



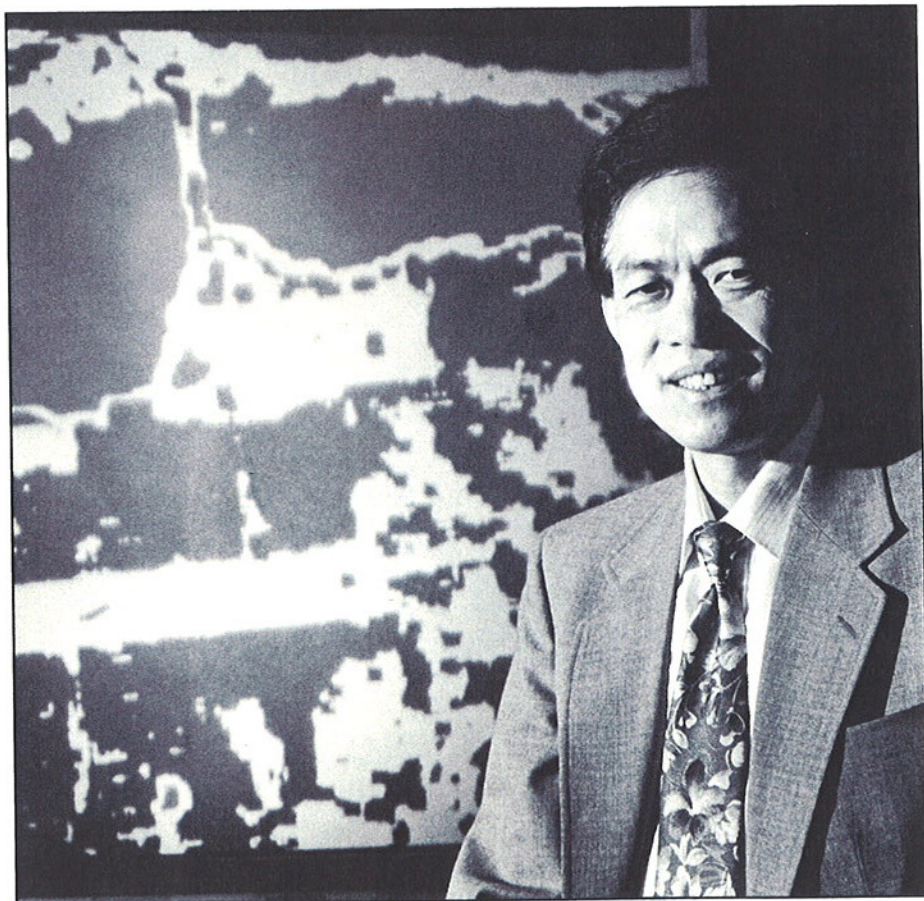
# RLE

# *currents*

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The Research Laboratory of Electronics at the Massachusetts Institute of Technology

## MAKING WAVES: Electromagnetics Research at RLE



Professor Jin Au Kong's work in microwave remote sensing has produced this polarimetric synthetic aperture radar (SAR) image of the San Francisco Bay area. The image is categorized into three terrain types: ocean, park, and urban areas.

(Photo by John F. Cook)

It wasn't until 1873 that Scottish physicist James Clerk Maxwell formulated an unprecedented set of mathematical equations to coherently describe the interrelationship of electric and magnetic fields. For centuries, people had witnessed the invisible force fields of various electrical and magnetic phenomena, such as the static electricity generated when rubbing a piece of amber. In an attempt to explain these various phenomena, scientists used terms such as "fluid" or "current" to describe the seemingly unrelated forces of electricity, heat, light, and magnetism. A powerful influence that precipitated the connection of electricity and magnetism came in the early 1800s. *Naturphilosophie*, a school of thought which had its origins in Germany, postulated that nature was engaged in an ongoing struggle, that all progress resulted from synthesis (which itself was a product of opposing forces), and that everything in nature was related to everything else.

Danish physicist Hans Christian Oersted, an advocate of *Naturphilosophie*, first demonstrated that moving electrical charges (or currents) exhibit magnetic effects and can produce a magnetic field. During a lecture in 1820, while connecting a battery to a circuit, he coincidentally observed that a nearby compass' needle was deflected as though the battery's electric current

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## Director's Message

In this issue, RLE's emphasis on the continuing exploitation of Maxwell's equations is described. It is difficult to think of any electrical and magnetic phenomena that are not characterized, in part, by these equations; thus, research associated with electromagnetics is broadly evident throughout the laboratory.

There is a wide range of applications that utilize the innovative solutions of Maxwell's equations in diverse media with unique boundary conditions. For example, electromagnetic transmission and reflection through the atmosphere as well as other naturally occurring materials has been carefully studied for remote sensing applications.

Other applications exploit different parts of the electromagnetic spectrum, as demonstrated by the use of microwaves for precision aircraft landing systems and by the time-domain studies of electromagnetic propagation along high-speed computer interconnects. Superconductivity provides an interesting new domain for electromagnetic characterization. Recently, microminiaturized motors have been studied and designed.

It is this endless flow of innovative applications, coupled with the enduring fundamental basis provid-



*Professor Jonathan Allen, Director  
Research Laboratory of Electronics*

ed by Maxwell and his followers, that facilitates the ongoing discovery of new phenomena and results. The RLE faculty in MIT's Department of Electrical Engineering and Computer Science not only lead important research in this area, but also provide basic instruction for students interested in this field. Indeed, the many fascinating ways in which electromagnetic phenomena have been studied are constantly being used in these fundamental subjects.

that electrical energy could be converted to mechanical energy through magnetism by building the first electromagnetic motor. Today, most electrical power is generated through the use of induction. By developing basic theories on electromagnetic physics, Faraday introduced the concept of imaginary lines of force for electromagnetic fields: *diamagnetism*, where materials are repelled at right angles to the lines of force; and *paramagnetism*, where materials are attracted or magnetized parallel to the lines of force. He investigated the space in which these lines

were able to create effects, a medium which he called "aether," and also conducted experiments on the ability of electromagnetic waves to pass through different materials or conductors.

Applying Faraday's discoveries, James Clerk Maxwell (also an advocate of the Naturphilosophie school) detailed the relationship between electricity and magnetism. In the 1870s, Maxwell's four equations brought together the work of many scientific predecessors, including Ampere, Ohm, and Faraday, who had identified various electrical and magnetic phenomena, but whose work was more focused on achieving experimental results. Maxwell did not discover the laws outlined in his equations, but his exact mathematical analysis neatly summarized the relationship between electricity and magnetism and converted Faraday's physical ideas into mathematical form.

Maxwell's first two equations comprise Gauss' laws for electric and magnetic fields, which specify the relationship between electric and magnetic charge density with adjacent electric and magnetic fields. The third equation, based on Faraday's law of induction,



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and Circulation  
Henry J. Zimmermann . . . . . Advice and  
Perspective

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Inquiries may be addressed to **RLE *currents***, 36-412, Research Laboratory of Electronics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139-4307.

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### ELECTROMAGNETICS AT RLE

*(continued)*

had acted as a magnet. Oersted's further studies introduced the concept of *electromagnetism*, where an electrical current flowed through a wire, and the conducting wire itself was enveloped in an invisible magnetic force field.

Conversely, magnetic fields also cause electrical effects. This concept of nonchemical electricity, known as *electromagnetic induction*, was demonstrated by British chemist and physicist Michael Faraday. In 1821, he proved



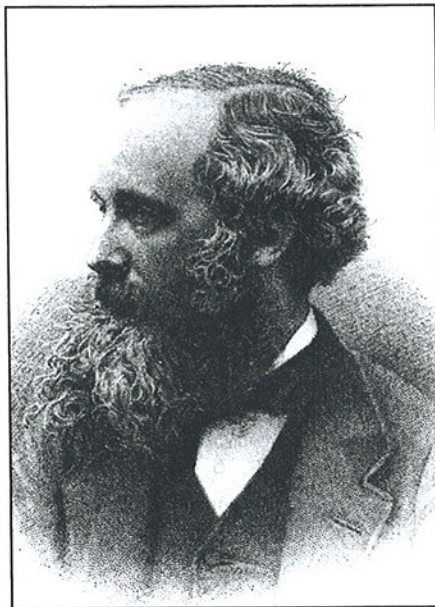
states that a changing magnetic field in time can result in an electric field. The fourth equation, known as Ampere's law, proposes a symmetry to the relationship described in the third equation: a changing electric field with time (or a conducting current) results in a magnetic field. Another way to look at the fourth equation is that a changing electric field in a nonconducting dielectric material is effectively a "displacement current." Maxwell proposed that this displacement current was a carrier for the transverse waves of electromagnetic energy.

In the process of identifying electromagnetic waves as coupled periodic electric and magnetic disturbances that spread out from an electric charge moving with a changing velocity (or an accelerated charge), Maxwell calculated the waves' velocity. He predicted that these transverse waves traveled at the speed of light. In predicting the existence of electromagnetic waves that could move at the speed of light, Maxwell laid what was to become the cornerstone of 19th century physics. By demonstrating the relationship between electromagnetism and light, he developed the common theory of *wave propagation*. Propagation refers to the outward spreading motion of electromagnetic waves, the process in which an electromagnetic disturbance at one point is propagated to a remote point from the wave's source without the medium itself actually moving. He also theorized that when electric and magnetic fields interacted, they produced *radiant energy*. It wasn't until nine years after Maxwell's death, in 1888, that German physicist Heinrich Hertz proved the existence of radiant energy and laid the groundwork for the future development of radio, television, and radar. And it wasn't until physicist Albert Einstein solved the mystery of how light travels through space in his theory of relativity in 1905 that electromagnetism provided the key element to the modification of classical mechanics.

## THE ELECTROMAGNETIC SPECTRUM

Although humans can detect only a small portion of the electromagnetic spectrum (we see visible light and feel the thermal heat of infrared energy), electromagnetic waves have an incredible range of frequencies and wavelengths. The wavelength of radio waves

can measure hundreds of miles long with frequencies less than 100,000 Hz. Gamma rays, found at the other end of the electromagnetic spectrum, have wavelengths that are measured in



*Scottish physicist James Clerk Maxwell (1831-1879) not only made valuable contributions to electromagnetics, but his prolific interests also greatly influenced a variety of other scientific fields. Maxwell's doctoral research on color vision and color theory produced the first color photograph, and his work in geometrical optics resulted in the development of the fish-eye camera lens. His essay on the rings of Saturn concluded that they were made up of nonmutually coherent masses of matter, a prediction confirmed 100 years later by the Voyager space probe. The Maxwell-Boltzmann distribution law stemmed from his studies on the properties of gas molecules. Many other terms and theories used in statistical mechanics and thermodynamics were conceived by Maxwell and carry his name, including Maxwell's demon, the Maxwell bridge, the Maxwell equal area rule, and the electromagnetic unit of magnetic flux called a maxwell. (Engraving by G.J. Stodart from a photograph by Fergus of Greenock, courtesy the D.J. Lovell Collection, MIT Museum)*

tenths or hundredths of a nanometer (the size of subatomic particles) and radiate at frequencies greater than  $10^{20}$  Hz. Waves from different bands of the electromagnetic spectrum possess unique characteristics, since their

behavior depends on their particular frequency, but all electromagnetic waves have several common properties, such as the ability to travel at the speed of light in a vacuum. Unlike any other wave phenomena, electromagnetic propagation can occur in the absence of any media.

Electromagnetic energy transfer is described in terms of how the waves interact with different media. In these interactions, the wave energy may be transmitted, absorbed, emitted, scattered, or reflected by or through the medium. The various types of media directly influence the behavior of the electromagnetic energy. Media can be described as moving, polarized, magnetized, dispersive, anisotropic, or bianisotropic. When an electromagnetic wave interacts with a material, its energy transfer characteristics are largely dependent on the wavelength corresponding to the composition of that material. For example, it can behave like other types of waves, such as sound waves, or hydrodynamic waves, or elastic waves. It can also behave as though it is made up of many individual photons, which have particle-like properties. This wave-particle concept is easily seen in the refraction of visible light as it propagates through materials of different optical densities such as air, glass, or water.

As Heinrich Hertz demonstrated, oscillating electrical charges produce electromagnetic radiation. Radio transmissions are achieved by electromagnetic waves produced by electrons that oscillate 100,000 to one million times per second in a transmitting antenna. When these waves reach a receiving antenna, the electrons inside respond by oscillating in unison with the incoming wave. The efficiency of the electromagnetic energy transfer is usually determined by the size of both the transmitting and receiving antennas; the largest possible antennas are used to enable the greatest efficiency. Various electronic devices can tune the receiver so that it only responds to certain electromagnetic wave frequencies, and amplifiers can be used to strengthen the incoming signal. One property of radio waves is that some are capable of being reflected from layers of ionized gas in the Earth's upper atmosphere. This enables the transmission of radio waves over long distances, overcoming the Earth's curvature.

*(continued on page 4)*



In the 1930s and 1940s, methods were developed to generate electric currents with more rapid oscillations in order to produce electromagnetic waves of higher frequencies and shorter wavelengths. While typical radio frequencies broadcast up to more than  $10^6$  Hz, and shortwave broadcasts transmit up to  $3 \times 10^7$  Hz, television and radar frequencies range from  $3 \times 10^7$  to  $3 \times 10^{10}$  Hz. Although the shorter, higher frequency waves of television and radar cannot take advantage of the reflective properties of Earth's ionized atmosphere, they can easily be transmitted in highly directional beams to specific targets and reflected back from those targets. This concept underlies the important applications used in microwave radar.

## ELECTROMAGNETICS RESEARCH AT RLE

RLE's Electromagnetics Group seeks to understand the interaction of electromagnetic fields with a variety of different media. This research involves the study of *electrodynamics*, which investigates the effects from electric currents that interact with magnetic fields as well as other electric currents. The group's research in this wide-ranging area contributes to self-consistent formulations of electrodynamics in various electromagnetic media and to the theoretical and experimental study of linear and nonlinear interactions of electromagnetic fields, which can be extended to other research on optical frequencies.

The Electromagnetics Group's recent work in electromagnetic waves and theory applications has included device modeling and other applications for microelectronic integrated circuits and superconducting electronics; microwave antenna design, modeling, and development; geophysical subsurface probing; synthetic aperture radar (SAR); and microwave remote sensing, as well as measurements and modeling for remote sensing; electromagnetic propagation over terrain and through the Earth's atmosphere; the investigation of transient electromagnetic pulse propagation and coupling problems; and the study of electromagnetic interference problems in avionic systems.

## Remote Sensing: An Eye in the Sky

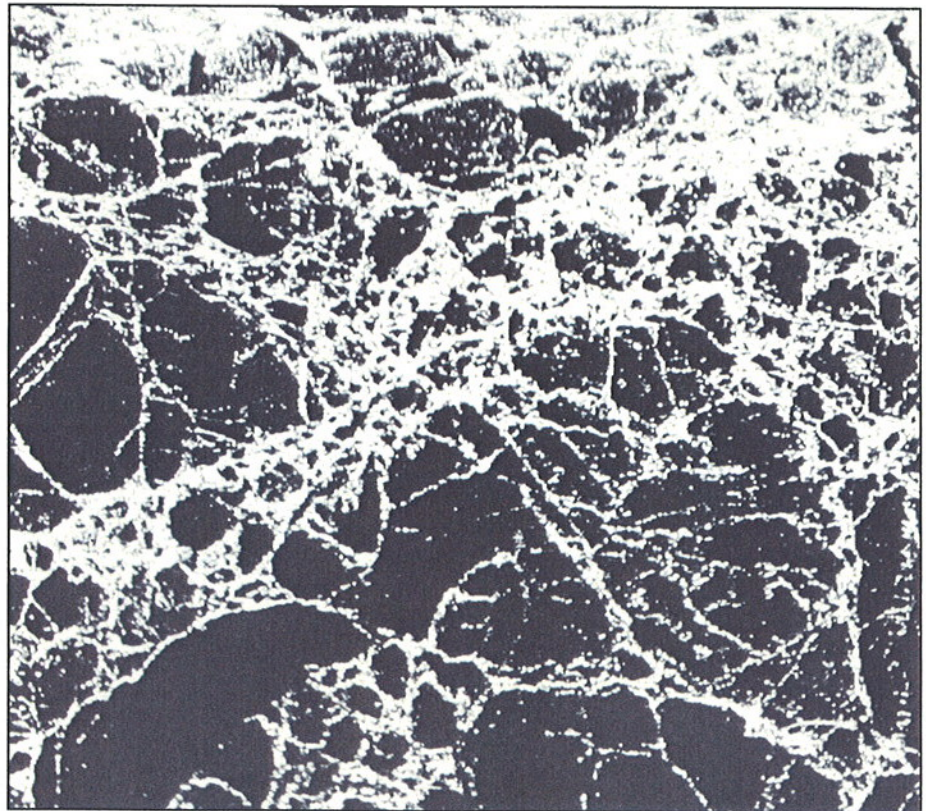
Remote sensing involves recording and analyzing electromagnetic energy from

visible light, infrared radiation, microwave radiation, and other forms of wave-propagated energy. Over the last thirty years, advances in remote sensing systems and computers have enabled scientists to develop a better understanding of the Earth. Data images are collected from Earth-orbiting satellites, processed and enhanced by computer, interpreted by scientists, and correlated with ground instruments. Information acquired from remote sensing can be used to monitor and evaluate many natural and agricultural resources, such as biomass and crop yield, range conditions, air and water quality, oil exploration, the motion of polar ice, and flood and fire control.

*Passive* remote sensing systems use infrared or visible light naturally reflected or radiated from the terrain. An electrooptical satellite sensor transforms the reflected or reemitted electromagnetic radiation into electrical pulses. A computer then converts the impulses into digital form on a magnetic tape. Many satellite sensors are multi-

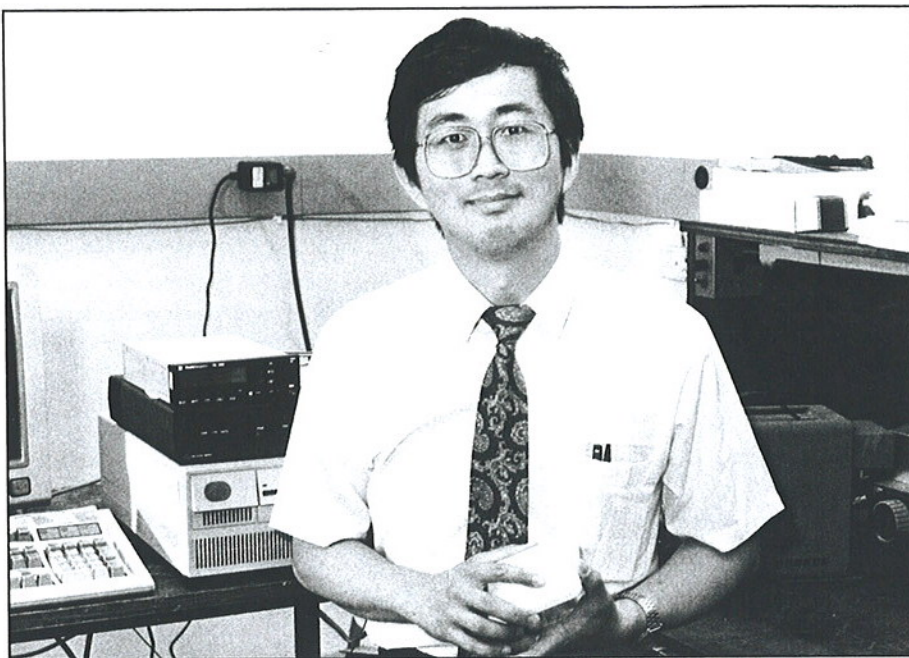
spectral scanners that collect information from several regions of the electromagnetic spectrum. The scanners use an oscillating mirror to channel the radiation through an optical system, which filters it into individual spectral bands. Areas of the Earth's terrain that exhibit unique physical properties reflect varying amounts of radiation in the different spectral bands. For example, forests radiate strong signals in the green spectral band and deserts produce strong signals in the red band.

*Active* remote sensing systems, such as spaceborne microwave radar systems in satellites or spacecraft, have much greater capabilities than passive systems. Radar's night vision and ability to penetrate through cloud cover and dense vegetation, while providing its own source of electromagnetic radiation, makes it ideal for mapping the details of geological surface features. By pointing an antenna off the side of an aircraft or spacecraft, *side-looking airborne radar* (SLAR) can obtain finely detailed images of the Earth's surface.



*This sea ice imagery was synthesized from polarimetric multifrequency data. The data was collected by synthetic aperture radar (SAR) installed on a NASA/JPL DC-8 aircraft flying over the Beaufort Sea area in the Arctic Ocean northeast of Alaska.*





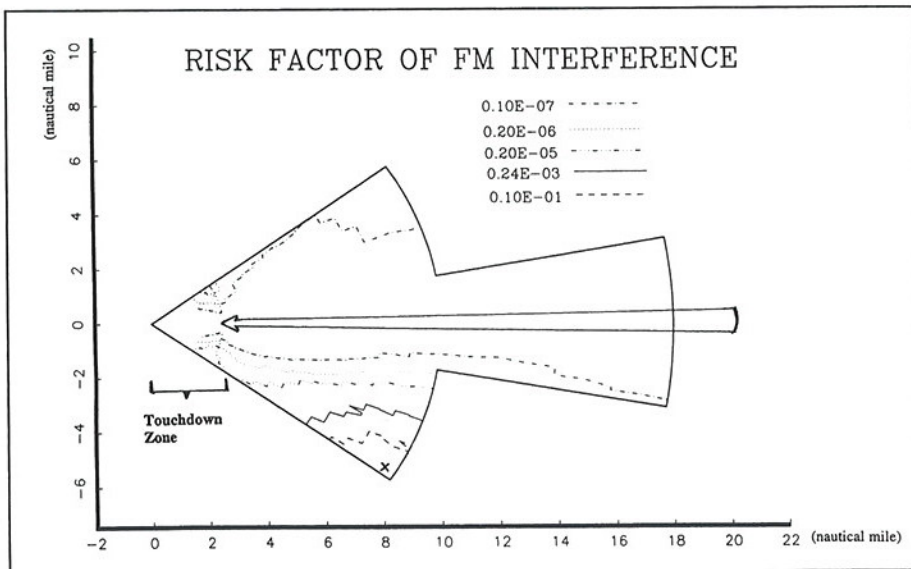
Research Scientist Dr. Y. Eric Yang conducts studies on a variety of airport precision landing systems. Here he displays a receiver that contains a microstrip antenna used in the proposed global positioning system (GPS). Dr. Yang is studying the likelihood of electromagnetic interference for future GPS applications and how FM signals may interfere with airport instrument landing systems (ILS). He is also carrying out millimeter-wave radar image simulation based on electromagnetic scattering theories in order to enhance a pilot's vision during poor weather. (Photo by John F. Cook)

SLAR permits the use of a large antenna, and since the size of the antenna is proportional to image resolution, it can provide much greater detail than other methods. The fan-shaped microwave beam targets objects at right angles to the craft's line of flight. By exploiting the craft's forward motion, a short radar antenna can be made to act like an elongated one. Continuous images of the terrain are produced, much like the scanning lines on a television picture tube, and recorded on photographic film. *Synthetic aperture radar* (SAR), a form of SLAR, achieves a high resolution of targets farther away from the antenna. Other factors such as the system's microwave pulse length and the collection of incident radiation from rough surfaces (diffuse scattering) and smooth surfaces (specular radiation) must be resolved.

Although the Earth's atmosphere may appear transparent to our eyes, the various gases at different levels of the Earth's atmosphere are responsible for the absorption and transmittal of electromagnetic energy at certain wavelengths. The ozone layer, for example, is an absorption band, and completely absorbs wavelengths shorter than 0.3 micron. Clouds, which are made up of water particles, not only absorb electromagnetic energy at wavelengths less than 0.3 centimeter, but scatter it as well. Only microwave energy and longer wavelengths can effectively penetrate cloud cover without being scattered, reflected, or absorbed. Other intervening regions of electromagnetic transmission act as atmospheric transmission bands or windows. One example is the random diffusion of electromagnetic waves in the upper atmosphere, which enables long-range electromagnetic wave reception or radio scattering. Scattering of electromagnetic waves can also be caused by the inhomogeneity or anisotropy of the transmitting medium and can degrade the reception of images for remote sensing.

Computers are used to digitally enhance remote sensing images and to assist scientists in interpreting the large amount of information collected by remote sensing techniques. In one method, a computer assigns each pixel in the image to a discrete numerical value based on the gray scale, which contains shadings ranging from white to black. Images are then converted to

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Using a statistical model, Research Scientist Dr. Y. Eric Yang investigates how out-of-band electromagnetic interference affects aircraft landing systems. This graph shows the contour profiles of probability risk of interference induced by several FM broadcast stations near an instrument landing system (ILS) transmitter. The aircraft touchdown zone is located near the tip of the "key-hole" region, or the so-called "frequency protected service volume" specified by the International Civil Aviation Organization. The "x" at the bottom edge of the key-hole region indicates the location of one of the FM broadcast stations in the area that may adversely affect the ILS. Comparison of this risk factor with the risk budget allocated for electromagnetic interference can determine if it is safe to operate in this environment.



binary form and can be reprocessed in order to obtain new digital values for a revised image. Scientists can then perform various mathematical operations to enhance the image's quality. Techniques include image stretching to increase contrast, and false coloring, which assigns different colors to the shades of gray. Reflectance, illumination, and light intensities can also be

group develops realistic theoretical models that are applicable to plowed fields, atmospheric precipitation, vegetation, and snow fields. This work includes polarimetric radar calibration algorithms, a branching model for the remote sensing of vegetation, and various theoretical models to study electromagnetic wave scattering from geophysical terrain such as ice and snow. The

## Electromagnetics in the Computer Age

In order to provide shorter interconnects between microchips, the modern multilayer integrated circuit packages used in high-performance mainframe computers employ not only conventional strip transmission lines, but also vertical transmission lines or *vias*. Because the vias may have the same length as the strip transmission lines, the Electromagnetics Group has been studying transient electromagnetic wave propagation on the vias to understand the optimal speed at which multilayer integrated circuits can operate.

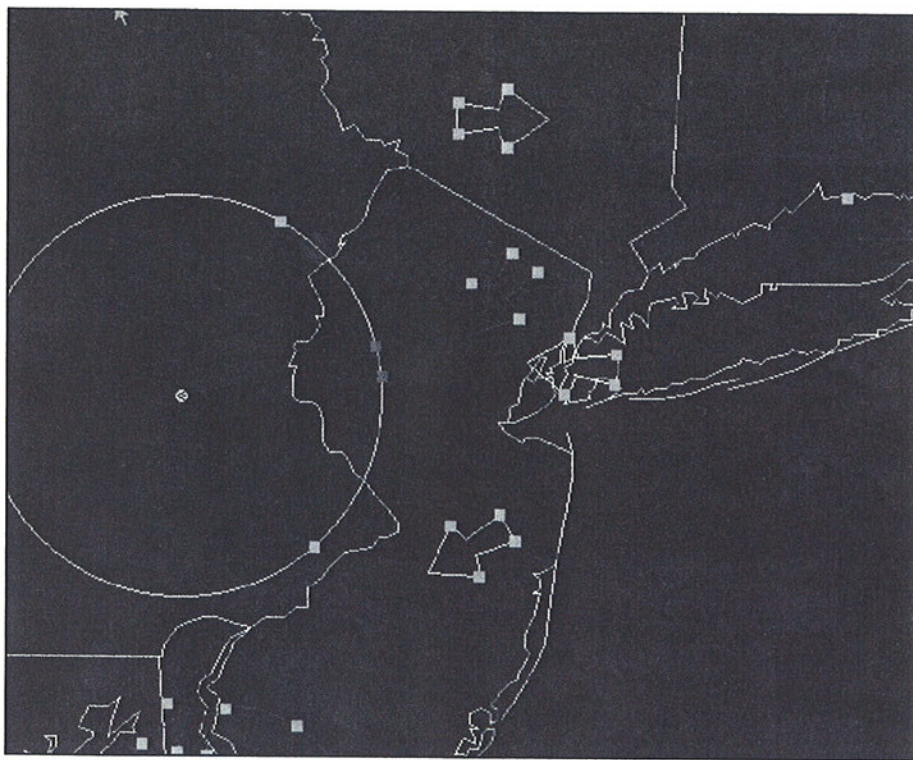
Electromagnetic propagation in multilevel computer interconnect structures is also being investigated by the Electromagnetics Group. Advanced numerical techniques are used for modeling and simulation to identify sources of interference and radiation and to improve the computer's design.

Recent studies have focused on electromagnetic emissions in printed wiring board components such as transmission lines and heat sinks. These investigations have been extended to larger computer components which may be possible candidates that resonate within the frequency range of emissions tests. The metallic enclosures used to house computer systems are also being studied because of the possibility of strong magnetic fields. The Electromagnetics Group is seeking to determine the optimum features and properties for resistive materials and techniques to minimize the electromagnetic field intensity in a computer's metallic enclosure. This work will enhance the design of integrated circuit interconnections to better meet the regulatory limits on electromagnetic emission levels.

## Electromagnetic Waves and Flight Safety

Since World War II, microwave radar has been adapted for many purposes, including aircraft navigation. Highly accurate tracking guidance systems and distance measuring equipment have been used for air traffic control *en route* or within an airport's control area. These precision landing systems play a vital role, particularly during adverse weather and heavy traffic conditions.

Early aircraft blind-landing systems were studied at MIT's Round Hill pro-



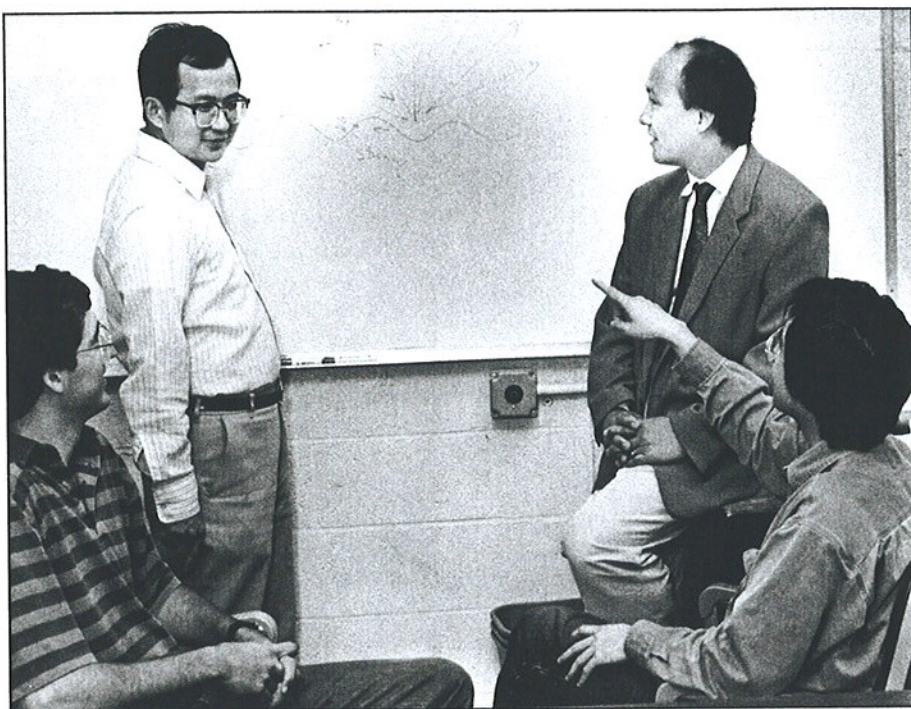
*Electromagnetic Simulation Applied to Landing Systems (EMSALS) is a computer simulation tool used by RLE's Electromagnetics Group to model and analyze the growing problems of frequency congestion and electromagnetic interference at airports in ten metropolitan US areas. The program analyzes the proposed installation of instrument landing systems (ILS) and microwave landing systems (MLS) by calculating and evaluating various factors in order to determine the best frequency assignments for these systems. This computer graphic is an interference assessment of a proposed ILS transmitter for Newark Airport's runway 29.*

altered to enhance the image's quality. Using the data collected in the different spectral bands, scientists can use the computer to proportionately size an image and enhance its various geological features.

RLE's Electromagnetics Group pursues studies in both the active and passive microwave remote sensing of the Earth's terrain. To enable the interpretation of remote sensing data, the

development of these models enables accurate data interpretation and scene simulation characteristics. The scattering of electromagnetic radiation by continuous and multilayered random media such as ice-covered water is also investigated by the group, which uses modeling studies to compare the effects of surface roughness, scattering center, and other factors involved in remote sensing.





Research Affiliate Dr. Robert T. Shin (second from right) leads a discussion on the modeling of electromagnetic wave scattering from rough surfaces with (from left) graduate student Joel T. Johnson, Visiting Scientist Dr. Leung Tsang, and Research Assistant William T. Au. (Photo by John F. Cook)

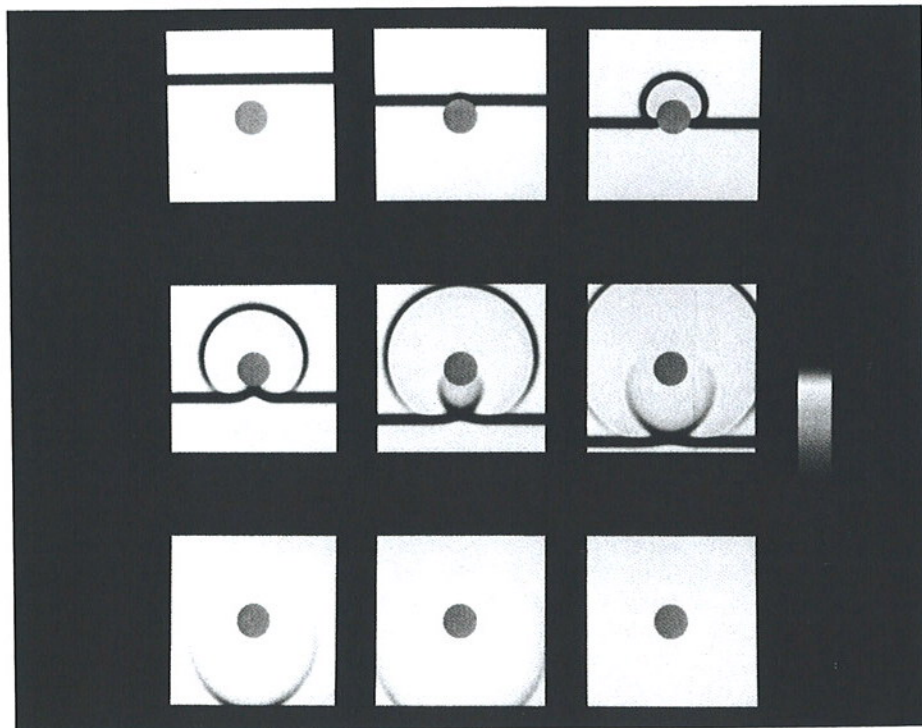
ILS signal is very sensitive to surrounding environments, thus it requires extensive site engineering to install the system. Aircraft are also restricted to a single, straight-in approach path, and there is growing concern about electromagnetic spectrum congestion and interference problems. Spectrum congestion is caused by the growing demand for precision landing systems near major metropolitan areas, which usually have several active airports. In addition, the ILS localizer, which provides lateral guidance during an aircraft's landing, has its frequency band (108-112 MHz) directly above the commercial FM broadcast band (88-108 MHz). Since the transmitting power of FM stations is much greater than the ILS, FM broadcast signals may interfere with airborne ILS receivers.

RLE's Electromagnetics Group has carried out extensive computer simulations to determine the extent of channel congestion as well as potential FM

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gram during the 1920s and 1930s. (See article on page 20.) Shortly before World War II, the Civil Aeronautics Authority Microwave Blind Landing Project and the Sperry Short-Wave Antenna Project were two experiments carried out at MIT in this area. MIT's wartime Radiation Laboratory 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.

GCA was only one of several airplane navigation systems that were created during the war. Another, the *instrument landing system* (ILS), is still used today as the aviation industry's standard for low-approach guidance systems to aid pilots in poor visibility. Although ILS is currently the worldwide standard precision approach guidance system, it has several drawbacks. The



The simulation of electromagnetic wave scattering by a conducting cylinder is generated by animation software that is used to illustrate various electromagnetic scattering phenomena. The finite difference-time domain (FD-TD) technique is used to discretize and numerically solve Maxwell's equations within the computational domain shown. A Gaussian pulse plane wave is incident on the cylinder (propagating from top to bottom) and the total magnetic field, which is parallel to the cylinder, is plotted to illustrate the "creeping wave" diffraction phenomena.



interference problems. The computer model Electromagnetic Simulation Applied to Landing System (EMSALS) was developed for this project, and the simulation results have been used by the Federal Aviation Administration as a planning tool to install new aircraft landing systems. The group has been involved in assessing the risk allowance (which is related to an aircraft's landing position) and the probability of FM interference in order to determine if harmful interference exists. The EMSALS computer model is also being used to analyze spectrum allocation near major metropolitan areas for MLS. Another area of investigation is the effect of out-of-band electromagnetic interference on aircraft automatic landing systems. The group will use extensive computer simulations to carry out this project.

### On the Horizon

RLE's Electromagnetics Group is investigating possible candidates for future aircraft landing systems. These include the microwave landing system (MLS), the global positioning system (GPS), and synthetic vision sensors (SVS). Studies of MLS and GPS focus on electromagnetic interference issues. Until recently, MLS was scheduled to replace ILS as the standard ground-equipped precision landing system within the next decade, since its shorter wavelength offers some advantages. However, GPS performed successfully during the recent Persian Gulf conflict and caught the attention of FAA and airline industry officials. Efforts are now moving forward to resolve technical issues to implement a satellite-based navigation and landing system around GPS. The group's GPS study examines the possibility of signal jamming, since the system's satellite signal is relatively weak. There is also the potential to create "synthetic vision" to assist pilots in an airport environment without ground navigation equipment. The SVS system would employ advanced millimeter-wave radar and infrared sensors. New computer simulation tools are being developed, based on the electromagnetic scattering model of terrain clutters and discrete objects, to determine the effectiveness of SVS during adverse weather conditions.

by Dorothy A. Fleischer



## FACULTY PROFILE:

### Jin Au Kong

*Born in Kiangsu, China, in 1942, Professor Jin Au Kong is a seventy-fourth-generation descendant of Chinese philosopher K'ung-Futzu, or Confucius. After receiving his bachelor's degree from Taiwan University in 1962 and his master's from Taiwan's National Chiao Tung University in 1965, he worked as a doctoral student under Professor David K. Cheng at Syracuse University. In 1968, he received his doctorate on electromagnetic wave propagation and radiation in moving media. Professor Kong joined RLE's Electrodynamics of Media Group in July 1969 to conduct research in quantum and classical electrodynamics, and was concurrently appointed Assistant Professor of Electrical Engineering and Vinton Hayes Postdoctoral Fellow in the Department of Electrical Engineering and Computer Science.*

*Widely recognized for his work in electromagnetic wave propagation, radiation, and scattering, and their applications in microwave remote sensing, geophysical exploration, and electromagnetic transmission and coupling in microelectronic integrated circuits, Professor Kong has published more than four hundred journal articles and conference papers and eight books (including Electromagnetic Wave Theory, Applied Electromagnetism, and Theory of Microwave Remote Sensing). He is also editor-in-chief of the Journal of Electromagnetic Waves and Applications, chief editor of Progress in Electromagnetics Research, and editor of the Wiley Series in Remote Sensing.*

*Professor Kong has served as a consultant to many government and private organizations, including the New York Port Authority, the Lunar Science Institute, the US Army Engineering Topographical Laboratory, Raytheon, Lincoln Laboratory, Hughes Aircraft, and Schlumberger-Doll. From 1977 to 1980, he was a consultant to the United Nations Undersecretary General on*



Professor Jin Au Kong  
(Photo by John F. Cook)

*science and technology and an interregional advisor on remote sensing for the UN's Department of Technical Cooperation for Development.*

*A fellow of the IEEE, Professor Kong was appointed Distinguished Lecturer in the Antennas and Propagation Society from 1982 to 1984. In 1984, he was appointed chairman of the Department of Electrical Engineering and Computer Science's concentration area on energy and electromagnetic systems. Professor Kong was awarded the Excellence in Teaching Award by the MIT Graduate Student Council in 1985. He is president of the Electromagnetics Academy and a member of the American Geophysical Union, the American Physical Society, and the International Union of Radio Science.*

#### • How did you become interested in electromagnetics research?

My interest in electromagnetics began as a junior in college. I was mainly attracted by the beauty and elegance of Maxwell's equations. Maxwell's equations and the whole framework of electromagnetics are formulated into a rigorous and well-founded scientific discipline. The more you study it, the more attracted you become to this science.



In graduate school at Syracuse University, I decided to make electromagnetics my profession. There were several reasons for my decision. As a discipline, electromagnetics has perhaps the most diversified applications, ranging from extremely low frequencies to optical frequencies and beyond. Its rich history and many great accomplishments serve as inspirations to the people who choose to work in this field. I had also witnessed the decline of vacuum tube technology and the transition that the people in this area had to make. I wanted to work on more fundamental disciplines that had versatile and relevant applications.

Electromagnetics crosses many scientific disciplines. It interacts with physics, mathematics, chemistry, and many other engineering sciences. My professors advised me that if I chose to work in electromagnetics, it would be easier for me to change disciplines later, but doing the opposite would be more difficult. The truth of this statement has been reaffirmed by my colleagues and students, many of whom have moved into solid-state devices, circuit design, computer science, and communications. Also in electromagnetics, the more experience you have, the more proficient you become. Electromagnetics teaches you how to abstract, to simplify, to formulate, to model, to apply—all of which are important elements in engineering science.

• *Why did you choose to teach?*

I think that teaching is probably in my family's blood. Many of my family members, including my father, were teachers. My ancestor Confucius, of course, was the greatest teacher of all! When I was very young, I had to memorize and recite all four books of Confucius' thoughts. Reading and understanding those books was tough, but now I can relate back to what I read and understanding them has been a tremendous influence.

• *Did you have a mentor?*

When I picked an "English" name after graduating from college in Taiwan, I chose the first two initials of my idol—Professor Julius Adams Stratton. His book on electromagnetic theory is the

bible in our field. I admire him not only because of his scholarly and professional achievements, but mostly because he is a very kind person. That is what impresses me most. I admire and respect his work as well as his personality.

• *What brought you to the United States and MIT?*

When Professor David Cheng of Syracuse University visited Taiwan, he was looking for a student to work with him. My school conducted an exhaustive oral examination to find one student, and I was selected. After I arrived at Syracuse in July 1965, Professor Cheng asked me to work on linear antenna arrays; changing their amplitude, phase, separation, and other elements. I didn't find that very interesting, so by the end of the summer, I asked if I could work on the electrodynamics of moving media. That became the subject of my doctoral dissertation. After I finished my thesis defense in April 1968, I stayed at Syracuse for one more year as a postdoctoral research engineer. In 1969, I came to MIT because it had the best students and faculty in engineering science. It was also the first and only job offer I had at that time.

• *Could you describe the progression of your electromagnetics research in RLE?*

There were many ongoing research activities in electromagnetics when I arrived in 1969. I initially worked on the quantum mechanical and classical relativistic aspects of electrodynamics in moving media and quadrupole media. This was the leading research center for electrodynamics of moving media and electromagnetics in general.

Before NASA's last moon mission in 1972, I was recruited by Professor John Harrington, who was then the director of MIT's Center for Space Research, to work on a project that involved the electrical properties of the lunar subsurface. This included the design of an antenna and the development of models that would predict lunar subsurface properties using a cross-dipole antenna deployed by the astronauts on the lunar surface. Data was collected from another antenna on the lunar rover vehicle. This work

helped me move into other research areas such as oil exploration and sub-surface probing.

Also in the early '70s, Professor David Staelin introduced me to passive radiometry. We received a contract from the Jet Propulsion Laboratory, and that's when I started remote sensing research. This work developed into active radar imagery, synthetic aperture radar, and other similar research topics. Now I am the principal investigator on several remote sensing projects and have supervised many theses on the subject. Four of our graduated doctoral students now work at the Jet Propulsion Laboratory.

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**As a discipline, electromagnetics has perhaps the most diversified applications, ranging from extremely low frequencies to optical frequencies and beyond. Its rich history and many great accomplishments serve as inspirations to the people who choose to work in this field.**

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• *What are some of the issues involved in your remote sensing work?*

In regions of ice, such as the Great Lakes or the Arctic Sea, the monitoring of ice breaking for commercial shipping lanes is of great economical importance. Also, in regions such as the western United States where water resources come mostly from the melting of snow in the mountains, the estimation and monitoring of snow depth is crucial to water resource management and irrigation. In areas of vegetation and forests, remote sensing helps to determine crop yield, desertification, deforestation, soil moisture, biomass estimation—these are all issues of importance. But, in order to estimate the thickness of ice and snow and the biomass of vegetation



from space-borne sensors, we must be able to model the ice, snow, and vegetation electromagnetically. So, we have developed theoretical models and computer software to interpret and simulate the results of the remote sensing data.

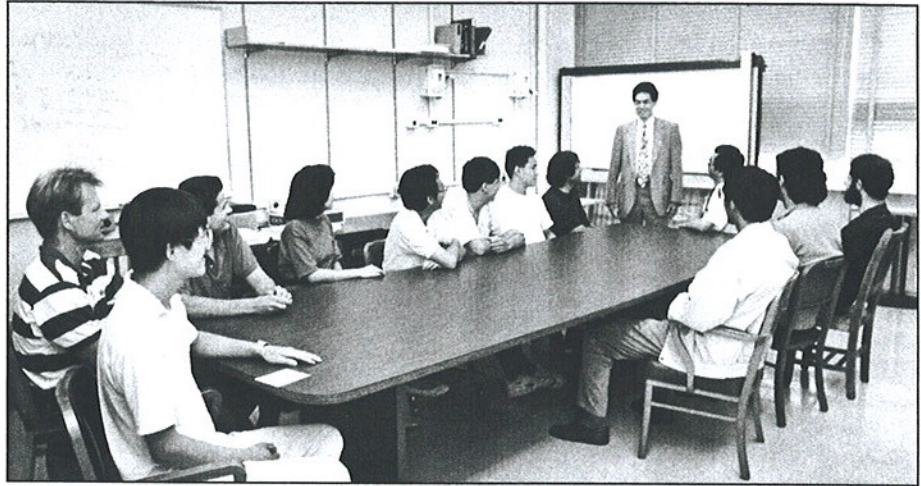
• *What are some of the techniques used in this work?*

Recent developments in radar and radiometry have been in the direction of polarimetry and high resolution. Microwave sensors can see through cloud cover and not only look at the Earth's terrain cover, but also into and under the terrain cover at low frequencies. We collect data using space-borne sensors and from simple field measurements, sometimes using a cherry picker to observe snow and vegetation. Most of our work in modeling is done mainly in the microwave region, and it can be described realistically enough so that we can apply a computer model to interpret the data. We then try to interpret what the images are telling us about the conditions of the vegetation or the snow or the ice. By analyzing these images, we can also work with biomass estimations. It's a very challenging task.

• *Your group's other projects address problems with computer interconnects and the problems associated with airport landing systems.*

Two of my former college classmates from Taiwan, who are now at IBM, recruited me to work on the electromagnetic modeling of IBM's 3081 processor and its related multilevel interconnect problems. We are also supported by the Digital Equipment Corporation and several other companies to identify sources of interference and radiation and to suggest improvements to the computer's design in order to reduce the interference and radiation. Advanced numerical techniques are applied to the modeling and simulation in this important application. Dr. Robert Shin heads up our effort in this area, and our research group recently received a best paper award for this work.

In 1988, the Federal Aviation Administration (FAA) asked us to work



"Our group is always working on projects that can be relevantly applied," notes Professor Jin Au Kong, "But, we also strive for a deeper understanding of the fundamental issues in electromagnetic wave theory. We hold group seminars every week and also meet in smaller groups to discuss fundamental issues that have no application at all." Clockwise from left: Graduate student Kevin Li; Visiting Scientists Dr. Lars H. Bombolt and Dr. Antonio Orlandi; Research Assistants Li-Fang Wang and Hong T. Ewe; graduate student Ante Salcedo; Research Assistants Alex X. Mou and John H. Oates; Research Scientist Dr. Y. Eric Yang; Professor Jin Au Kong; and Research Assistants Murat E. Veysoglu, M. Ali Tassoudji, and Shib-en Shib. (Photo by John F. Cook)

on electromagnetic interference modeling for airport landing systems and to assess the limitations of the instrument landing system (ILS). We developed a computer software program to assist in determining whether FM interference, as well as ILS mutual interference, may prevent the installation of a new localizer on specific airport runways. The FAA has found this simulation program to be useful, before ILS is replaced by a new system. When the simulation program is applied to the entire United States, it becomes clear that ILS cannot fulfill the precision landing needs required for the year 2000. Our conclusion was that the ILS will eventually have to be replaced. The British are also interested in applying our simulation program to their environment. Looking beyond the immediate future, the synthetic vision approach (which is composed of infrared and millimeter sensors) and the global positioning system, in addition to the microwave landing system, may become a viable means for future precision landing systems on the ground and inside the airplane. Dr. Eric Yang is heading up our effort in these important applied electromagnetics areas.

• *You once said that your research focuses on how electromagnetic waves are affected by media, not vice versa.*

Areas such as plasma physics and solid-state physics require the use of Maxwell's equations, but the medium is the major concern in those fields. In electromagnetics, Maxwell's equations are the center of our universe. We are mainly concerned with how to solve Maxwell's equations and how to apply electromagnetics in different fields. We are interested in how an electromagnetic field or wave is influenced by other factors, more than how the electromagnetic wave affects or deforms a medium, even in nonlinear electromagnetics. The medium is a secondary concern while the electromagnetic fields and waves are our primary concern.

• *Is there a current project that you're excited about?*

I am excited about the progress we are making in modeling the Earth's terrain to predict the results of remote sensing measurements. We are also excited about working in the time domain and using finite difference techniques for



electromagnetic computation. Also, we are exploring applications for new advances in materials research and applying theories in our electromagnetic simulation models in order to find devices that could benefit from the existence of materials such as superconductors. Electromagnetically, any medium is part of the universe, so when new materials are discovered, they are always within the domain of electromagnetics.

• *In terms of your research, what is your greatest challenge?*

The most challenging thing is to look at a problem and predict what its solution will be, before you actually solve the problem itself. To that end, I always encourage my students to look beyond the mathematics, to look at the physics behind it, and to attach a meaning to every mathematical manipulation. In this way, they can acquire the physical understanding and intuition that will help them solve problems before going through the detailed math, and to know what they need to do in order to get the solution.

• *What are the limitations in developing technological applications for electromagnetics?*

There is no limitation in developing technological applications for electromagnetics. The limitations in solving electromagnetic-related problems are dictated by a judicious choice of mathematical techniques and by a computer's processing power and its speed. The time required in finding a numerical solution to a problem that is described in dimensions larger than a few wavelengths can be unbearably long. Maybe one day, computer power will reach a stage where Maxwell's equations can be solved numerically and where the solutions can match all initial and boundary conditions. Even then, electromagnetics phenomena will still require a scientist's physical understanding and intuition in order to guide analysis. The reason why we must go through the mathematics is to get to the understanding and analytical aspects of the problem so that we can understand the problem and develop our own intuition about it. When we see the same type of problems again,

we have a pretty good idea of how to approach them. Then we can decide what kind of mathematics is required to get the correct numbers.

• *What do you consider to be the most important issue facing your field of research today?*

In the past few decades, much of the investment in electromagnetics research has been in the area of electronic warfare. The defense industry was also the biggest employer in electromagnetics research. Things are now changing, and I believe that electromagnetics researchers will be forced to change their directions to more civilian

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**In electromagnetics, Maxwell's equations are the center of our universe. We are mainly concerned with how to solve Maxwell's equations and how to apply electromagnetics in different fields.**

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and commercial applications. Our society will be the direct beneficiary of this change.

• *How would you characterize your research as providing a direct benefit or service to society?*

Fourteen years ago, I was the keynote speaker for a symposium in Togo, Africa, that I organized for the United Nations' Department of Technical Cooperation for Development. It addressed remote sensing applications in developing countries, such as in the Middle East, Africa, and Asia. Remote sensing centers are now in abundance in these countries. One project in Saudi Arabia was designed to locate nomadic people in the desert for the Saudi government. It helped the government to develop education, health care, and other essential services (particularly the provision of food and water) for these

people. So, what began as a small effort in the application of remote sensing imagery, turned out to be a great service to the nomadic people.

• *What is your vision of the future?*

Advances in computer power and architecture have greatly affected how we solve electromagnetic problems. Evolving numerical methods, the integral equation approach, the finite element, and the differential equation approach; from the frequency domain to time domain, and from serial programming to parallel computing—all of these steer us in new directions and affect research in areas such as wave-material interactions, radiation hazards, electromagnetic interference and compatibility, and wireless communications.

Applied electromagnetics has such wide interconnections. There are so many ideas that we are constantly exploring in terms of new technological advances in seemingly unrelated areas. As a scientific discipline, electromagnetics has never-ending applications to other fields. For instance, in treating interference as it relates to airport landing systems, there are many challenging issues, including multipath problems and frequency interference in the high-frequency spectrum, which will arise with the advent of high-frequency wireless communications. Wireless communication is a fascinating application that I have always been interested in. In dealing with the propagation of electromagnetic waves through the atmosphere, wireless communication issues will again be an important area in the future.

• *You mentioned radiation hazards, is your research concerned with human safety issues as they relate to electromagnetics?*

It is an area of public concern that definitely needs further study. We are very interested, but we do not have current projects funded in this area.

• *What is needed for continued progress in the field?*

The interaction with industry and keeping abreast with developments in other areas such as materials, computer archi-



(continued from page 20)

ture, biomedicine, space science, and communications, among others.

• *You have promoted this interaction with the establishment of a new professional society in electromagnetics.*

Yes, the Electromagnetics Academy has already sponsored several conferences called the Progress In Electromagnetics Research Symposia. The Electromagnet-

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ics Academy is an honor society that recognizes accomplishments, but does not collect membership fees. The first conference in Boston in 1989 presented 300 papers, and the second conference in Cambridge in 1991 had 600 papers. This year, we moved to the Jet Propulsion Laboratory at Cal Tech and had over 800 papers.

• *What has been the most rewarding aspect of your work?*

We have produced some of the most brilliant students in the field, and they now occupy important positions in academia, industry, and other engineering science fields. It has been a pleasure to keep in close contact with them at many of the scientific meetings and professional exchanges. In terms of research and writing, I have always enjoyed making small contributions, especially when the results have relevant applications or when the presenta-

tion of material makes the subject matter interesting and easier to understand.

• *Do you have advice for students interested in electromagnetics?*

For those of you who intend to do thesis research in electromagnetics, you must be prepared to build a firm foundation and grasp the fundamentals by taking courses and making good use of the library. Read extensively in your area of interest, whether it is in the area of remote sensing modeling or computational techniques. To work on a topic in isolation and to be oblivious to the current literature is the worst possible approach to research in any field. You shouldn't treat a graduate thesis as an advanced homework problem. Although you may not find the solution to your original problem, it is true that when you go deeper into a topic, you can always make a contribution. You must not approach your research as doing homework. This is why some students who have a perfect academic record are not always good researchers. You must be able to think on your own feet. No one knows better than you about the problem you're working on. Guidance and suggestions are helpful only when you know how to make good use of them. You need a high goal to be motivated, but only by taking moderate, little steps can you reach your highest goal. Most important of all, do not restrict yourself to a narrow topic. Be prepared and open-minded in making contributions to seemingly unrelated topics. Cross-fertilization is an intellectually rewarding exercise. In the field of electromagnetics, it is always stimulating and rewarding to achieve as much depth as breadth, in the understanding of the theory and its various applications.

• *What do you consider to be your most significant achievement?*

I hope that is still to come! Many times when you make a small contribution, you feel it is significant at that particular moment. After a while, you realize that it is not really as important as you thought it was. So, you hope that the most significant achievements are still to come in the future.

present state. The properties and peculiarities of wave propagation, attenuation, reflection, polarization, etc., at these enormous frequencies in the several media must be quite exhaustively studied. . . " In 1938, Barrow supervised Lan Jen Chu's doctoral dissertation. Dr. Chu was to join the MIT faculty and make important contributions to the theory of wave transmission in hollow tubes of elliptical and rectangular cross section and in Barrow's electromagnetic horn.

Round Hill's research program involving the propagation of radio waves and light through fog was the basis for studying instrument landing for airplanes. In conjunction with the Civil Aeronautics Authority, the CAA-MIT Microwave Instrument Landing System was presented as a conference paper in 1940. Plans to install a complete experimental microwave landing system at the Boston Municipal Airport were scrapped as World War II took center stage. All those early projects carried out at Round Hill and those within the Electrical Engineering Department's Communications Division became the foundation for establishing MIT's Radiation Laboratory and the MIT Radar School.

The Round Hill estate was inherited by Colonel Green's sister when he died in 1936. She subsequently donated the property to MIT in 1948. In later years, the estate was the site of several notable experiments: Professors Jerome B. Wiesner and William H. Radford developed new and reliable methods of transmission scattering for microwaves, and Nobel laureate Dr. Charles H. Townes and Dr. Ali Javan used the mansion's quiet surroundings to conduct optical maser experiments in the wine cellar. In 1964, MIT sold Round Hill to the Society of Jesus of New England, and in 1966, the College of the Holy Cross dedicated the Round Hill Astrophysical Field Station. Today, Round Hill is the site of a condominium development.

Source: Karl L. Wildes and Nilo A. Lindgren, *A Century of Electrical Engineering and Computer Science at MIT, 1882-1982* (MIT Press, 1985).



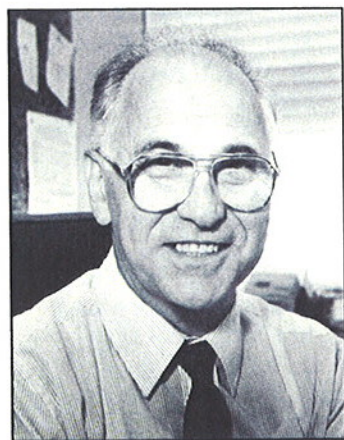


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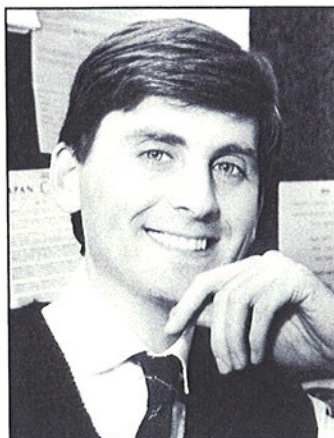
**Dr. Boris L. Altshuler**, Professor of Physics, was announced as corecipient of the 1993 Hewlett-Packard Europhysics Prize for Outstanding Achievement in Solid-State Physics by the European Physical Society. Professor Altshuler and his collaborators were cited for their pioneering theoretical work on coherent phenomena in disordered conductors and for profoundly influencing the understanding of physics in transport

phenomena in disordered metals and semiconductors. Their achievement led them to explain the origin of the negative value of the magnetoresistance coefficient in disordered metals and has made fundamental advances in a new branch of physics known as mesoscopy. The award's other corecipients are: Arkadii G. Aranov of the Ioffe Physico-Technical Institute in St. Petersburg, Russia; David E. Khmelnitskii of Trinity College at Cambridge University and the Landau Institute for Theoretical Physics in Moscow; Anatoly L. Larkin of the Landau Institute and Moscow State University; and Boris Z. Spivak of the University of Washington. Professor Altshuler's current research in RLE's Surfaces and Interfaces Group involves the theoretical study of microstructure properties, including the quantum interference of electron waves and electron-quantum dot interactions. (Photo by John F. Cook)



**Dr. Bruno Coppi**, Professor of Physics, received the Special Prize for Scientific Research of the Prime Minister of Italy. The award is presented to those individuals who have dedicated their lives to the betterment and promotion of culture, centered around the highest standards of research and experimentation. Professor Coppi, a principal investigator in RLE's Plasma Physics group, was cited for his outstanding scientific

research. He will receive the prize with fourteen other honored recipients in the arts and sciences at a ceremony in Rome in December 1993. Earlier this year, Professor Coppi was also appointed to a three-year term as a senior fellow of the Italian Academy for Advanced Studies in America and, in addition, received the 1993 Italgas Prize for Energy Science in October at a ceremony in Turin, Italy. (Photo by John F. Cook)



**Dr. Jesús A. del Alamo**, Associate Professor of Electrical Engineering and Computer Science, was awarded MIT's Harold E. Edgerton Award on May 19, 1993. The award was established in 1983 in honor of Professor Harold E. "Doc" Edgerton, who died in 1990, and recognizes a junior faculty member for distinction in teaching, research, and service to the MIT community. Professor del Alamo was cited for advancing the

understanding of compound semiconductor devices and developing a strategy to achieve high breakdown voltage in III-V transistors. He and his collaborators in RLE's Materials and Fabrication Group conducted the first electronic tunneling spectroscopy experiments to determine state densities for one-dimensional semiconductors. In addition to his research, Professor del Alamo was recognized for his excellent teaching skills and service to the MIT community. He is the only junior faculty member on the department's Professional Education Policy Committee, which guided the development of the new five-year Master of Engineering degree. (Photo by John F. Cook)



**Dr. James G. Fujimoto** (SB '79, SM '81, PhD '84), Associate Professor of Electrical Engineering and Computer Science, was elected to fellow in the Optical Society of America. Professor Fujimoto, a principal investigator in RLE's Optics and Devices Group, conducts research on femtosecond optics and its application in quantum electronics and laser medicine. His group has produced laser pulses as short as a few wave-

lengths of light and has used them to investigate ultrafast dynamics in optoelectronic materials and devices. Professor Fujimoto received a National Science Foundation Presidential Young Investigator Award in 1986 and was a corecipient of the 1990 National Academy of Sciences Award for Initiatives in Research. He is a member of the American Association for the Advancement of Science and the American Physical Society.

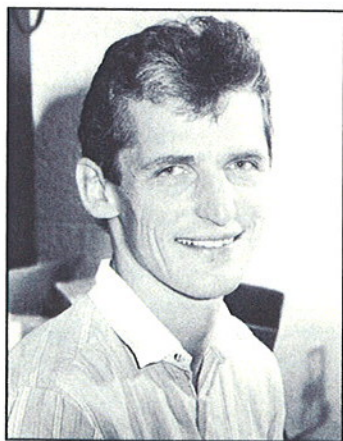
(Photo by John F. Cook)





**Dr. Marc A. Kastner**, Donner Professor of Science, was appointed director of MIT's Center for Materials Science and Engineering, effective July 1, 1993. He succeeds Professor Bernhard J. Wuensch, who served as director for five years. Professor Kastner joined the MIT Physics Department faculty in 1973, and served as head of the Division of Atomic Condensed Matter and Plasma (1983-1987) and associate

director for the Consortium for Superconducting Electronics. As a principal investigator in RLE's Quantum-Effect Devices Group, Professor Kastner has made contributions to the understanding of the electronic structure of amorphous semiconductors. In 1988, he received the Outstanding Scientific Accomplishment Award from the U.S. Department of Energy's Division of Materials Science. His recent research has focused on the single-electron transistor, which has increased understanding of quantum mechanical processes in semiconductor devices. A graduate of the University of Chicago (BS '67, MS '69, PhD '72), Professor Kastner is a fellow of the American Physical Society and the American Association for the Advancement of Science. (Photo by John F. Cook)



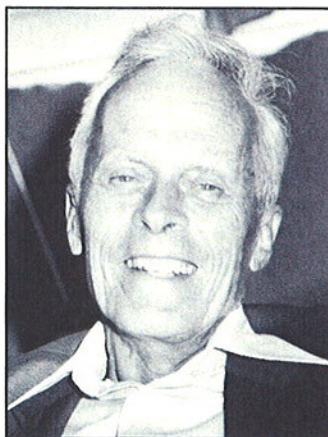
**Dr. Wolfgang Ketterle** was appointed Assistant Professor of Physics on September 1, 1993. Professor Ketterle joined RLE's Atomic, Molecular, and Optical Physics Group in 1990 as a postdoctoral associate. His research with Professor David E. Pritchard has focused on the cooling or slowing of atoms by isotropic light and the dark spontaneous force optical trap (called "dark SPOT") used to trap cooled atoms. The dark SPOT technique greatly improves the density of trapped atoms in order to study their collective physical properties. Cold trapped atoms are used in atomic optic and quantum optic experiments and to test fundamental theories in these areas. Professor Ketterle is a graduate of the University of Heidelberg ('78) and the Technical University of Munich ('82). He received his doctorate in physics from Ludwig-Maximilians University and the Max-Planck Institute for Quantum Optics in 1986. (Photo by John F. Cook)

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**Dr. Leslie A. Kolodziejski**, Karl R. Van Tassel Career Development Associate Professor, was selected to serve a three-year term as Esther and Harold E. Edgerton Associate Professor, effective September 1, 1993. The Edgerton professorship was established in 1973 by the MIT Corporation to honor Professor and Mrs. Harold E. Edgerton, who provided support and encouragement to the MIT community for more than half a century.

Professor Kolodziejski, a principal investigator in RLE's Materials and Fabrication Group, conducts research in II-VI and III-V materials growth using chemical beam epitaxy techniques for electronic and optical applications. Professor Kolodziejski came to MIT as an assistant professor in 1988 from the faculty of Purdue University (BS '83, MS '84, PhD '86). She is a member of the American Physical Society, the Materials Research Society, the Optical Society of America, and the IEEE. (Photo by John F. Cook)



**Professor Campbell L. Searle**

Professor of Electrical Engineering and Computer Science **Campbell L. Searle** (SM '51) and **Dr. William M. Siebert** (SB '46, ScD '52), Ford Professor of Engineering in the Department of Electrical Engineering and Computer Science, were named corecipients of the Department Head's Special Recognition Award. The award recognizes their leadership in the design and development of the department's new professional education curriculum

for the Master of Engineering degree. Dr. John V. Gutttag, Professor of Electrical Engineering and Computer Science, who was recently appointed Associate Department Head of Computer Science and Engineering, was also named corecipient of the award.

Concomitantly, Professor Searle announced his retirement this year, after serving forty-five years at MIT, thirty-five of those on the faculty. He joined RLE in 1948 as a research assistant and completed his master's thesis on missile guidance and telemetry under RLE's Project Meteor. After promotion to research staff in 1950, his research included the devel-





**Dr. William M. Siebert**

graduate officer in the Department of Electrical Engineering and Computer Science and chairman of both the departmental Committee on Graduate Admissions and MIT's Committee on Graduate Admission.

Professor Siebert continues to develop mathematical models for physiological systems, particularly the peripheral mechanical and neural structures in the auditory system. His research is aimed at understanding how these structures contribute to an organism's functioning, and, in collaboration with Professor Searle, he has investigated the role of human auditory mechanisms in speech recognition.

*(Photo by John F. Cook)*

opment of an atomic clock with the late Professor Jerrold Zacharias. More recently, Professor Searle's research included the study of auditory localization and the design of computer models for various physiological processes. In the early 1960s, he was head of the Semiconductor Electronics Education Committee, an international educational development effort that introduced solid-state electronics into university curricula. He also served as



**Mr. William H. Smith** was appointed RLE Fiscal Officer, effective July 1, 1993. He succeeds Mr. Donald F. Duffy, who retired after thirty-one years at MIT. Mr. Smith joined MIT in 1988 as a financial staff assistant in the Biology Department. Since 1990, he has served as RLE's Assistant Fiscal Officer. A graduate of the University of Massachusetts/Boston (BA/Economics '85), Mr. Smith will oversee RLE's Fiscal Group, which handles

all proposal generation, budget preparation, and contract monitoring. His plans include the development of new computer-based products and fiscal services for RLE researchers.

*(Photo by John F. Cook)*



**Dr. Gregory W. Wornell** (SM '87, PhD '91), Assistant Professor of Electrical Engineering and Computer Science, was appointed to the ITT Career Development Assistant Professorship, effective July 1, 1993. The ITT chair was established in 1981 by a grant from the International Telephone and Telegraph Corporation to provide support to promising junior faculty in the department. Professor Wornell joined RLE's Digital

Signal Processing Group in 1985 as a graduate student and research assistant and was appointed to the MIT faculty in 1991. Currently, Professor Wornell studies the use of self-similar and fractal geometries, nonlinear dynamics, and chaos theory in problems involving signal modeling, signal processing, and communication systems design. Two recent projects have focused on wavelet-based representation and algorithms used in generalized fractal processes as well as binary data transmission and detection with chaotic signals. *(Photo by John F. Cook)*



**Dr. M. Selim Shahriar** (SB '86, SM '89, PhD '91) was appointed as a research scientist in RLE's Atomic, Molecular, and Optical Physics Group, effective September 1, 1993. Since joining RLE in 1985 as an undergraduate, Dr. Shahriar has worked with Professor Shaoul Ezekiel as a research assistant and postdoctoral associate on precision studies of atom-field interaction. His recent research involved the application of

stimulated Raman interaction to the development of a high-speed phase conjugator, an ultracold atom trap, and a high-capacity optical data storage system. Dr. Shahriar will study the development of high-resolution magnetometry using laser-induced Raman interaction and investigate high-speed, high-efficiency, self-phased conjugation in an atom trap.

*(Photo by John F. Cook)*





# alumni notes

On June 11, 1993, *The Boston Globe* reported that **Dr. Robert H. Domnitz** (SB'67, SM'68, PhD'75) was appointed by the Commonwealth of Massachusetts to serve as a liaison with local telecommunications companies in the state. Dr. Domnitz will foster relations between approximately 300 businesses engaged in telecommunications and will address issues related to regulation, legislation, financing, and joint ventures. In the late 1960s and early 1970s, Dr. Domnitz was a graduate student in RLE's Communication Biophysics Group under Research Scientist Nathaniel Durlach. For a short time, he was also an RLE research staff member and research affiliate. Dr. Domnitz is founder and president of Technical Collaborative, Inc., an electronics company involved in design, manufacturing, and consulting, based in Lexington, Massachusetts.

In a related item, *The Globe* also reported that **Mr. Sidney Topol**, an alumnus of MIT's Radar School, was appointed chairman of the new Massachusetts Telecommunications Council in June 1993. Mr. Topol, a retired chairman of Scientific-Atlanta, Inc., said the council will promote public policy issues and bring together investors with interests in telecommunications.

**Dr. Robert J. Shillman** (SM'72, PhD'74), founder and chairman of Cognex Corporation of Needham, Massachusetts, was profiled in *The Boston Globe* on August 18, 1993. The article describes "Dr. Bob's" penchant for fun, his fostering of Cognex's "zany corporate culture," and the role that it has played in the company's success. From 1969 through 1972, Dr. Shillman was a National Science Foundation fellow and a research assistant in RLE's Cognitive Information Processing Group. His doctoral thesis involved programming a reading machine to recognize the unique features of letters of the alphabet in order to determine how humans distinguish between the letters. He continued his association with RLE until 1980 as a staff member and a research affiliate. *The Globe* reports that, "Since its founding in 1981 Cognex has become the world's leading provider of computer systems that replace human vision in manufacturing. . . ."



## Collegium

The RLE Collegium was established in 1987 to promote innovative relationships between the laboratory and business organizations through research projects and special partnerships. Its goal is to increase interaction and communication between RLE researchers and outside professionals in electronics and related fields. Collegium members have the opportunity to develop close affiliations with the laboratory's faculty, research staff, and students, and can quickly access emerging results and scientific directions. This kind of professional interaction provides RLE Collegium members with the most up-to-date technical information, often in areas not fully addressed by business and industry.

Collegium benefits include access to a wide range of RLE publications, personalized seminars and laboratory visits, and other opportunities for technology transfer. RLE also hosts visiting scientists from collegium companies. Individual research projects and special partnerships may develop with mutual technical interests and the appropriate external sponsorship.

The RLE Collegium membership fee is \$20,000 annually. Members of MIT's Industrial Liaison Program can elect to transfer 25 percent of their ILP membership fee to the RLE Collegium. Collegium fees will encourage new research initiatives within RLE.

RLE welcomes inquiries regarding the laboratory's research. To request an **RLE Progress Report**, an **RLE Collegium Prospectus**, or for more information on other RLE publications, please contact:

Research Laboratory of Electronics  
Massachusetts Institute of Technology  
77 Massachusetts Avenue  
Cambridge, MA 02139-4307  
Collegium: (617) 253-2509/2510  
Publications: (617) 253-2566  
Fax: (617) 258-7864

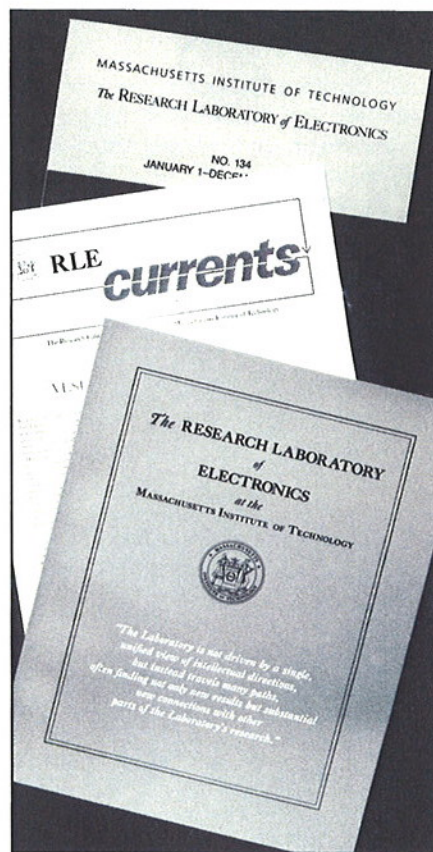


## Publications

RLE has recently published the following technical reports:

***From Random Fields to Networks***, by Ibrahim M. Elfadel. RLE TR No. 579. June 1993. 215 pp. \$19.00

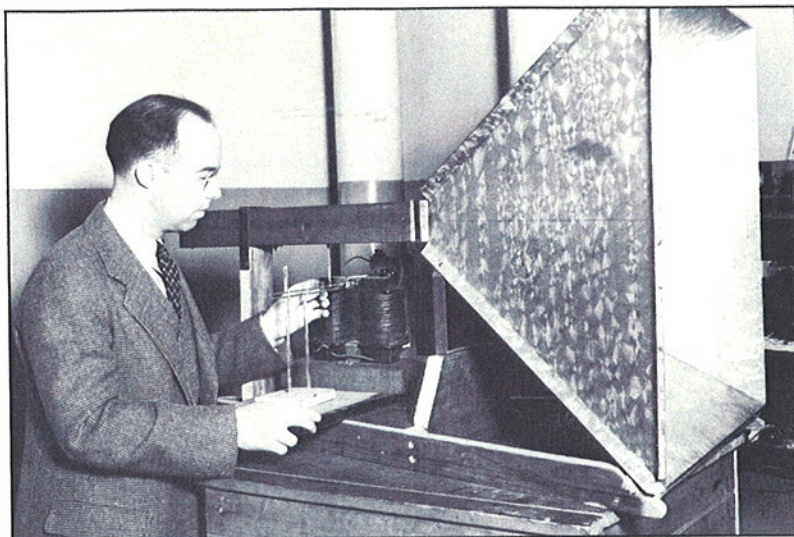
***Fault-Tolerant Computation Using Algebraic Homomorphisms***, by Paul E. Beckmann. RLE TR No. 580. June 1993. 196 pp. \$17.00



In addition, ***RLE Progress Report No. 135***, which covers the period January through December 1992, provides extensive information about the research objectives and projects of RLE's research groups. It also lists faculty, staff, and students who participated in each research project, in addition to current RLE personnel, and identifies funding sources. The ***Progress Report*** is available at no charge.



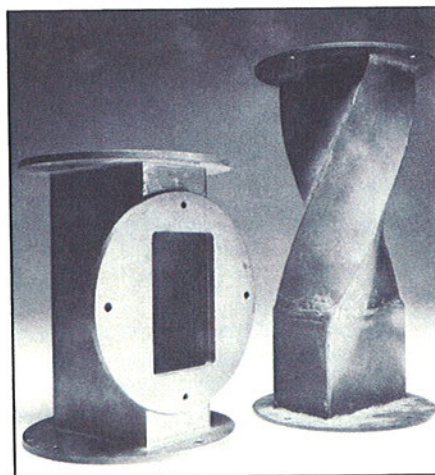
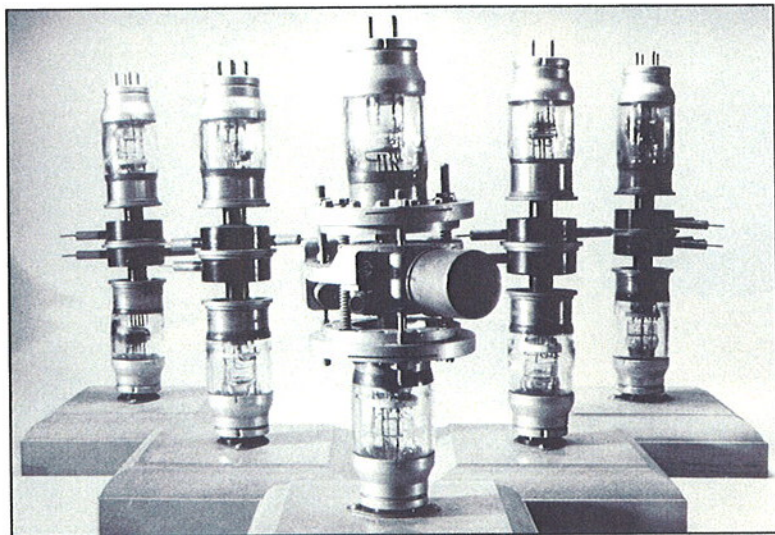
# History of Electromagnetics Research at RLE



**1938**

*Professor Wilmer L. Barrow adjusts the transmitter of an electromagnetic horn antenna that is part of a system he developed for "static-less" ultrahigh frequency wave transmission. The system consisted of a conductor tube, a transmitting terminal device, and either a receiving terminal unit or a radiating end such as the electromagnetic horn. The horn's hollow tube operated on waves only a few hundredths of a meter long and filtered out low-frequency signals while transmitting high-frequency waves. This system pioneered high-efficiency transmission of communication signals. Professor Barrow later taught at the MIT Radar School and became its director in 1943.*

*(Photo courtesy MIT Museum)*



**1940**

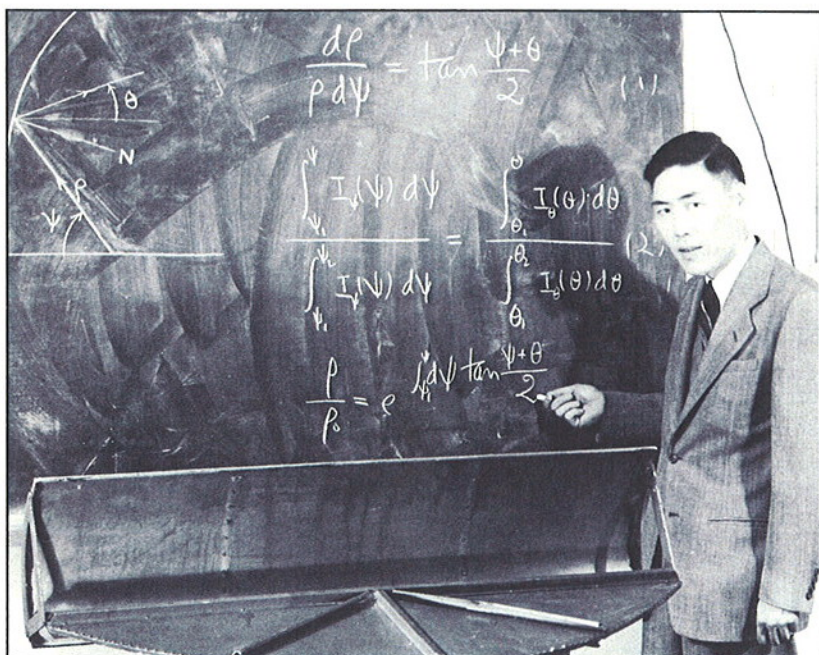
*Three-thousand-megahertz 10-centimeter klystrons (above left). In the Sperry Short Wave Antenna Project at MIT, two were attached to receiver horns and used to radiate a beam of microwave energy in a split beam pattern. An experiment carried out by Professor Wilmer L. Barrow and a team of research assistants (including Edward C. Dench, Frank D. Lewis, Walter W. Mieher, Daniel S. Pensyl, and Henry J. Zimmermann) demonstrated the devices' ability to track a moving two-by-three-foot sheet of aluminum. In the photograph at right are two 10-centimeter waveguides, a T junction (left) and a "twister." The T junction waveguide was outfitted with a tuning plunger and used with the Sperry klystrons to maximize a standing wave. The twister changed a vertical polarized wave to a horizontal polarized wave.*

*(Photos by John F. Cook)*



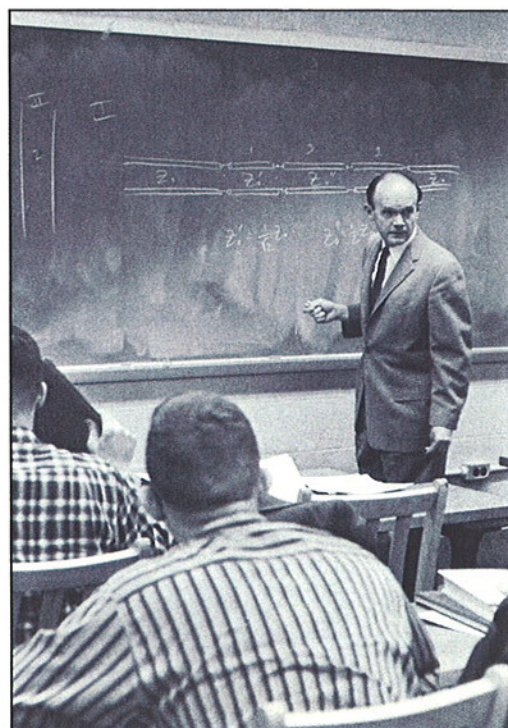
## 1946

During the late '20s and early '30s at MIT's Round Hill research program, Professor Julius A. Stratton worked with graduate students (later Professors) Henry G. Houghton and William H. Radford on transmitting electromagnetic wave signals through fog to assist in the blind landing of aircraft, and later to locate land and ocean objects from the air. Professor Stratton's book, *Electromagnetic Theory*, published in 1941, is still considered an essential text in the field today. As a staff member in MIT's war-time Radiation Laboratory, he worked on the development of long-range navigation systems (LORAN) and became RLE's first director in 1946, continuing the Rad Lab's tradition of interdisciplinary research. Professor Stratton was also instrumental in establishing many innovative academic and research policies in his several administrative capacities at MIT (including provost, chancellor, and president). (Photo courtesy MIT Museum)



## 1952

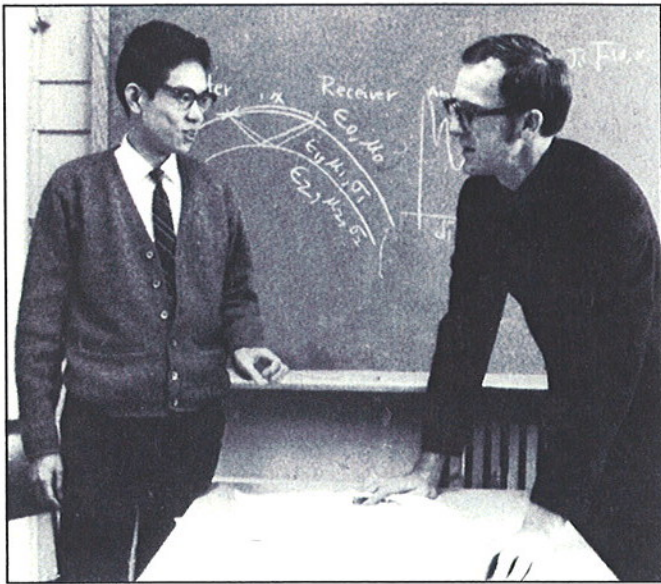
Professor Lan Jen Chu, a doctoral student of Professor Wilmer L. Barrow in 1938, developed new antenna designs for the radar systems created at MIT's Radiation Laboratory and traveled to his homeland, China, to introduce microwave radar during World War II. He conceived the "Chu formulation" of electrodynamics and discovered the small-signal power theorem, which was the forerunner of the small-signal energy principles of plasma physics. Professor Chu was known not only for his contributions to modern electromagnetic theory and its applications, but also for making it accessible to undergraduates and for developing special programs for exceptionally gifted students. (RLE file photo)



## 1960s

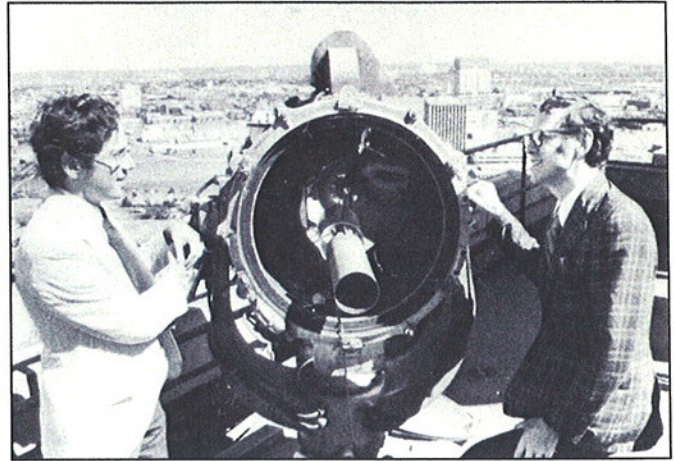
Professor Robert L. Kyhl explains a transmission line model for electromagnetic waves in dielectric slabs. (Photo by Ivan Massar/Black Star)





1972

Professors Jin Au Kong (left) and Paul L. Penfield, Jr., discuss an experiment conducted by astronauts during the Apollo XVII moon mission to study the electrical properties of the lunar subsurface. Subsurface probing of lunar electrical properties seeks to provide information on the structure, history, and origin of the moon. (Photo by Ivan Massar/Black Star)



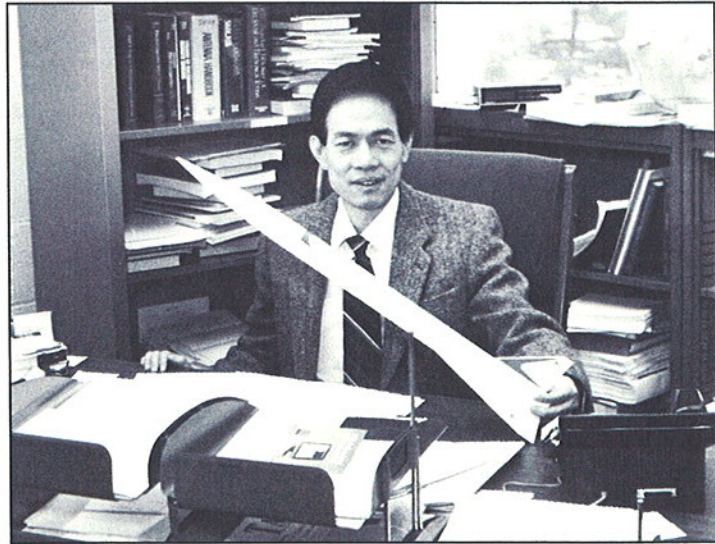
1975

On the rooftop of MIT Building 54, Professors Jeffrey H. Shapiro (left) and Robert S. Kennedy check an optical communication receiver used in one of their propagation experiments to determine the fundamental performance capabilities of optical communication systems. (Photo by Ivan Massar/Black Star)



1986

Research Assistant Carey M. Rappaport (left) and Professor Frederic R. Morgenthau investigate optimized electromagnetic techniques for the microwave radio-frequency heating of biological tissue. Such techniques may create methods to produce hyperthermia conditions for use in certain types of cancer therapy. (Photo by John F. Cook)



1991

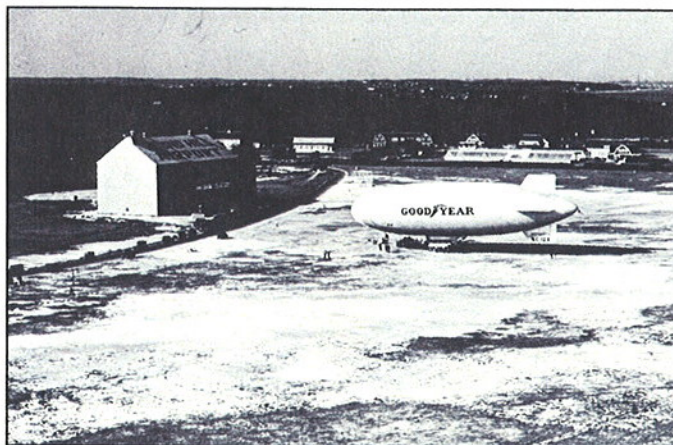
Professor Jin Au Kong displays a model of what may someday be the design for airplanes capable of vertical take-offs and landings using the microwave landing system. (Photo by John F. Cook)



## MIT Research Takes to the Air at Round Hill

In 1923, with the start of continuous-wave broadcasting, Colonel Edward Howland Robinson Green established radio station WMAF, "The Voice from Way Down East," at his 277-acre estate in South Dartmouth, Massachusetts. As radio transmissions reached below the 200-meter wavelength, Colonel Green invited qualified experimenters to set up work at his sprawling Round Hill estate on the western shore of Buzzard's Bay. Arrangements were made with then MIT President Samuel W. Stratton to build facilities for the Department of Electrical Engineering's new Communications Division, which were initially financed by Colonel Green, the president of Texas Midland Railroad.

The first projects, supervised by Professor Edward L. Bowles, were carried out in 1926 to determine the experimental radio station's signal strength and the radiation patterns of different antenna arrays. Round Hill's radio station was described as "having the world as its laboratory." It followed Donald MacMillan's and Admiral Richard E. Byrd's polar expeditions, tracked the *Graf Zeppelin* dirigible during its maiden transatlantic flight, and was the sole communication link for areas devastated by the Vermont floods in 1927.



*The dirigible Mayflower, on loan to MIT, was used to map the radiation patterns of various antenna arrays at Round Hill.*  
(Photo courtesy of MIT Museum)

Colonel Green's interest in aviation inspired him to construct an experimental airfield at Round Hill in 1928. Professor Julius A. Stratton (no relation to Samuel Stratton) was a former student of Bowles who began studying electromagnetic wave transmissions through fog. This work had obvious benefits to aircraft navigation. Stratton demonstrated that for wavelengths greater than 5 centimeters, energy absorption was insignificant. He

made the theoretical observation that maximum absorption should be reached at 2 centimeters and, at this wavelength, water particles might evaporate by radiant energy. Unfortunately, no appropriate two-centimeter energy sources were available in 1928.

Dr. Wilmer L. Barrow, who joined the department's Communications Division in 1931, started his antenna research under Bowles and Stratton. Barrow wrote: "A new and especially promising field for research is that of ultrashort radio waves, by which I mean those at least below a meter in wave length. A suitable and efficient generating method is much to be desired. The technique of measurements must be advanced considerably over its

*(continued on page 12)*

Massachusetts Institute of Technology  
**RLE currents**  
Research Laboratory of Electronics  
Room 36-412  
77 Massachusetts Avenue  
Cambridge, Massachusetts 02139-4307

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