electromagnetics and Electronic Systems and held the Julius A. Stratton Professorship of Electrical Engineering and Physics.

Following graduation from Iowa State University (BS '57, MS '58), he came to MIT and received his PhD in 1962. He worked in RLE as a graduate student under Professor Nathaniel Woodson, as an instructor, and an assistant professor. He joined the MIT faculty in 1962. Professor Melcher's research focused on electrodynamic and continuum electromechanics, and was widely recognized for practical applications in air pollution control, energy conversion, plasma physics, fluid flow measurement, thickness control of sheet glass, electrical generation via fluid flows in electric and magnetic fields, electric power apparatus, and physiology. He was the author of several books: *Field-Coupled Surface Waves*; *Electromechanical Dynamics*; *Continuum Electromechanics*; and *Electromagnetic Fields and Energy*. He was also a founder of the *MIT Faculty Newsletter*.

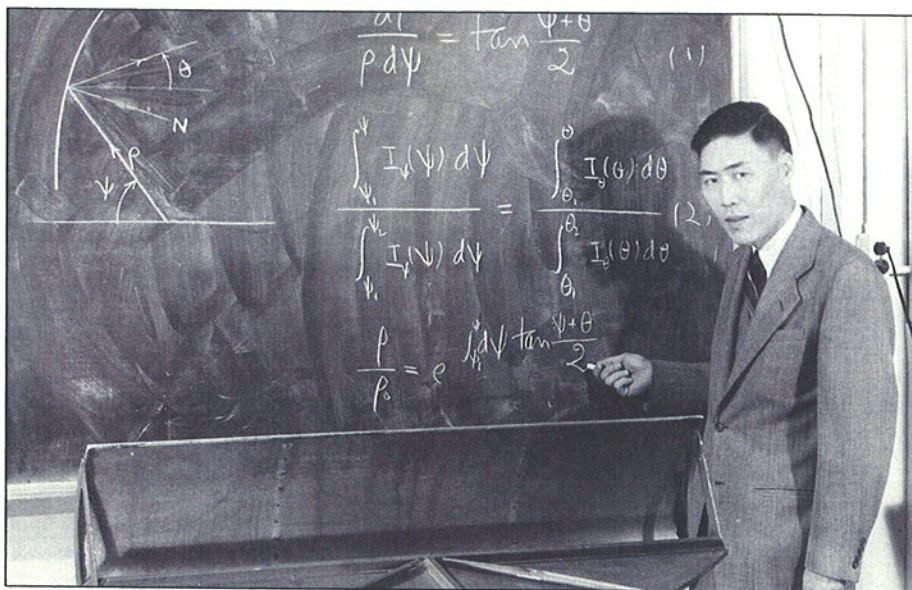
Professor Melcher received the American Nuclear Society's 1958 Mark Mills Award, an American Society for Engineering Education's 1969 Outstanding Teacher Award, a 1971 Guggenheim Fellowship, MIT's 1978 Graduate Student Teaching Award, and Iowa State University's 1971 Young Alumnus Award and 1981 Professional Achievement Citation in Engineering. He was a member of the National Academy of Engineering, the American Physical Society, the American Chemical Society, the American Society of Mechanical Engineers, and a Fellow of the Institute of Electrical and Electronic Engineers. Memorial gifts can be made to the American Cancer Society.

(*Photo by L. Barry Hetherington*)

RadLab's Microwave Tradition at RLE



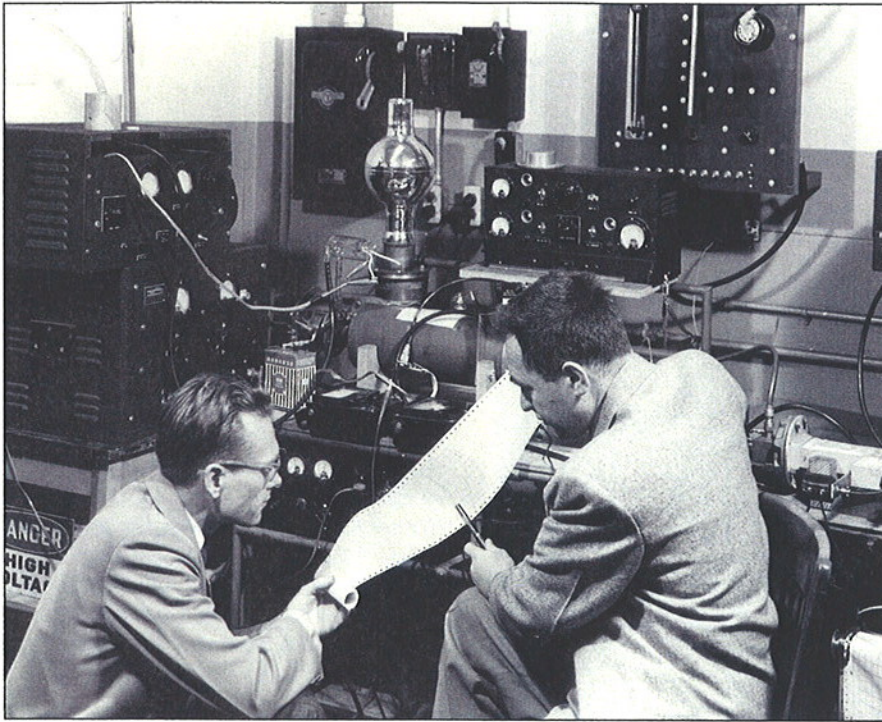
CHU, LAN JEN. Electrical Engineering (electromagnetic theory). 31 Winthrop Rd, Brookline, Mass. ScD Elec Engr, Mass Inst Tech '38. RL 1942-46. Calculation: r-f, antennas. Design, supervision: large & scanning antennas, special-purpose ship, ground systems. General problems: electromagnetic theory. Basic research. (6/42-46). (Gr 43, 54, Div 12, ASG-OSW China, BR).



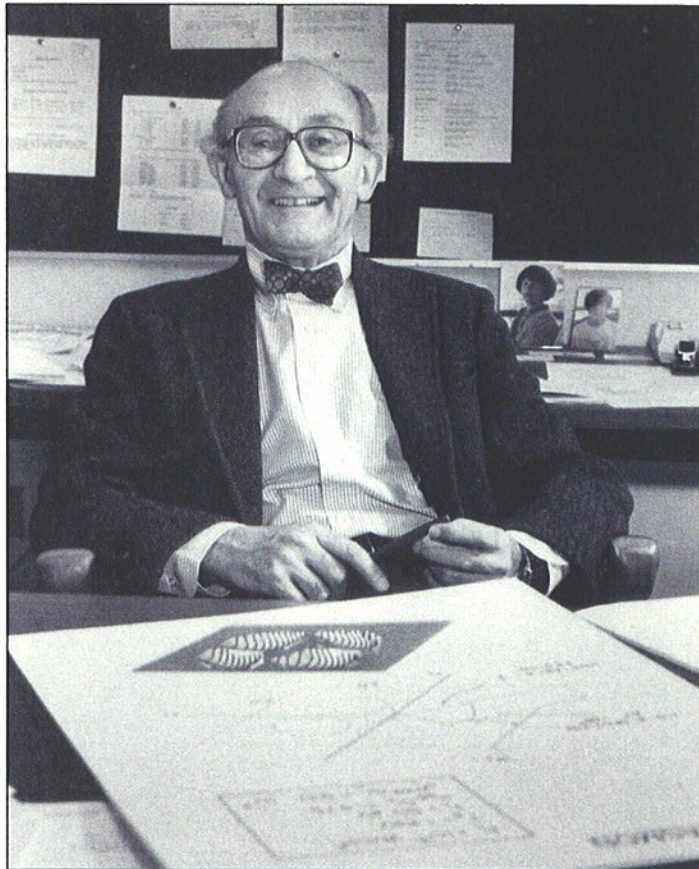
When the RadLab began in 1940, Dr. Lan Jen Chu was a consultant on magnetrons, transmission lines, and wave propagation problems. As a pioneer in highly sophisticated radar antenna systems, he made contributions to modern electromagnetic theory and its applications in microwave beam tubes and antennas. Dr. Chu conceived the "Chu formulation" of electrodynamics and also discovered the small signal power theorem, the forerunner of the small signal energy principles of plasma physics. He was known for making electromagnetic theory accessible to undergraduates and was instrumental in developing special programs for exceptionally gifted students. (RLE file photo)



In 1954, then-graduate student Hermann A. Haus worked with Professor Chu on his doctoral thesis, and together they developed a theory of noise fluctuations in microwave tubes. Today, Institute Professor Haus works with graduate student Dilys Kit-Ling Wong on optical interferometric switching in RLE's Optics and Devices Group. (Photos by John F. Cook)

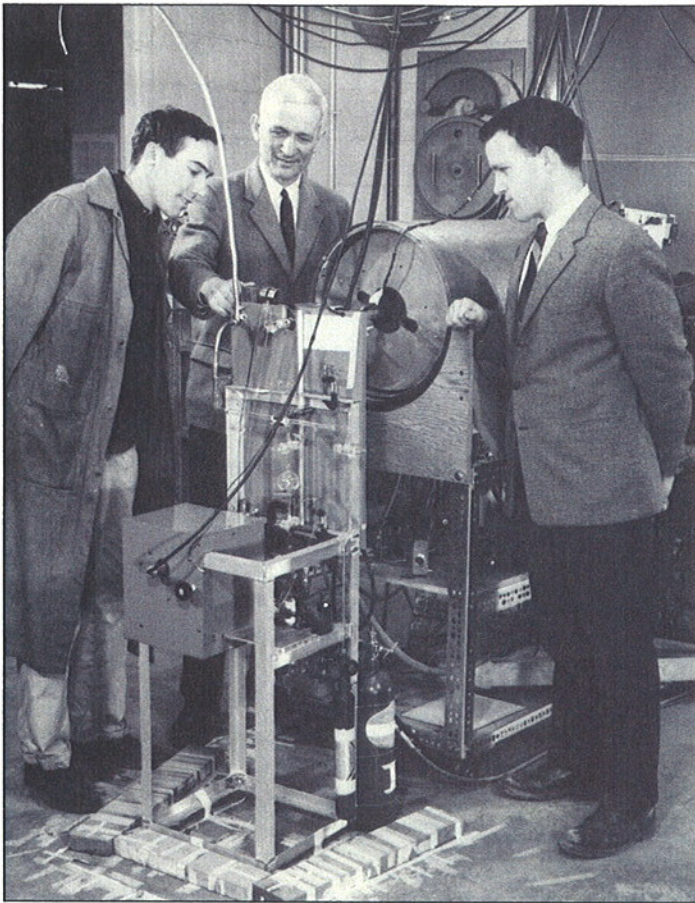


In 1954, Professor Louis D. Smullin (right) and Professor Hermann A. Haus examine measurements of high-frequency noise in microwave vacuum tubes. At RadLab, Professor Smullin supervised the TR and Duplexer section, and the testing of microwave tubes. In 1946, Professor Smullin organized and headed RLE's Microwave Tube Laboratory. (Photo by Benjamin Diver)



SMULLIN, LOUIS DIJOUR. Electrical Engineering. c/o I. Smullin, 2220 Rich-ton St, Detroit 6, Mich. SM Commun, Mass Inst Tech '39. RL 1941-46. Re-search, design: S-band spectrum analyzer, pre-plumbed duplexers, coaxial-line com-ponents (11/41-4/42); S-band magne-tron test bench (4/41-7/42); & liaison, sect ch TRs, duplexers (7/42-12/45). Author & volume editor: RL Technical Series (12/45-46). (Adv Devel, Gr 53, OP.) Federal Telecommunications Lab Inc, 67 Broad St, New York 4, N. Y.

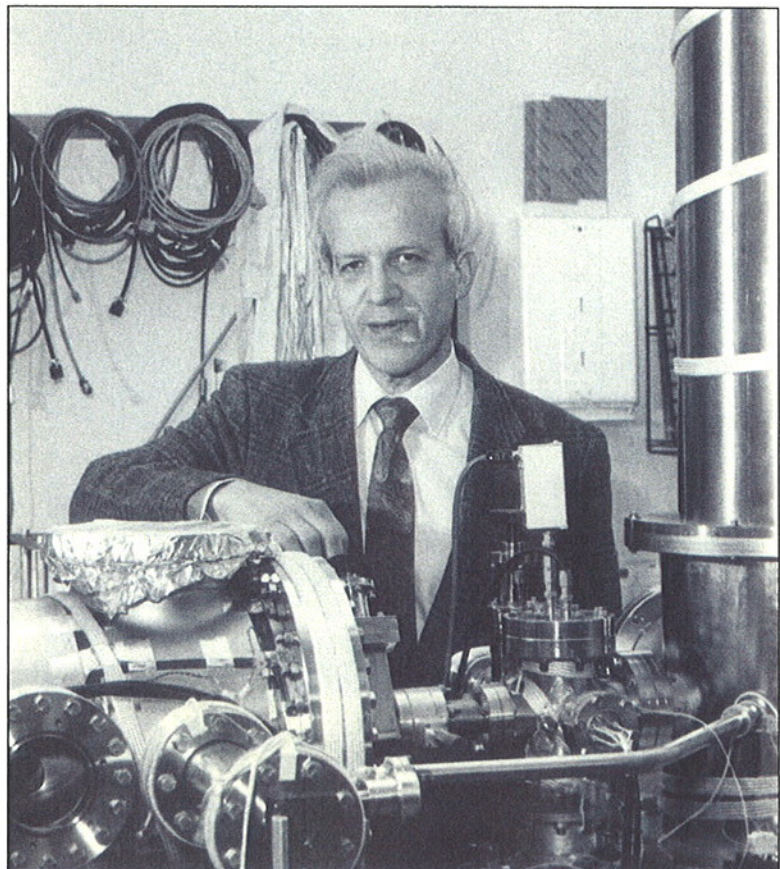
As a doctoral student, Professor Abraham Bers worked under Professor Smullin in 1959, and today he researches nonlinear wave phenomena in plasmas in RLE's Plasma Physics Group. Professor Bers' study of radio-frequency current drive, which he pioneered with his students, indicates its possible use in stabilizing certain magnetohydrodynamic instabilities driven by obmic currents that may lead to new current drive applications. (Photo by John F. Cook)



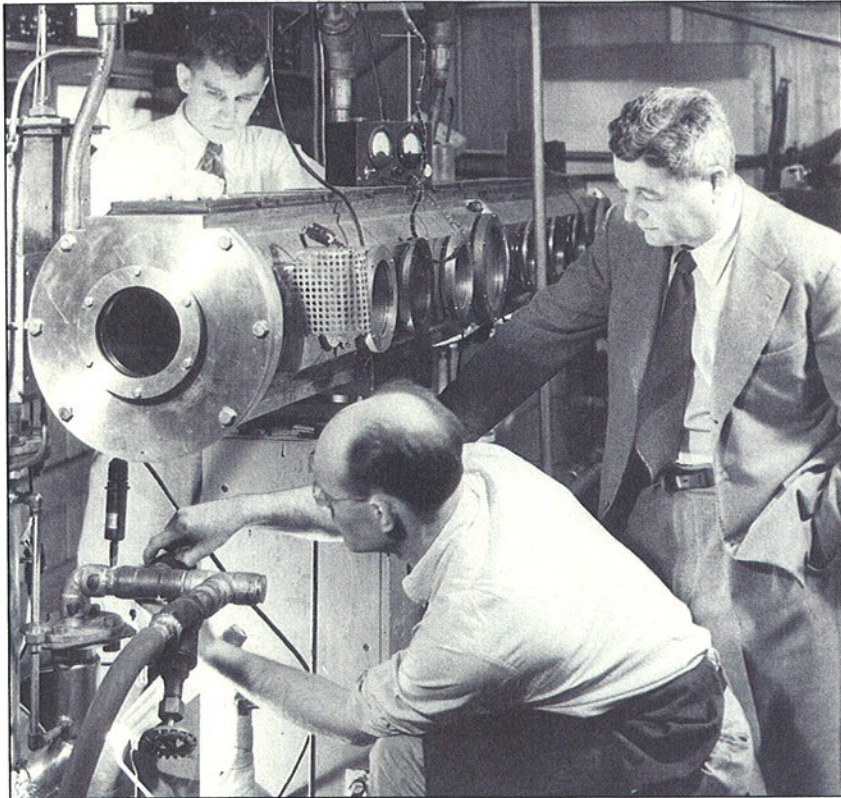
Dr. Norman F. Ramsey, Jr., became one of nine RadLab members to receive the Nobel Prize (see complete list on page 18). In RadLab, he was the first leader of the Fundamental Development Group (Group 41) which developed X-band radar systems. He went on to become a professor of physics at both Columbia and Harvard. At Harvard, graduate student Daniel Kleppner worked on his thesis under Dr. Ramsey. In this 1964 photo, Dr. Ramsey (center) demonstrates the hydrogen maser to students Stuart Crampton (left) and Daniel Kleppner. In 1989, Dr. Ramsey received the Nobel Prize in Physics for his work in precision measurements, including the creation of the hydrogen maser. (Photo courtesy Harvard University Cruft Laboratory)

RAMSEY, NORMAN F. JR. Physics. Pupin Physics Lab, Columbia U, New York, N. Y. PhD Phys, Columbia U '39. RL 1940-43. Gr ldr, research: S-band magnetrons (11/40-1/41); & development first X-band magnetrons (1-3/41); first waveguide plumbing, TR box, X-band ground, airborne systems, AIA, ASD, H2X experiments (1/41-12/42). Gr ldr, liaison production: AIA, ASD (5-12/42). Liaison: British labs (6-8/41);

Today, in RLE's Atomic, Molecular, and Optical Physics Group, Professor Kleppner carries out research in high-precision measurements, quantum optics, and experimental atomic physics. Professor Kleppner uses the equipment in this photograph as part of a research program on the ultraprecise spectroscopy of hydrogen to measure the Rydberg frequency. (Photo by John F. Cook)

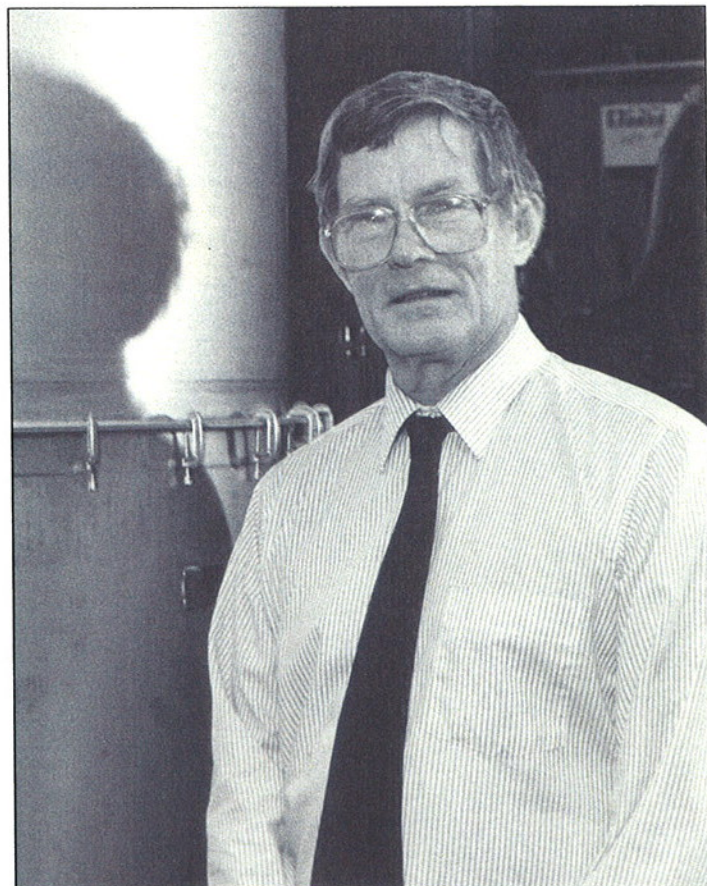


ZACHARIAS, JERROLD R. Physics. Dept Physics, Mass Inst Tech, Cambridge 39, Mass. PhD Phys, Columbia U '33. RL 1940-45. Research: antennas (12/40-3/41); USS Semmes system (3-5/41); SCR-517, -520, BTL (5/41-1/42); all r-f components (3/42-1/44). Div 5 hd (1/44-7/45). (Antenna, Roof, Gr 53, Div 5.) Dir, Lab for Nuclear Science & Engineering, Mass Inst Tech, Cambridge 39, Mass.

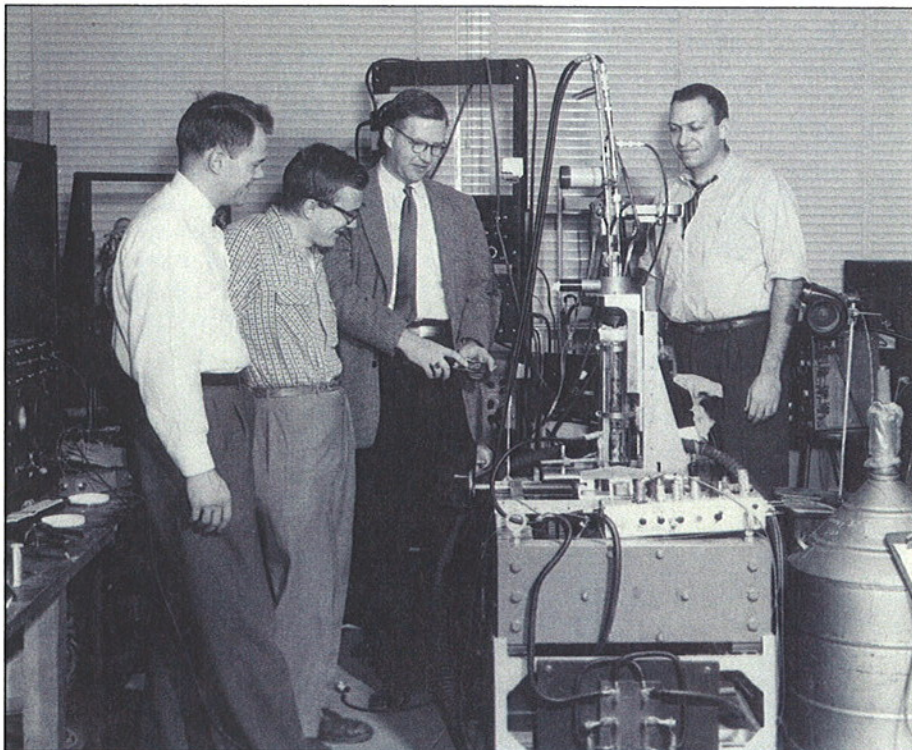


Professor Jerrold Zacharias (right) supervises mechanic John J. McLean as he installs the vacuum system on a molecular beam apparatus. MIT instructor Darragh E. Nagle watches from behind. RLE's atomic beam laboratory, under Professor Zacharias, studied and developed atomic beam frequency standards that resulted in the creation of the cesium atomic clock. During his tenure at RadLab, Professor Zacharias headed up Division 5 (transmitter components) in 1944. (RLE file photo)

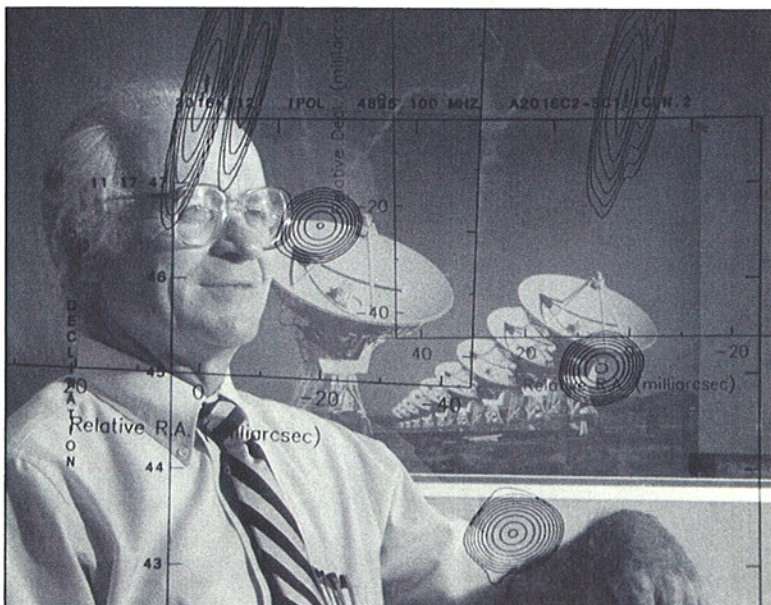
In 1953, as a doctoral student, Professor John G. King wrote his thesis under Professor Zacharias, and assisted him on the studies which led to the atomic clock. Today, Professor King's investigations include the electrical neutrality of molecules and the use of molecular microscopy techniques in biological and surface studies to further the understanding of mechanisms involved in embrittlement, integrated circuit failure, and biological sensitivity on a molecular scale. (Photo by John F. Cook)



As an engineer in RadLab, Professor Malcom W. P. Strandberg worked on several projects, including X-band and K-band radar systems. He made the transition to RLE as a research associate in the Basic Research Group. In 1948, he completed his doctoral thesis under Professor Albert G. Hill, then RLE's Associate Director. In this 1957 photograph, Professor Strandberg demonstrates the S-band maser experiment to postdoctoral associate Charles F. Davis, graduate student Brian Faughnan, and postdoctoral associate George Wolga. Professor Strandberg's RLE group in microwave spectroscopy studied the characteristic absorption of radiation in the region of millimeter or centimeter wavelengths. (RLE file photo)

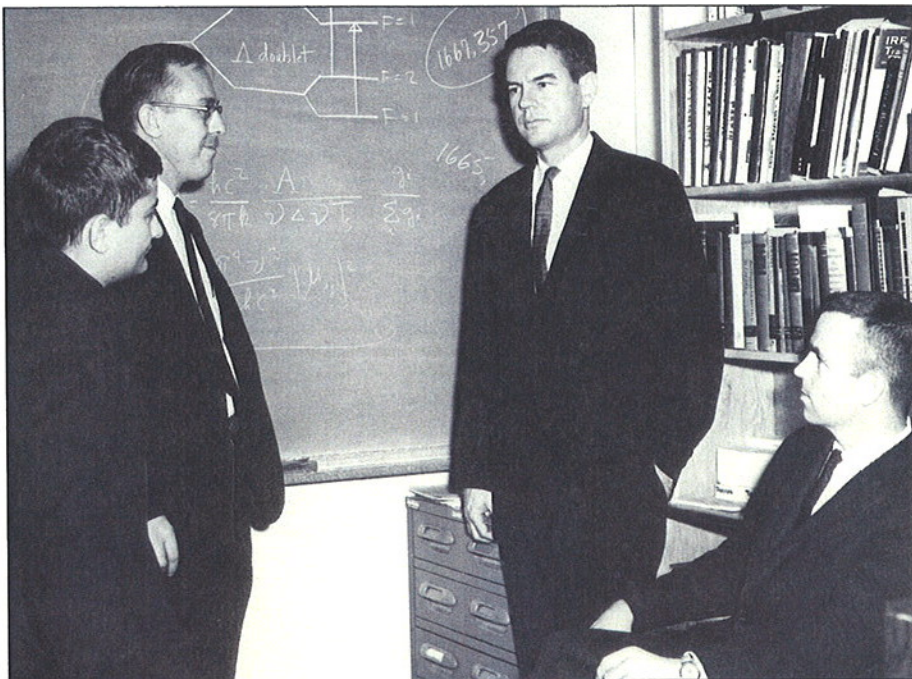


STRANDBERG, MALCOM WOODROW PERSHING. Electrical Engineering (electronics). 4824 S Eye St, Tacoma 8, Wash. SB Engr Sc, Harvard U '41. RL 1941-45. Engr: X-band system development (6-9/41); X-band spectrum analyzer & high-Q X-band cavities (2-4/42); D2-1 installation, operation (4-10/42); APQ-34 AFC devel (10-12/44). Assoc proj engr: K-band r-f head (9/43-9/44). Proj engr: XT-2 (9/41-2/42); Carpet II automatic searching jammer (11/42-9/43); X-band tunable r-f head (12/44-12/45). (Adv Devel, Gr 44, OSRD England, 53, 53.4.) Research associate, Basic Research, Mass Inst Tech, Cambridge 39, Mass.

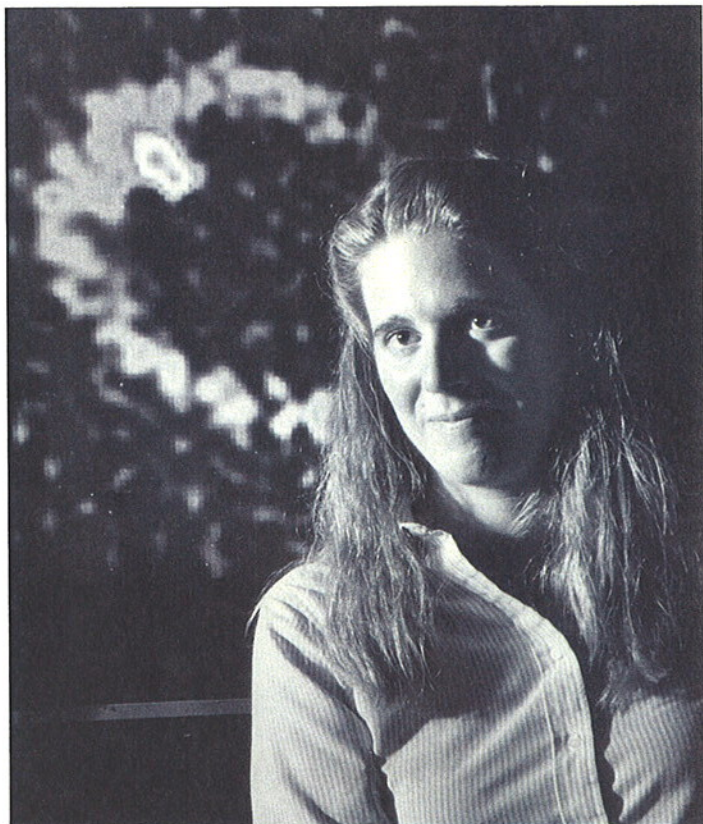


Professor Bernard F. Burke was a thesis student under Professor Strandberg. Today he is a faculty member in RLE's Radio Astronomy Group. In this photograph, Professor Burke looks out from behind superimposed maps of a gravitational lens produced by the radio telescope antennas of the Very Large Array (in the background) and the very large baseline interferometer (VLBI). (Photo by John F. Cook)

WIESNER, JEROME B. Electrical Engineering (commun). 4710 Greenfield Rd, Dearborn, Mich. MS Elec Engr, U Mich '38. RL 1942-45. Development: X-band components (5-12/42); ASD-1 r-f system (12/42-5/43); TR (5-11/43); K-band comp (11/43-4/44). Sect ch: r-f head, H2K. Assoc gr ldr: r-f (1-5/44). Proj engr: PC (2-10/45). (Gr 53, det PC.) Dept Elec Engr, Mass Inst Tech, Cambridge 39, Mass.



Professor Burke has said that "the first modern achievement at MIT was to develop the autocorrelation method for radio astronomy, and the hydroxyl (OH) line was the first major discovery made with that technique." This was a collaboration between Sandy Weinreb, M. L. "Lit" Meeks, and Professor Allen H. Barrett. The collaborators gathered for a 1963 photograph (from left): graduate student Sander Weinreb, Professor Allen H. Barrett, Dr. M. Littleton Meeks, and graduate student John C. Henry. (Photo courtesy MIT Museum)

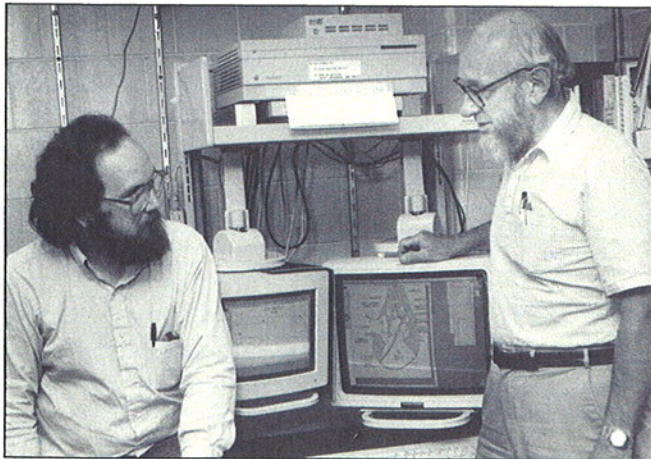
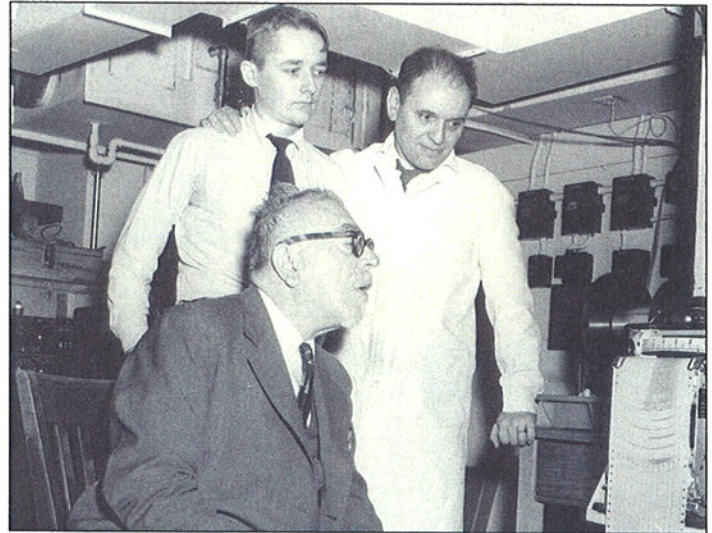


Carrying on the research tradition in the RLE Radio Astronomy Group is Professor Jacqueline Hewitt, who completed her doctoral thesis in 1986 under Professor Burke. She now collaborates with Professor Burke in the identification of several gravitational lens systems. She also uses VLBI techniques to study nearby stars, and to investigate the stability of their radio emissions. (Photo by John F. Cook)

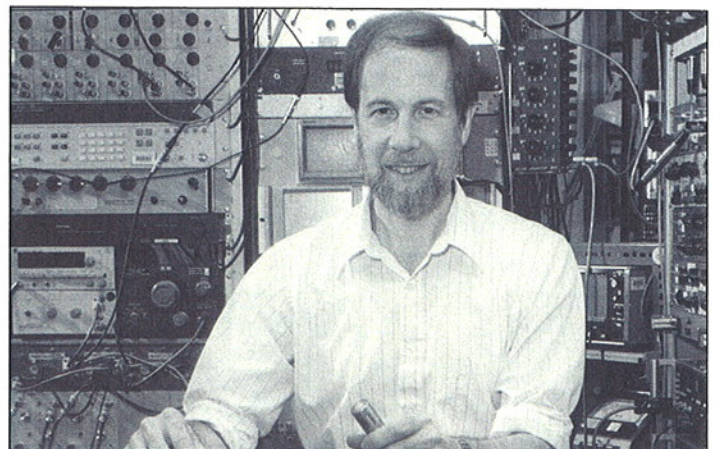


In 1948, former RadLab staff member Professor Jerome B. Wiesner (center) discusses results from the first electronic analog correlator with Professors Yuk Wing Lee (left) and Norbert Wiener. Professors Wiesner and Lee were instrumental in translating Professor Wiener's theory of nonlinear systems into practical applications. By combining the methods and techniques of mathematicians and communication engineers, the study of communication theory in RLE was not confined to electrical systems. (RLE file photo)

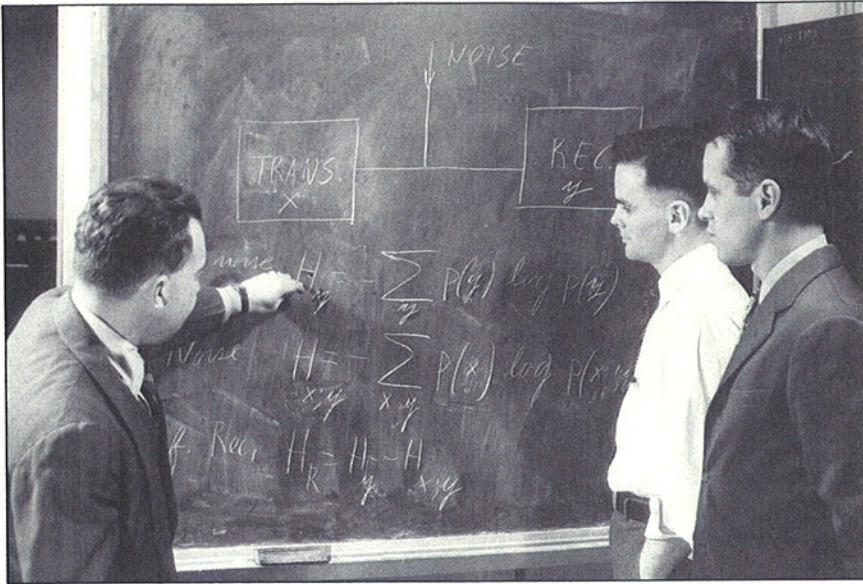
In the 1950s, as new theories of modern communication were introduced, connections were drawn between the nervous system and statistical communication machines, such as the analog correlator. Professor Norbert Wiener (seated), Dr. John Barlow (left), and Professor Walter A. Rosenblith observe the autocorrelation function of brain waves, enabling the application of statistical communication techniques to communication biophysics. This research established quantitative relations between neuroelectric data and the characteristics of sensory stimuli. (RLE file photo)



Today, in RLE's Auditory Physiology Group, Professor William Peake (right) and Research Scientist John Rosowski use computers to illustrate the anatomy and physics of how sounds are coupled from the external to the inner ear. Professor Peake was a thesis student of Professor Rosenblith's, and studied electrical activity in the auditory nervous system and structures in the brain. (Photo by John F. Cook)

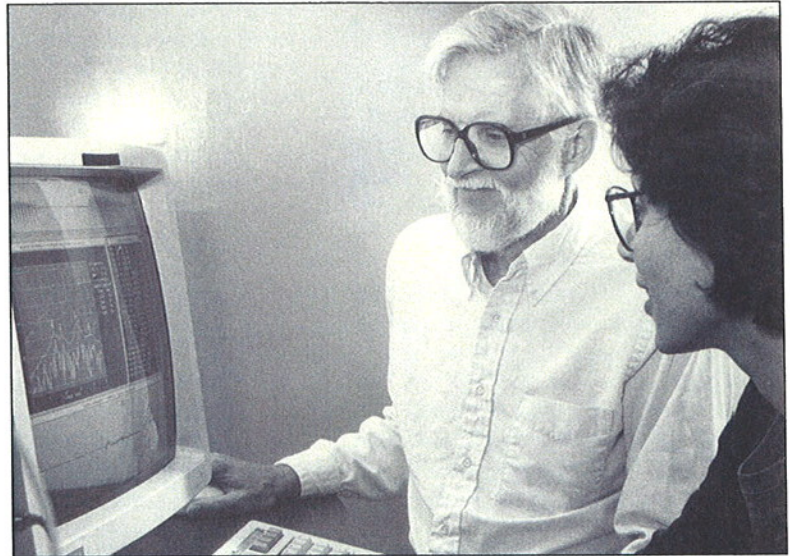


Principal Research Scientist John J. Guinan, a former thesis student under Professor Peake, uses ultrasensitive microphones to measure sounds in the ear canal generated by the ear itself during the hearing process. (Photo by John F. Cook)

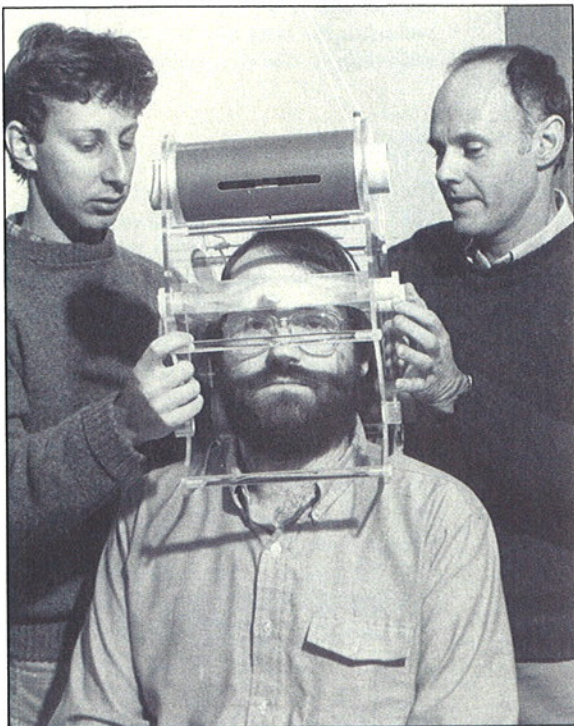


Influenced by Professor Norbert Wiener's communication theories and collaborating with Professor Claude E. Shannon in the area of information theory, Professor Robert M. Fano became interested in the transmission of speech and message encoding. At RadLab, he had worked in Group 53 (radio frequency) with many other future faculty members who were to join him later at RLE. Here, Professor Fano (left) discusses a noise problem with students Leon G. Kraft, Jr., and Wilbur B. Davenport, Jr. (RLE file photo)

FANO, ROBERT MARIO. Electrical Engineering (commun). Dept Electrical Engineering, Mass Inst Tech, Cambridge 39, Mass. SB Elec Engr, Mass Inst Tech '41. RL 1944-46. Research: BUPX plumbing (6-12/44); APX-15 r-f modulator (12/44-3/45); high-power loads (6/44-8/45); microwave filters (3-9/45). Liaison: Gr 53 & Div 7 (12/44-8/45). Author: RL Technical Series (8/45-46). (Gr 53, OP.) Research associate, Dept Elec Engr, Mass Inst Tech, Cambridge 39, Mass.



Today, in RLE's Speech Communication Group, Professor Kenneth N. Stevens and graduate student Lorin F. Wilde examine computerized speech analysis and synthesis data. Professor Stevens, whose earlier research focused on the modeling of the human vocal tract, is now concerned with the process of how sounds become modified within natural speech and the understanding of discrete representations when speakers encode and listeners decode messages. (Photo by John F. Cook)



Professor Stevens' former thesis student, Senior Research Scientist Dr. Joseph S. Perkell, conducts experiments to explore the control and coordination of the speech articulatory movements. Dr. Perkell (right) and Research Engineer Marc Cohen prepare subject Dr. Thomas Carrell for one of these experiments, which involves measuring the movements of the subject's tongue using an alternating magnetic field transducer system. (Photo by John F. Cook)

UPDATE: Industrial Connections



RLE actively promotes innovative relationships between the Laboratory and business organizations through Collegium membership, research projects, and special partnerships. The goal is to increase communication between RLE researchers and industrial professionals in electronics and related fields. *currents* is pleased to report on two recently formed industrial partnerships.

HDTV Alliance Formed with General Instrument

The General Instrument Corporation of San Diego, California, and RLE have formed the American Television Alliance. RLE's Advanced Television Research Program (ATRP) and General Instrument will work together to develop two all-digital, simulcast, high-definition television (HDTV) systems. The two systems will then be submitted for competitive testing by the FCC to determine a national HDTV standard for terrestrial broadcast television. RLE's group is led by Professor Jae S. Lim (SB '74, SM '75, ScD '78), and General Instrument's group is headed by Dr. Jerrold A. Heller (SM '64, PhD '67), Executive Vice President of General Instrument's Video-Cipher Division.

The Advanced Television Research Program at RLE was established in 1983 by Professor William F. Schreiber to develop the science and technology essential to advanced television systems (see *currents*, vol. 3, no. 2). ATRP is supported by the Center for Advanced Television Studies, a group of ten companies which broadly represent the American television broadcast industry. General Instrument, a world leader in broadband distribution, transmission and access control for cable, satellite, and terrestrial broadcast, is a member of this group.

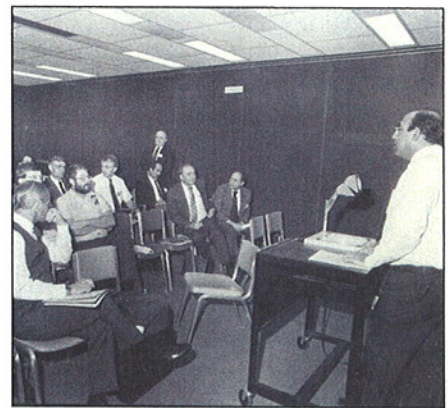
Before forming the alliance, General Instrument and RLE were competitors in developing an HDTV standard. ATRP's Channel Compatible system used a

combination of digital and analog technology, and was the first to use digital data to represent a major portion of the information required for HDTV. The Channel Compatible system also simulcast old and new formats via separate channels, enabling today's receivers to receive broadcasts at the current resolution. General Instrument's DigiCipher™ system was the first all-digital system in the FCC competition. The HDTV Alliance will enable MIT and General Instrument to share resources and expertise in producing two different all-digital systems for FCC testing. Their competitors are NHK of Japan, Zenith, AT&T, and an American-European consortium. The alliance's two systems are scheduled for testing in September 1991 and March 1992, with an American HDTV standard expected to be announced in 1993.

IBM-RLE Partnership in Electronic Design Automation

RLE and the International Business Machines Corporation of Armonk, New York, are working together to implement a highly integrated computer network of IBM advanced workstations using the AIX™ operating system. Within this environment of ten IBM advanced workstations, faculty members and students in RLE's Circuits and Systems Group are developing electronic design automation algorithms and prototype software for performance-directed synthesis, high-level synthesis, design verification, synthesis for testability, database consistency maintenance, circuit simulation, and circuit parameter extraction. This computing environment will be used to enhance research in the fields of electrical engineering and computer science in relation to new applications in electronic design automation. As part of this partnership, James Kukula from IBM Poughkeepsie has joined RLE as a visiting scientist to work with Professors Jonathan Allen, Srinivas Devadas, and Ja-

cob White and their students in the Circuits and Systems Group. This group will make recommendations for new hardware and software that will benefit electronic design automation research and development, and lead to innovative design automation capability.



Graduate student Ricardo Telichevesky presents his experiences with integrating the IBM 6000 in a heterogeneous environment during an IBM research review held at RLE in April. Faculty and students in RLE's Circuits and Systems Group delivered talks to IBM scientists and researchers involved in the area of electronic design automation. (Photo by John F. Cook)

RLE Collegium

The RLE Collegium was founded in 1987, and the annual membership fee is \$20,000. Members of MIT's Industrial Liaison Program can elect to apply a portion of their ILP membership fee to the RLE Collegium. Collegium members have the opportunity to develop close affiliations with the Laboratory's research staff and can quickly access emerging results and scientific directions. Collegium benefits include access to a wide range of publications, seminars, and laboratory visits. For more information on the RLE Collegium, please contact RLE Headquarters or the Industrial Liaison Program at MIT.