RLE
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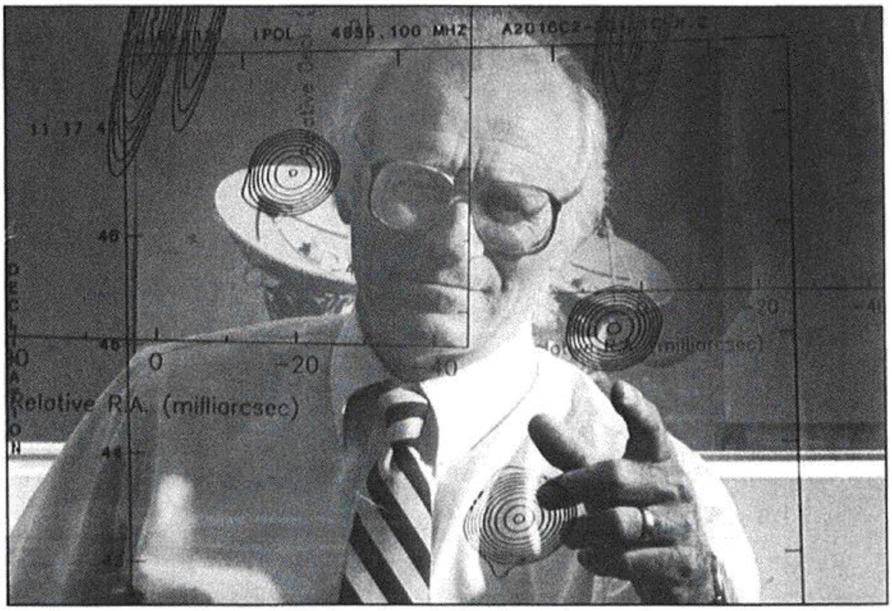
The Research Laboratory of Electronics at the Massachusetts Institute of Technology

RADIO ASTRONOMY AT RLE:
All Things Celestial

Since the time of primitive civilizations, earthlings have looked skyward for clues to the past and prophesies of the future. Familiar celestial features and mysterious cosmic phenomena have fascinated us, even before humans developed the ability to write. As one of the oldest sciences, astronomy was important in the establishment of time recording standards, such as clocks and calendars, and the development of celestial navigation techniques. Early advances in astronomy can be traced back to the Babylonian, Egyptian, Greek, and Chinese cultures.

When we examine our galaxy, we not only see objects beaming light to us from more than a million light years away, but we also see an expanding universe of celestial bodies that are racing away from us at incredible speeds to unknown destinations. Various cosmic phenomena such as pulsars, quasars, x-ray stars, and radio galaxies raise questions as to how we fit into the universe. Astronomers strive to answer these questions as new instruments and scientific methods are developed to examine the cosmos. Each new wavelength band reveals new aspects of the universe, and the *radio* sky differs dramatically from what is seen by optical telescopes.



Professor Bernard F. Burke beckons from behind superimposed maps of the radio source 2016 + 112 (a gravitational lens) produced by the Very Large Array (VLA) and very-long-baseline interferometry (VLBI). The radio telescope antennas of the VLA loom in the background. A detailed description of these maps is on page 3. (Photo by John F. Cook)

Specific areas of astronomical study are usually determined by a scientist's interest and the available equipment. Astrophysics is a branch of astronomy that examines the physical properties of celestial bodies (such as luminosity, chemical composition, size, temperature and origin). Cosmology investigates the overall structure of the universe. Radio astronomy studies ce-

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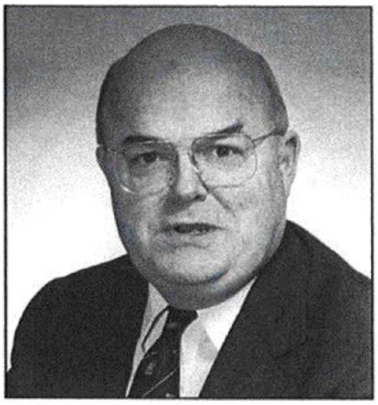
Director's Message

The study of extraterrestrial space has been a scientific fascination for many centuries, aided by a succession of probe technologies aimed at providing increasingly accurate measures of the size, motion, temperature, color, and distance of celestial bodies. In RLE, a broad range of the electromagnetic spectrum has been used to obtain and transmit this information. The effect of a very large telescope is achieved by utilizing an array of observation sites widely dispersed in space and utilizing interferometric techniques to accurately measure exceedingly distant phenomena. The increasing size of the baseline of these interferometers over time, from a few miles between terrestrial stations, to hundreds of thousands of miles between space stations, bears testimony to the aggressive growth of measurement technologies that permit the coordinated acquisition of large volumes of data from synchronized sites. Research in radio astronomy has not only built on expertise in electromagnetics, but also on the ability to build exceedingly high-frequency receivers in gallium arsenide, and new computational image processing techniques that can retrieve weak images from highly corrupted signals. In this sense, radio astronomy is a typical example of RLE's interdisciplinary research programs that effectively build on the expertise arising from a wide range of disciplines.



Professor Jonathan Allen, Director Research Laboratory of Electronics

RADIO ASTRONOMY

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lestial objects by the measurement and analysis of their emitted electromagnetic radiation.

The Science of Radio Astronomy

Radio astronomy is a relatively new science. In 1931, Karl G. Jansky at Bell Laboratories was investigating problems of radio noise or static. His research uncovered radio noise emitted by the Milky Way, and his discovery, combined with advances in radar during World War II, opened the way for the development of powerful radio telescopes to locate and map the sources of radio waves in space.

Since no single scientific instrument can meet all the observational requirements to study the radio sky, astronomers must use a variety of equipment, such as radio telescopes and other radar equipment, to analyze electromagnetic waves. All telescopes collect electromagnetic waves, but in different forms. Optical telescopes gather electromagnetic waves from the visible light spectrum using mirrors to collect and focus the light. Radio telescopes collect radio waves (from approximately 1 to 30 millimeters in wavelength) using highly directional antennas that are usually parabolic, or bowl-shaped. The radio waves are focused on a second antenna, and are transmitted as electrical signals to a radio receiver. The signals are then amplified and recorded. Radio frequency signals from space can be easily and precisely manipulated. Networks of several radio telescopes can receive oscillating wave signals from distant objects, and these separate signals can be amplified and compared. From this comparison, *interference fringes* can be derived, and if the observations are sufficiently complete, a radio map of the object can be obtained.

The first radio telescopes could not achieve the visual quality of optical telescopes because radio wave frequencies are approximately 1 million times lower than visible frequencies. The diameter of the telescope's mirror or antenna and the frequency of the signals are important factors for visual quality. The angular resolution of the telescope also determines the amount of structure one can see. To achieve the results equal to that of a 200-inch opti-

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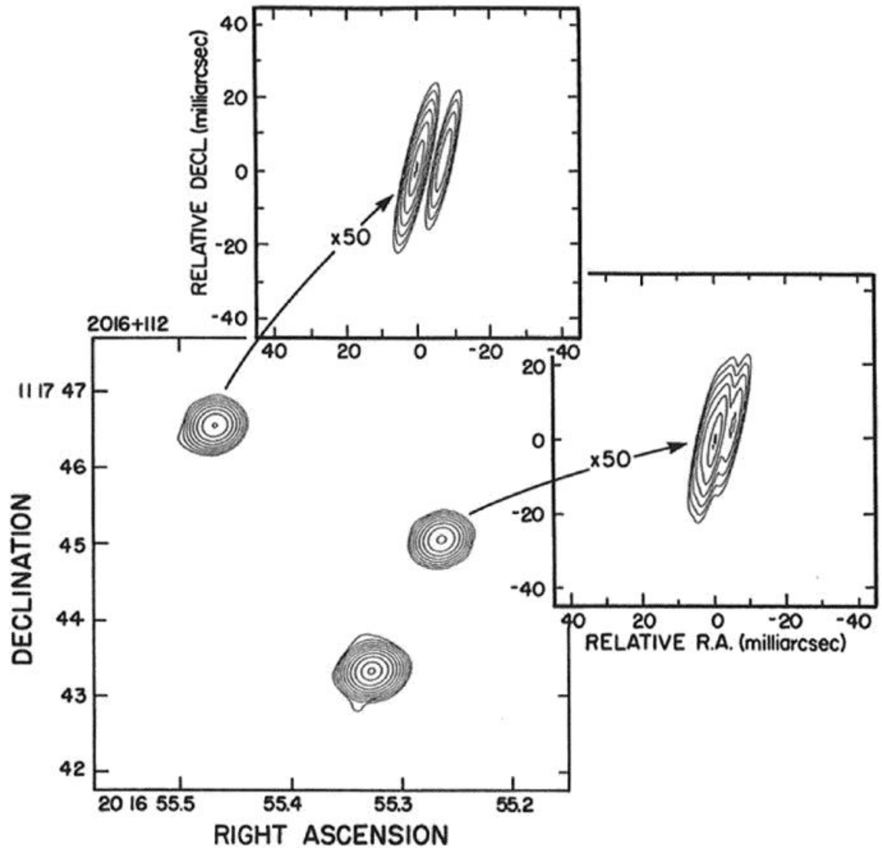
RLE

cal telescope, a radio telescope would need an antenna many miles in diameter. This is the idea behind *very-long-baseline interferometry* (VLBI), where several radio telescopes are combined to produce angular resolutions better than one second of arc. The *Very Large Array* (VLA) in the New Mexico desert consists of 27 antennas, each 88 feet in diameter. The array is spread across the plains of St. Augustine, with a maximum extent of over 20 miles. It can produce images of the radio sky that rival those of an optical telescope.

In previous times, telescopes were used to collect faint light and allow the observer to see with greater detail and sensitivity. Today, instruments, such as the spectroscope, can break light into various colors of the spectrum. It exploits the fact that when chemical elements are heated to high temperatures, they emit light which can be separated into a spectrum by passing it through a prism. No two chemical elements have the same spectrum. Molecules also exhibit spectra, and the different properties seen in the spectra of stars, planets, and galaxies can be studied to investigate their chemical composition, temperature, atmospheric pressure, speed, and direction. For example, the relative brightness of the spectrum at different wavelengths indicates temperature, and the patterns made by dark lines indicate chemical composition. Scientists can often determine an object's temperature, pressure, and the density of its center from the observed spectra. Spectra from different planets can also indicate the chemical composition of their atmosphere. In former times, spectra were studied at optical wavelengths, but the advent of radio astronomy has broadened the field, and radio spectrometers can now measure the spectral properties of the interstellar gas. The same techniques are also applied to studies of the Earth's atmosphere, since oxygen, water, and ozone all have characteristic spectral features.



These VLA and VLBI maps illustrate the radio source 2016+112, a gravitational lens *studied by Professor Bernard F. Burke. This phenomenon occurs when the gravitational field of a massive galaxy (or group of galaxies) focuses light from a distant quasar near or along its line of sight, thus giving multiple images of the quasar. This particular gravitational lens was first identified by the RLE's Radio Astronomy Group. Recent VLBI studies show that each quasar, at radio wavelengths, has a similar structure on a milliarcsecond scale. The inset VLBI maps are magnified to scale 50 times.*

Radio Astronomy at RLE

Professor Bernard F. Burke carries out an extensive observational program combined with an experimental program in VLBI that focuses on *gravitationally lensed quasars*. His group actively searches for new gravitational lenses using the MIT-Green Bank radio source catalog for a list of possible candidates. In this study, interferometric methods are used to measure the radio distribution and polarization of multiple images formed by the interaction of intervening matter with radio emissions from distant quasars. Two examples of *Einstein rings,* a particular form of gravitational lens, have been found, where a distant radio source is so accurately aligned with a foreground galaxy that it forms a ring-like image. One recent discovery was configured in such a way that highly accurate measurements were gathered of the mass-to-light ratio from the central part of the foreground galaxy, thus setting limits on the amount of *dark matter* within that galaxy. The search for gravitational lenses has prompted a new survey that Professor Burke anticipates will find more of these phenomena. Professor Burke is also involved in several international VLBI projects that use radio telescopes on orbiting satellites to extend interferometric baselines to separations greater than the earth's diameter.

Professor David H. Staelin and his students are involved in passive microwave studies of the planets (including Earth), studies of nonthermal radio emission of pulsars and planets, and the development of long baseline optical interferometry to measure stellar size and position. Early observations of the atmospheric spectra of Venus, Jupiter, and Earth led to the ongoing development of current and future Earth-orbiting weather satellites, which began with the Nimbus-5 and Nimbus-6 microwave spectrometer experiments.

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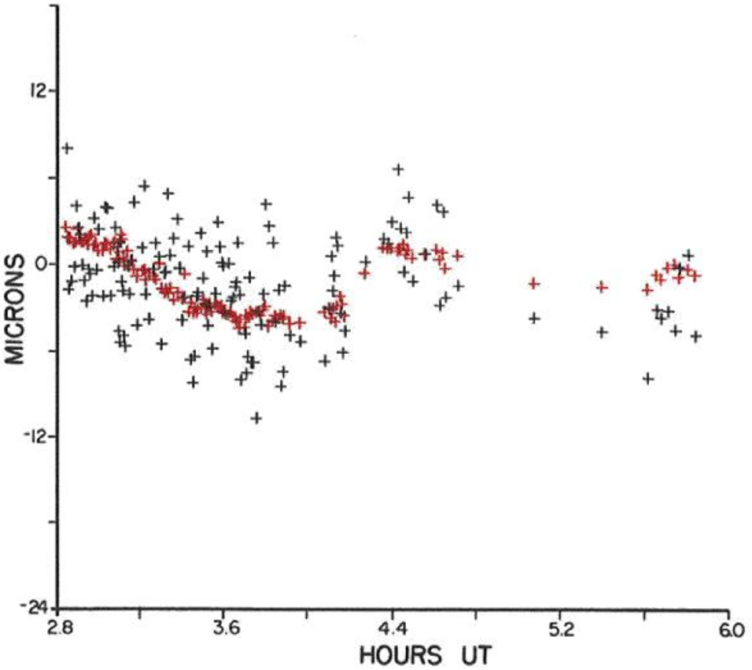
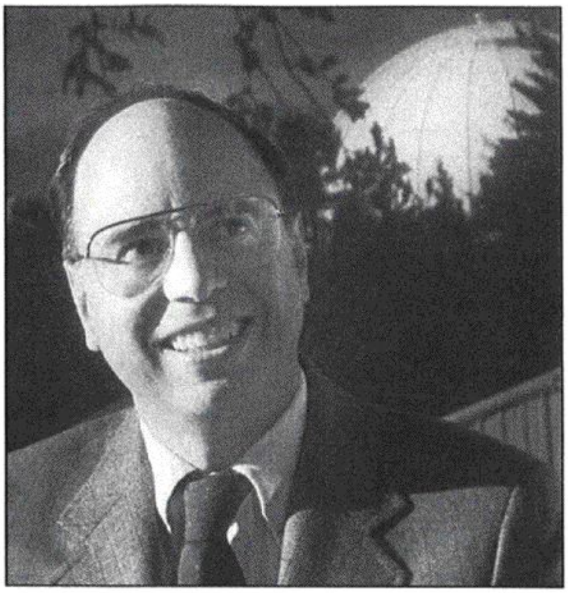
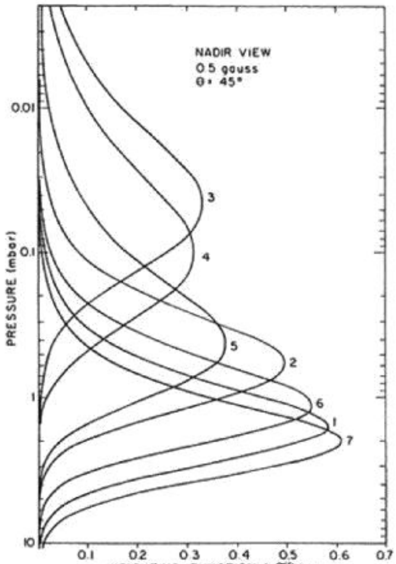


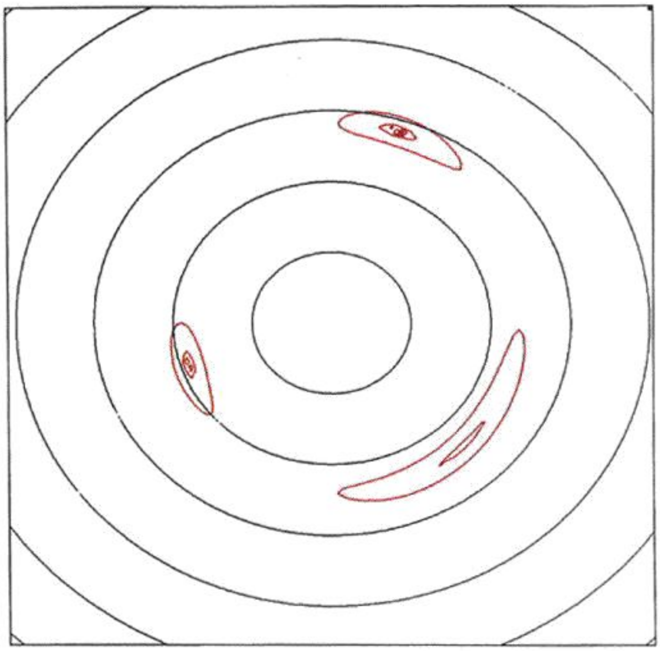
This astrometric interferometer delay line offset (in microns) observed at Mount Wilson shows fluctuations due to atmospheric temperature inhomogeneities as a function of time. Black crosses show one-color performance and red crosses show improved performance of the two-color correction scheme. The residual drift arises from random mirror motion and humidity variations. The two-color method for interferometric astronomy can reduce the error in stellar position measurements due to atmospheric turbulence.



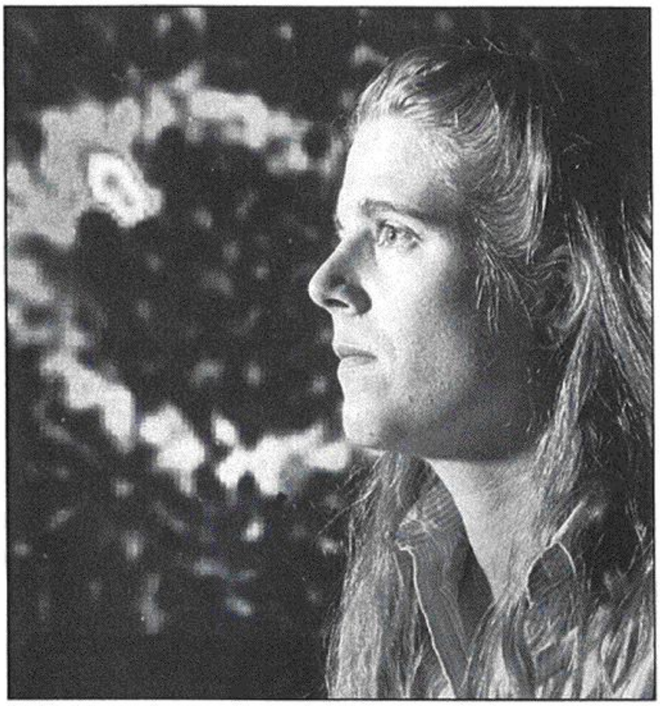
Professor David H. Staelin conducts part of his research at the Mount Wilson Astrometric Interferometer facility in California. This facility, jointly developed by the Naval Research Laboratory, the Smithsonian Astrophysical Observatory, and RLE, has improved the accuracy of existing astrometric observatories, and has demonstrated technology that will enable further improvements. Stellar diameters and the relative position of hundreds of stars have been measured at Mount Wilson. For example, the orbital parameters of Alpha Andromeda, a close binary star, has been measured with nearly 100 microarcsecond root-mean-square accuracy. (Photo by John F. Cook)

Principal Research Scientist Dr. Philip W. Rosenkranz develops algorithms to process measurements of the Earth taken by the Advanced Microwave Sounding Unit (AMSU), which will be one of the instruments used in the next generation of weather satellites for the National Oceanic and Atmospheric Administration (NOAA). Dr. Rosenkranz's computer display shows measurements taken over the eastern Pacific Ocean by the Special Sensor Microwave Imager (SSM/I), which currently observes some of the same frequencies that the AMSU will observe in its future program. The SSM/I is also used to test Dr. Rosenkranz's algorithms for inference of vapor and liquid water in the atmosphere and wind speed near the Earth's surface. The figure shows the sensitivity of temperature-sounding channels as a function of pressure level in the atmosphere. (Photo by John F. Cook)





Professor Jacqueline N. Hewitt's research involves radio astronomy, signal processing, and image processing techniques to acquire high-resolution images of gravitational lens systems, and the use of these lenses to address problems in astrophysics. Professor Hewitt uses the data gathered to characterize the gravitational potential which produces the lenses, and its effect on light ray and radio wave propagation. A calculated image of a gravitational lens (red) is superimposed on a contour plot of the gravitational potential that produces this lens (black). These calculations are used to find the best model to describe the gravitational potential, and to predict observable properties of the lensed images. This model, for example, describes well the properties of a gravitational lens observed with the Very Large Array (VLA) radio telescope. The image here is displayed at a much higher resolution than can be observed with the VLA, but at a resolution accessible with very-long-baseline interferometry (VLBI). VLBI measurements should show the arcs that are characteristic of gravitational lensing.



The radio image of an Einstein ring gravitational lens *provides a fiery backdrop for Professor Jacqueline N. Hewitt. An Einstein ring gravitational lens is a particularly symmetric case of gravitational lensing where the source is imaged into a ring. The phenomenon received its name because Einstein suggested deflection of starlight by the sun, and a ring that would appear if stars were perfectly aligned. (Photo by John F. Cook)*

Professor Staelin was the principal investigator for these experiments. As co-discoverer of the Crab Nebula pulsar, which helped to establish the existence of neutron stars and such forms of matter, he continues to study similar nonthermal radio emissions from the planets and associated emission mechanisms. Professor Staelin is co-investigator for the Voyager Planetary Radio Astronomy experiments, and uses the data gathered from Jupiter, Saturn, Uranus, and Neptune. He has also participated in developing the Mark I, II, and III astrometric interferometers at Mount Wilson Observatory in California. These interferometers have established new levels of precision for stellar position and size measurements, and will lead to a new generation of more accurate systems.

Professor Jacqueline N. Hewitt's research interests include gravitational lenses and nearby stars. Professor Hewitt has identified several gravitational lens systems, and her efforts to exploit these systems employs the VLA and VLBI imaging techniques, as well as models of the gravitational field. Scientists anticipate that studies of gravitational lens properties will provide new estimates of the *Hubble constant* (the speed at which the expansion of the galaxy increases with distance), and how much dark matter is distributed in various galaxies. Data analysis is being conducted to determine whether Einstein rings can be used to measure the Hubble constant. Professor Hewitt's investigations have shown that the low-level, quiescent emission of low-temperature main-sequence stars can be detected with sensitive VLBI arrays. Therefore, VLBI studies may provide new measurements of perturbations due to possible nearby planets and of parallax distance. Data gathered with the VLBI array will be used to create microarcsecond images of stars and to investigate radio emission stability.

Principal Research Scientist Philip Rosenkranz conducts research into atmospheric remote sensing of the Earth using microwave radiometers to improve the measurement of atmospheric parameters such as temperature. Dr. Rosenkranz has proposed the use of a new instrument to *sound,* or measure, the mesosphere and upper stratosphere that will contribute to studies of the middle atmosphere. He also contin-

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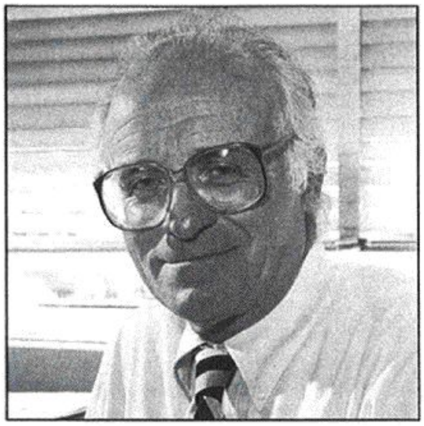
FACULTY PROFILE:

Bernard F. Burke

Boston native and William A. M. Burden Professor of Astrophysics Bernard F. Burke completed his SB in 1950 and PhD in 1953 at MIT. In 1953, he joined the Department of Terrestrial Magnetism at the Carnegie Institution in Washington and became a section manager in 1957. Upon his return to MIT in 1965 as Professor of Physics, Professor Burke introduced interferometric techniques at the Haystack Radio Observatory in Westford, Massachusetts. As leader of RLE's research group in this area, he shared the 1971 Rumford Prize awarded by the Academy of Arts and Sciences.

Together with the National Radio Astronomy Observatory and the Canadian National Research Council, his research group developed techniques for very-long-baseline interferometry (VLBI). This method uses atomic frequency standards to synchronize radio telescopes at remote locations around the world and has improved angular resolution for radio telescopes by 1,000-fold. Professor Burke's group was also first to conduct inter- and transcontinental VLBI. Recently, he has served as the U.S. principal investigator to develop orbiting VLBI stations and has also participated in European and Soviet VLBI mission studies.

He has served as Visiting Professor at the University of Leiden (1971-72), Sherman Fairchild Scholar at the California Institute of Technology (1984-85), and held a Smithsonian Regents Fellowship in 1985. In 1963, he received the Warner Prize of the American Astronomical Society and, in 1988, was corecipient of a NASA Group Achievement Award. He served as President of the American Astronomical Society (1986-88), is Fellow of the American Academy of Arts and Sciences, and was elected to the National Academy of Sciences in 1970. He chairs and serves on several advisory boards for NASA and the National Science Foundation, and participates on the editorial boards of many professional journals.



*As **currents** goes to press, Professor Bernard F. Burke has been nominated by President George Bush to a six-year term on the National Science Board, the governing body of the National Science Foundation. His appointment awaits Senate confirmation. (Photo by John F. Cook)*

• *How did your interests in radio astronomy develop?*

I was a graduate student in RLE, I believe it was 1951, and Al Hill was director of the lab. One of our old Rad Lab friends was Taffy Bowen, who had gone on to direct the Radio Physics Division of the Commonwealth Scientific Industrial Research Organization in Australia. Al met Taffy at some affair in Washington, and Taffy told him about the great things that were happening in radio astronomy. So, Al asked Taffy to come to MIT and give a series of lectures. There were three lectures: one was on the sun, another on the moon, and another on everything else in the universe. Al's hope was that one of the faculty members would catch fire after hearing the lectures, and start radio astronomy at MIT. That didn't happen, but there was one graduate student at those lectures who realized there are wide horizons when you're just starting out in life. A year later, as the end of my degree came in sight, I began to inquire about where I might go after graduation. MIT was starting its first moves to establish Lincoln Lab, and one of their consultants was Henry Booker from Cornell. Through Henry, I learned about a new program at the Department of Terrestrial Magnetism at the Carnegie Institution of Washington, and I started my first postdoc there in September 1953.

• *As a student in RLE, you worked on microwave spectroscopy with Professor "Woody" Strandberg. Was he your mentor?*

I was Woody Strandberg's graduate student, and although our work in microwave spectroscopy was completely laboratory oriented, it prepared me with all the tools I needed to go into radio astronomy. Woody was my mentor when I was a graduate student, but when I went into radio astronomy, I had to go to another institution. Merle Tuve was certainly my mentor at Carnegie.

• *At Carnegie, you codiscovered that Jupiter was a strong radio source with Kenneth Franklin in 1955. How significant was this finding?*

It was very exciting when we discovered radio noise from Jupiter. It was completely unexpected because the intensities of the radio bursts were so much greater than any theoretical prediction had made them. We thought perhaps it was lightning. But, it turned out there wasn't any lightning on Jupiter because the noise was millions of times stronger. Then, we discovered that the noise was circularly polarized, which meant that somehow there had to be a magnetic field involved. We and several other groups were able to show there was a periodicity in the noise. But, the periodicity was not related to the rotation of the planet as we saw it, because the clouds have a west-to-east circulation. Instead, there was a slightly slower rotation which was noticed by other people. So, three groups realized simultaneously that we were seeing the true rotation of Jupiter. Then, friends at the National Radio Astronomy Observatory (NRAO) detected a different kind of radio noise at a higher frequency from Jupiter. The Van Allen belts had just been discovered around the Earth, and quickly we realized that Jupiter also had Van Allen belts. I like to point this out as an example of unexpected consequences. The radio astronomers were able to show that the Van Allen belts of Jupiter were so intense that any spacecraft traveling there would have to be radiation hardened.

• *What enticed you to return to MIT in 1965?*

When Woody Strandberg was my thesis supervisor, he arranged for me to do part of my work at Brookhaven. That involved doing some of my work at Columbia, where Charles Townes had a research group. I spent several weeks there and got to know Charlie. When he became Provost at MIT, he delegated Al Barrett to talk to me and inquire if I might be interested in a position. I did enjoy teaching, and although I had a purely research position at Carnegie, I also taught a radio astronomy course at the University of Maryland. Another factor was that Harvard and MIT were collaborating on a project to build a very large radio antenna in New England. So coming back to MIT was both a joining of my research interests and my desire to take up teaching.

• *How did RLE's work in radio astronomy evolve?*

Let me first say what *didn't* happen. MIT was marvelously positioned to go into radio astronomy because we had all this gear left from the Rad Lab. There was much to do after the war, so the laboratory physicists went back to laboratory physics, much of which had been stimulated by the Rad Lab. Radio astronomy mainly started in the Netherlands, in Britain at Jodrell Bank and the University of Cambridge, and in Australia. They weren't rich, but they had lots of gear, and radio astronomy is something you can start with eager people and a minimum of equipment. So, that's why it started elsewhere. In the United States, only the Naval Research Laboratory had a radio astronomy group. Cornell did too, but it petered out.

The first act of radio astronomy at MIT occurred in the early '60s, when Jerry Wiesner was Director of RLE and President Kennedy's Science Advisor. I think Jerry had a secret desire for MIT to build up a program in radio astronomy. One of Jerry's graduate students, Sandy Weinreb, developed a correlation spectrometer for radio astronomy as his thesis topic. He couldn't do it at MIT because there were no facilities, except to build and test the electronics. The actual observations were done at the National Radio Astronomy Observatory in Green Bank, West Virginia. Sandy used to joke that he shared his thesis supervisor with President Kennedy!

Charlie Townes came to MIT, and he was interested in radio astronomy. Al Barrett had just joined the faculty, and Lincoln Lab was building the Haystack Observatory. Al collaborated with the Lincoln people, and since Haystack wasn't built yet, they used the Millstone antenna. In 1963, they were the first to discover a new spectral line, the hydroxyl (OH) line. This was a collaboration between Sandy Weinreb, M. L. "Lit" Meeks, and Al Barrett. I believe one of the first modern achievements at MIT was to develop the autocorrelation method for radio astronomy, and the OH line was the first major astronomical discovery made with that technique.

The first act of radio astronomy at MIT occurred in the early '60s, when Jerry Wiesner was Director of RLE and President Kennedy's Science Advisor.

When I returned to MIT in 1965, I was interested in using Lincoln Lab. But, I will be frank and say that Lincoln Lab was not entirely enthusiastic about it. I think they were afraid the radio astronomers would use Haystack too much. Or maybe, they wanted the radio astronomers to bring more money with them. However, Paul Sebring, the Director of Haystack, was very supportive. He enjoyed the radio astronomers because he realized they were doing some of the most exciting work. I had been here just a few months, and I was casting around for something to do. The OH lines were shown to have very peculiar properties in certain regions, and the intensity in emissions was far stronger than predicted. So, I proposed that the Millstone and Haystack antennas be used together as an interferometer. This wasn't VLBI yet, it was just a regular interferometer that would show the OH sources were very small in size. It was a great collaboration involving Al Barrett, his two graduate students Al Rogers and Jim Moran, and myself. Our first experiments were successful, and showed that the masers were so small in size that their brightness had to be much higher than any theoretical prediction.

We decided that a longer baseline was needed, and since we knew people at Harvard from the Camroc antenna project (this was a plan for a 100-meter or larger antenna), we put together a collaboration using their Agassiz Station telescope and Millstone. We successfully brought the telescopes together with a radio link because they were too far apart, and this gave us a baseline 20 times longer than the Millstone to Haystack baseline. It also showed that things were of the order of an arcsecond in size. That was a very exciting discovery.

During the radio link experiment, another experiment done by Al Rogers and Jim Moran involved deliberately opening the radio link so the two antennas operated separately. We could still see interference fringes, which meant the oscillators were stable. The NRAO was developing a similar set of experiments using separate antennas; the Cornell and Green Bank antennas. Their experiments weren't working, and they weren't keeping it a secret. (This is a nice illustration of why you should tell people what you're doing.) I remember walking up a stairway somewhere on campus with Al Barrett, and I said to him that we could use separate local oscillators and separate recorders to do a very-long-baseline experiment. And he said he had been thinking of something like that too!

In February 1967, I sent letters proposing the experiment to Paul Sebring at Haystack and Dave Heeschen, the Director at Green Bank. We did our first experiment in May with some urgency, since it was a bit of a horse race. The first successful experiment was claimed by the Canadians. The Naval Research Laboratory and NRAO also did a successful experiment a few weeks before us. But, they were working at a much lower frequency, and we were pushing up to higher frequencies. The measure of our success came when everyone switched to our frequency, the OH line frequency. The important thing is that the Canadians, the NRAO, and ourselves were using different methods at the same time, and we enjoyed the collaboration.

In the late '60s, much of our effort went toward developing VLBI at higher

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frequencies, and George Papadopoulos was a graduate student who took up the project. We moved up to the waterline frequency at 22 gigahertz and successfully performed an experiment a few years later. At the same time, we worked to increase the baseline to get higher angular resolutions. We also did the first transcontinental and first intercontinental VLBI. I remember that because one of my graduate students was in Sweden, I was in northern California at Hat Creek, and George was at Green Bank. We had our personnel strung out across the globe for that experiment! The VLBI research was geared to getting longer baselines, more astrophysics (that is, the study of maser properties), and shorter wavelengths.

At about the same time, my graduate student Ted Reifenstein was at Green Bank working on a special spectrometer used to study hydrogen recombination lines (sometimes called Kardarshev lines). Another graduate student, Tom Wilson, was in Australia to map the hydrogen recombination lines in the southern hemisphere for NRAO. Also at the same time, Marty Ewing helped us prepare an experiment to measure black body radiation from the top of White Mountain. It was fun because we had to go up to 12,000 feet and work under adverse conditions. Marty Ewing and Dave Staelin took the brunt of that adventure. Of course, Cosmo Papa and Jack Barrett built the equipment, so it was a group effort. We made a 9-millimeter measurement that showed the cosmic microwave background had the same effective temperature at 9 millimeters and at lower frequencies. So, many different things were happening at that time within our group.

Various types of interferometry continued into the '70s, and the NRAO started a new project called the Very Large Array (VLA). By this time, it was quite clear the Camroc antenna was going nowhere. The Vietnam conflict had "taken care" of science budgets. So, the one show in town was the VLA. Since I knew a lot about interferometry, it was a natural activity for me. I served on their advisory committee, and I became a trustee of the Associated Universities, which is responsible for the NRAO and for Brookhaven. I had great interest in the VLA, and I wanted to ensure its success. Graduate student Perry Greenfield and I became experts with the VLA before it was finished. Interferometers are like that; even when there are only a few antennas, you can still make observations.

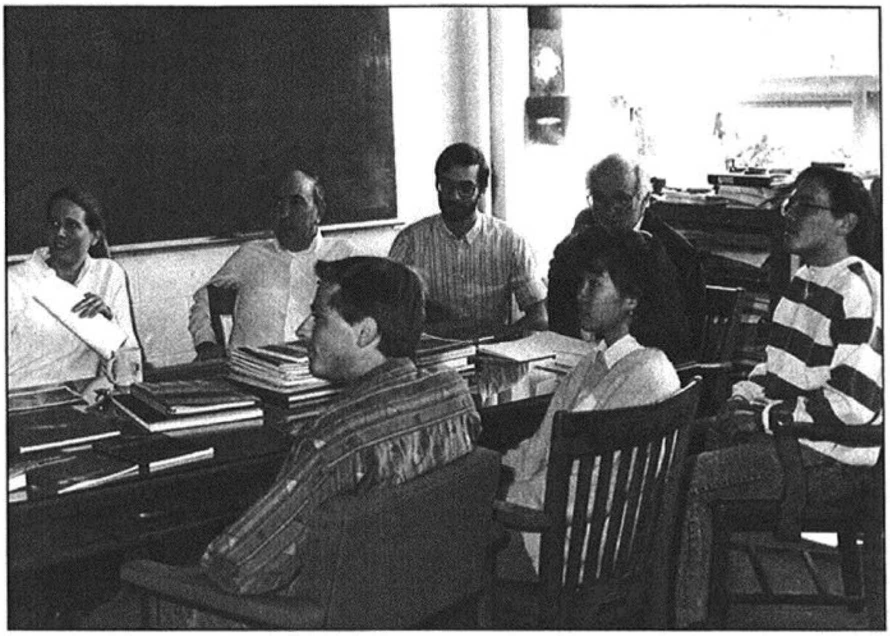
In 1979, radio astronomers at Jodrell Bank were working with Ray Weiman at the University of Arizona. They discovered a particular radio source that was an example of gravitational lensing. The VLA's interferometric properties made it a natural instrument to use, and we produced the first radio map of that source. That interested us in the properties of gravitational lenses. Although we continued to do VLBI and to study the OH and waterlines, the lensing work gradually became a larger part of our activities.

In the early '80s, not many large-scale surveys of radio sources were available at the high frequencies we needed to look for new gravitational lenses. It was an ideal graduate student project, so we sent several of them to Green Bank to use the old 300-foot telescope. We started a survey that became known as the MIT-Green Bank Survey, using Green Bank equipment and many MIT graduate students. Chuck Bennett and Charles Lawrence were the first vanguard of MIT students to use that telescope to survey the sky. We used the survey as a guiding source list to do a larger study with the VLA, and we mapped 4,000 sources. Many of our graduate students have worked on this survey—Jackie Hewitt (now on our faculty), Antonio Garcia-Barreto, Glen Langston; and more recently, Sam Conner, Joe Lehár, and Mike Heflin.

We started a new search for gravitational lenses using that body of work. Charles Lawrence found the second example of a radio gravitational lenses when he noticed a peculiar source. As things developed, Jackie Hewitt discovered the first Einstein ring, and Glen Langston found the second Einstein ring a year later. This came out of a decade of work that started with graduate students learning the business of radio astronomy with the 300-foot transit telescope at Green Bank. In November 1988, the old antenna collapsed, and that ended this phase of our work. But, they will be building a bigger and better antenna; the kind of antenna that should have been built for the Camroc project 25 years ago. Green Bank is one of the world's best locations for this particular antenna. So, it's going to be in the right place at the right time. The newest array will be the very-long-baseline array, or VLBA, which is in the process of being built. Craig Walker, an MIT graduate student who was active in VLBI in the '70s, is one of the key people involved with the technical aspects of that project. The VLBA is supposed to be in action by 1993, and we're looking forward to using it very much.

My interaction with Jin Kong in RLE's Center for Electromagnetic Theory and Applications is an example of how cross-disciplinary work can have good effects.

We also became interested in expanding VLBI in space. We've worked with NASA to put radio antennas on satellites in order to get longer baselines. Unfortunately, NASA doesn't have funds to do this. But, the Soviets and the Japanese have started projects, and I've been involved with both of them. The Japanese have started the VLBI Satellite Observing Platform, or VSOP. (One of the Japanese scientists influential in starting the project had a sense of humor because VSOP also stands for very superior old pale brandy.) The Soviets also have a project, called RADIOASTRON. Originally, Europe and the U.S. planned to collaborate on building a satellite called Quasat, and a workshop was held in 1984 in Austria. If you look at the RADIOASTRON project, it looks very much like the Quasat project. But I don't feel badly, since we didn't have the money, we shouldn't be dogs in a manger. The Soviets and Japanese will do it, and the U.S. will use its ground facilities to help make these satellites a success.



Faculty, staff, and students of RLE's Radio Astronomy Group meet to discuss research results (clockwise from left): Professor Jacqueline N. Hewitt, Sponsored Research Technical Staff member John W. "Jack" Barrett, graduate student Samuel R. Conner, Professor Bernard F. Burke, and graduate students Andre B. Fletcher, Grace Chen, and Joseph Lehár. (Photo by John F. Cook)

• *There seems to be extensive international cooperation within radio astronomy, in contrast to the competitiveness found in other technologies. What do you attribute this to?*

It has to do with the way the field has developed. Radio astronomy is a small field, and the radio astronomers of the world got to know each other when we were all young. Having a personal relationship makes a great deal of difference. There's competition as well because people like to be first. The collaboration with the Soviets, for example, was helped by an effort that occurred in 1959. Stalin had been dead for several years, and the Soviet and American Academies of Sciences wanted to reestablish scientific contacts between the two countries. One of the fields that they decided would be good to encourage was radio astronomy. A delegation of young Soviet astronomers came to the U.S., and a symposium was held. We got to know each other on a personal basis, and I think that established contacts that have endured over the years. There was a theoretical Soviet astrophysicist named Josef Slovsky, who was instrumental in promoting these contacts. He was regarded for many years as being politically unreliable by the Soviets. So, he couldn't leave the country himself, but he encouraged young people to get to know the Westerners whenever they visited. Also, Vitaly Ginzburg was another Soviet scientist who was instrumental in promoting international relationships. On the Japanese side, there are the Japanese scientists "Mori" Morimoto and Menoru Oda. Oda would have been a professor at MIT, except that he wanted to return to Japan, and he is very supportive of developing good relations between the U.S. and Japan.

• *What is your role on the various international VLBI groups?*

I play a collaborator's role where I attend joint meetings of the U.S. and Japan. I'm also chairman of a NASA group that is in charge of the U.S. aspects of collaboration with both the Soviets and the Japanese. The Europeans are also cranking up an effort called the International VLBI Satellite (IVS), and I'm a member of that group as well.

• *Do you collaborate with other RLE research groups?*

My interaction with Jin Kong in RLE's Center for Electromagnetic Theory and Applications is an example of how cross-disciplinary work can have good effects. Recently, we were contacted by the Department of Transportation, specifically the section concerned with the Federal Aviation Administration. The FAA wanted to develop a better landing system for aircraft in bad weather, called the microwave landing system. A problem with the present system is that it's running out of frequency spectrum space. So, they needed someone to look at the problem, but someone who didn't have a conflict of interest, yet someone who knew the business. Since there is a strong disagreement about this issue between the pilots, airlines, airport operators, and industry, it was necessary to bring in people from the outside. Jin and I represent two different aspects, so we were brought in as consultants. Previously, I had been chairman of a National Academy of Science committee called the Committee on Radio Frequencies, whose job it was to protect certain clear bands of the radio spectrum so that radio astronomy could work properly. While serving on that committee, I got to know the frequency management game pretty well. Jin has put together the project, and I act as a consultant. It's an interesting example of cross-disciplinary fertilization. Jin and I have different approaches, so it's a very complementary thing.

• What is the biggest issue facing your field of research today?

First, astronomy is expensive, and I think that getting the funding for new facilities is a big factor. Without new facilities, you're in danger of stagnation. But, new facilities always cost more than the old facilities. Second, groups like ours that encourage people to do practical things find it hard to get the financial support that allows the laboratory work to proceed. Pressure is focused on immediate achievement, and the way to get achievement quickly is to go to a national observatory or to Haystack (which is practically a national observatory) and make observations there; then you become a user. There's a severe danger that the practical people who make things happen are not going to get trained as they once were, and I think the whole country will feel this loss. That's a deeper feeling, the first one's more immediate. But, you have to worry about infrastructure, and no one in a position of power seems to worry about infrastructure. You can live off your capital, but after twenty years, all the people who knew how things work are gone, then you have trouble. So, there's trouble down the road, not trouble here and now. Long-range planning is a problem.

• What is the most rewarding aspect of your work?

Personally, I've had marvelous students, and my relationships with them have been most enjoyable. I never could have been successful without them. They multiply your power. Scientifically, we've been fortunate with new things happening all the time, so it just goes on from one enjoyable aspect to another—keeping it fresh and new.

• Do you see your work providing a benefit to society?

Astronomy gives an indirect and long-term benefit. One example is that the discovery of the radiation belts of Jupiter had an essential impact on the space program. Much of the rapid development of space technology was possible because space research people were able to take radio astronomy telescopes and use them directly. Later, they modified them explicitly for their purposes.

. . . keeping your mind open is so important because you may have to change direction. I think radio astronomy is a field where your preparation gives you a broad base, so changing direction is easy.

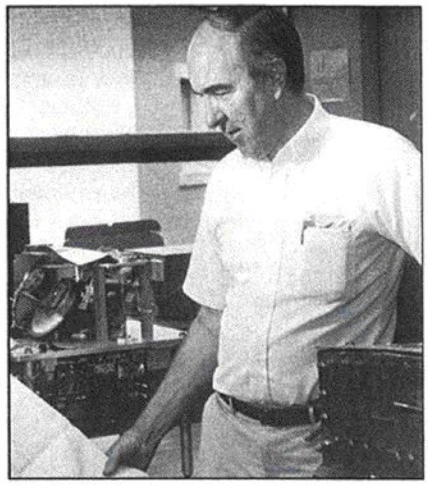
But, the first ones that were built were radio telescopes. You can't put a dollar value on that. It meant that in an essential field, the U.S. was accelerated by several years because we were there first. I think we also encourage the development of electronics, we're pressing on the frontiers of what can be done in electronics.

• Do you have advice for people contemplating a career in radio astronomy?

Keep your eyes open, keep your mind open, and love your science. After you get your bachelor's degree, first there's four or five years of graduate work that's immediately in front of you, and then a career that will last for another thirty or forty years. Who's going to extrapolate over that? That's why keeping your mind open is so important because you may have to change direction. I think radio astronomy is a field where your preparation gives you a broad base, so changing direction is easy. You're prepared to do lots of things.

RADIO ASTRONOMY

(continued from page 5)



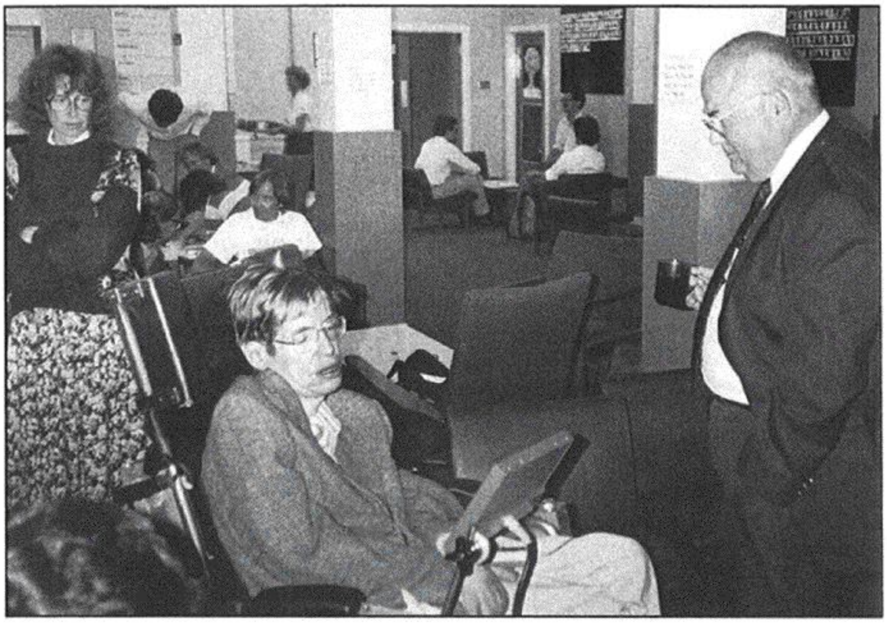
Sponsored Research Technical Staff member John W. "Jack" Barrett modifies a high-altitude wing pod that will permit mesospheric temperature observation and improved microwave transmittance of stratosphere and mesosphere observations. His experiment supports future scientific and operational geosynchronous satellites, and will help to improve the interpretation of microwave data from existing weather satellites. (Photo by John F. Cook)

ues to develop autocorrelation techniques to measure mesospheric thermal emission from atmospheric oxygen that may have future applications for weather satellites.

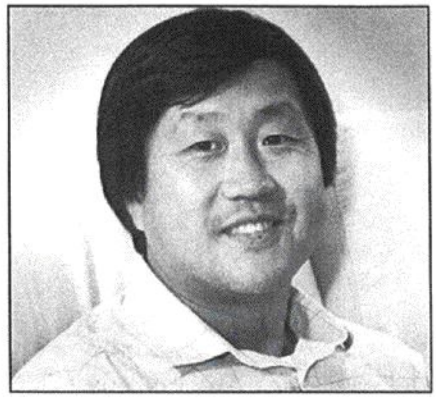
Research Staff John W. "Jack" Barrett provides engineering and technical support to RLE's Radio Astronomy Group. He is responsible for the design, construction, and evaluation of microwave radiometers and other equipment used in the group's radio astronomy applications. In 1988, he was corecipient (with Professor Burke) of the NASA Group Achievement Award for the exceptional planning and execution of the Tracking and Data Relay Satellite Very-Long-Baseline Interferometer. These demonstrations were conducted in 1986 and 1987 and produced the world's first astronomical space-ground VLBI observations.

by Dorothy A. Fleischer

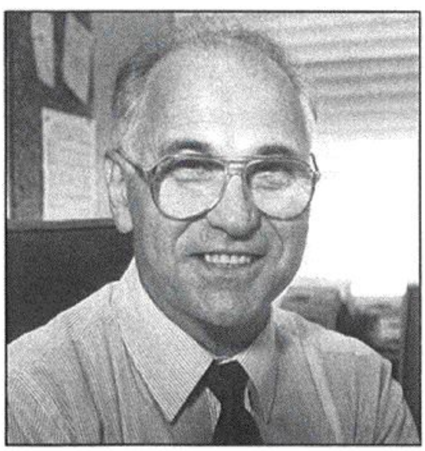
circuit breakers



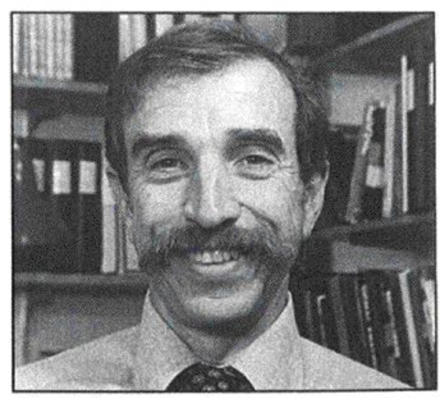
While on sabbatical at Cambridge University in England earlier this year, ***Dr. Jonathan Allen*** (ScD '68), Director of RLE and Professor of Electrical Engineering and Computer Science (right), had the opportunity to meet Dr. Stephen W. Hawking. Dr. Hawking is Lucasian Professor of Applied Mathematics and Theoretical Physics at Cambridge University and author of *A Brief History of Time: From the Big Bang to Black Holes.* Dr. Hawking suffers from a serious, physically debilitating disease, and although he cannot talk, he is able to lecture and communicate with the aid of a speech synthesizer that uses algorithms developed by Professor Allen in his MITalk text-to-speech research. Here, they discuss possible improvements to the current synthesizer after one of Dr. Hawking's lectures. *(Photo by Ann C. Allen)*



A research group led by ***Dr. Jae S. Lim*** (SB '74, SM '75, ScD '78), Professor of Electrical Engineering and Computer Science, has developed a voice coding technique selected by the International Maritime Satellite Organization (INMARSAT) and Australia's National Satellite System (AUSSAT) as the standard for both the INMARSAT-M mobile satellite communications system and AUSSAT's MOBILESAT service. INMARSAT operates global satellite communications systems for maritime, aeronautical, and land mobile applications. The algorithm developed by Professor Lim's group will be the standard for both the INMARSAT-M telephone system and for AUSSAT's MOBILESAT service, the world's first dedicated land mobile satellite voice and data to provide full mobile coverage of Australia and its coastal waters. *(Photo by John F. Cook)*

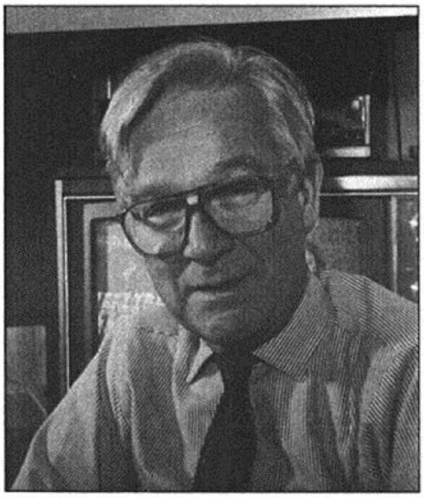


Dr. Bruno Coppi, Professor of Physics and member of RLE's Plasma Physics group, delivered the keynote address to the Two Worlds Science Conference held in Charleston, South Carolina, on May 26, 1990. Professor Coppi, widely recognized for his contributions to the field of plasma physics, was the first scientist to deliver a keynote speech to the Two Worlds Conference. The conference was sponsored by the Sigma-Tau Foundation, and held as part of the Spoleto Festival USA, affiliated with the three-week Italian Spoleto Festival held annually in the Umbria region of Italy. The Sigma-Tau Foundation sponsors the Two Worlds Conference to promote the interplay of scientific and humanistic cultures. *(Photo by John F. Cook)*

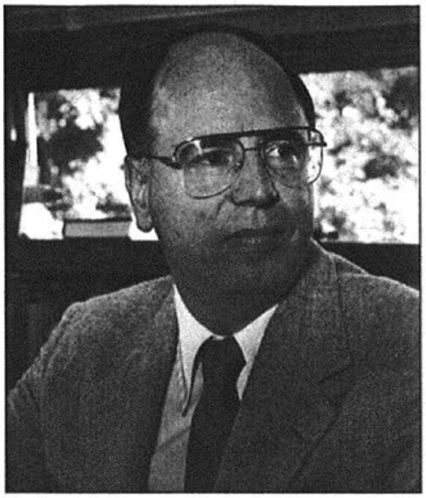


Dr. Alan V. Oppenheim (SB/SM '61, ScD '64) was appointed Distinguished

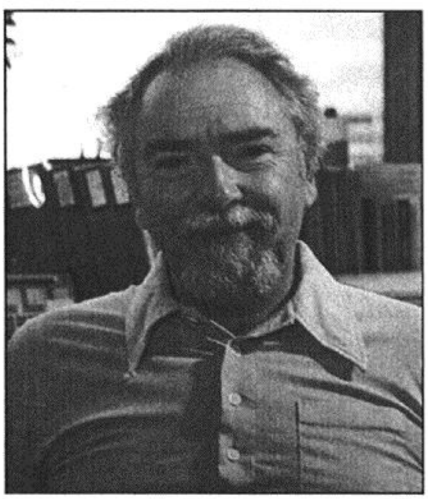
Professor of Electrical Engineering in September. Since joining the MIT faculty in 1964, Professor Oppenheim's research interests have been in the areas of speech, image, and geophysical signal processing. He has received many awards for outstanding research and teaching, including the 1988 IEEE Education Medal, the 1984 IEEE Centennial Award, and the Society and Technical Achievement Awards of the IEEE Society on Acoustics, Speech and Signal Processing. Professor Oppenheim is the author and editor of several widely used textbooks in signal processing and is a member of the National Academy of Engineering and a Fellow of the IEEE. *(Photo by John F. Cook)*



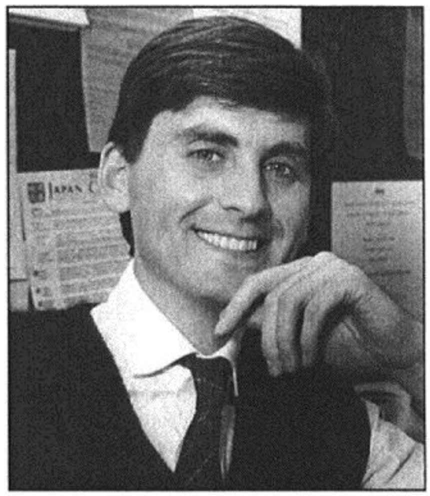
Dr. William F. Schreiber, Professor Emeritus of Electrical Engineering and former Director of the Advanced Television Research Program, retired from the Institute in June 1990, after 31 years on the faculty. During that time, Professor Schreiber pioneered developments in the field of image processing and transmission coding (see ***currents,*** vol. 3, no. 2). Most recently, he was honored with the David Sarnoff Gold Medal Award from the Society of Motion Picture and Television Engineers. The award cites his development of new techniques and equipment for television engineering. Professor Schreiber plans to continue his work in high-definition television and graphic arts color processing systems, and as an expert witness in patent cases. *(Photo by John F. Cook)*



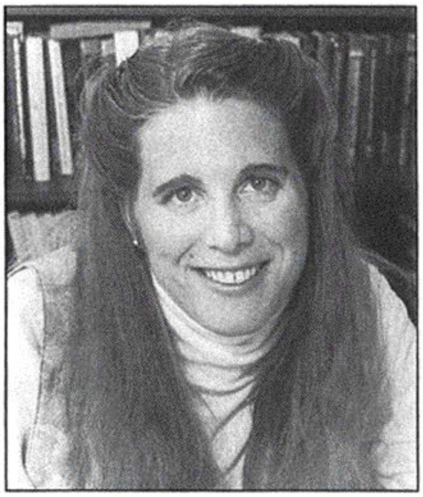
Dr. David H. Staelin (BS '60, MS '61, ScD '65), Cecil H. Green Professor of Electrical Engineering, was appointed Assistant Director of Lincoln Laboratory, effective July 1, 1990. Professor Staelin has been affiliated with RLE's Radio Astronomy group since 1959 and joined the MIT faculty in the Department of Electrical Engineering and Computer Science in 1965. He became full Professor in 1976, and has served as Chairman of the department's concentration in electronics, computers, and systems, and as a member of MIT's Commission on Industrial Productivity. Professor Staelin's research interests include electromagnetic systems and signal processing, remote sensing, radio and optical astronomy, video image processing, and manufacturing. He is a Fellow of the IEEE and the American Association for the Advancement of Science. *(Photo by John F. Cook)*



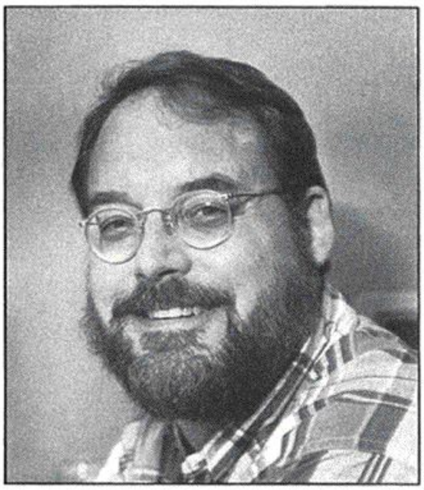
Dr. Thomas F. Weiss (SM '59, PhD '63), Professor of Electrical and Bioengineering, has been named corecipient of the Best Engineering Software Award presented by the EDUCOM/National Center for Research to Improve Postsecondary Teaching and Learning in the 1990 Higher Education Software Awards competition. MIT staff member Giancarlo Trevisan and graduate student David Huang shared the award with Professor Weiss for developing software that allows users to demonstrate the Hodgkin-Huxley model of nerve cell membrane response to electrical simulation for different environmental variables. The EDUCOM/NCRIPTAL Higher Education Software Awards program acknowledges developers and faculty whose efforts exemplify the best innovations in academic software and curriculum. Professor Weiss and his collaborators received the award at the EDUCOM conference in Atlanta, Georgia, in October. *(Photo by John F. Cook)*



Dr. Jesús A. del Alamo was appointed to the ITT Career Development Professorship in the Department of Electrical Engineering and Computer Science. Professor del Alamo joined the MIT faculty in 1988, after working at Nippon Telegraph and Telephone Corporation in Japan. A Stanford University graduate, his research interests include high-performance semiconductor devices for microwave and optical communications, and molecular beam epitaxy of III-V heterostructures for these devices. Professor del Alamo is the fifth appointment to the ITT chair, which was established in 1980 by a grant from the International Telephone and Telegraph Corporation to provide support for promising junior faculty in the department. *(Photo by John F. Cook)*



Dr. Jacqueline N. Hewitt (PhD '86), Assistant Professor of Physics, received a five-year David and Lucile Packard Foundation Fellowship in October. Since 1988, the Packard Foundation has awarded science and engineering fellowships to support basic scientific research conducted by talented young faculty members and to encourage fellows to continue productive university careers. Professor Hewitt was among twenty faculty members chosen from universities throughout the United States. She was cited for demonstrating unusual creative ability in her research work, which involves radio astronomy and astrophysics in RLE's Radio Astronomy Group (see page 5). Professor Hewitt has recently received the Annie Jump Cannon Award in Astronomy from the American Association of University Women and an Alfred P. Sloan Foundation Research Fellowship. *(Photo by John Cook)*

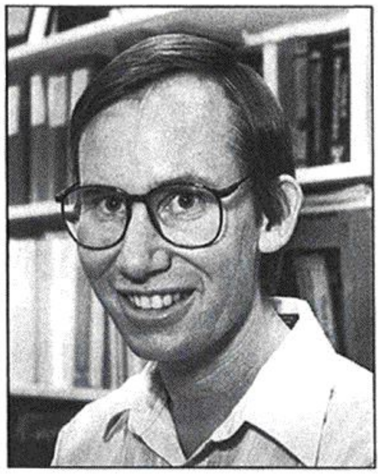


Dr. Donald K. Eddington was promoted to Principal Research Scientist in the

TENURE GRANTED

Congratulations to two RLE faculty members who were granted tenure in 1990:

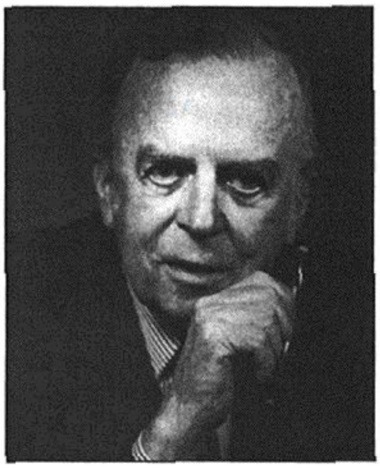
Dr. James G. Fujimoto (SB '79, SM '81, PhD '84), Associate Professor of Electrical Engineering and Computer Science. Professor Fujimoto joined the MIT faculty in 1985 and is a member of RLE's Optics and Devices Group. Professor Fujimoto studies femtosecond optics and its applications in quantum electronics and laser medicine. His research group has produced laser pulses as short as a few wavelengths of light, and has used them to investigate the ultrafast dynamics in optoelectronic materials and devices. He was a National Science Foundation (NSF) Graduate Fellow from 1972-82, and received an NSF Presidential Young Investigator Award in 1986. Recently, Professor Fujimoto was named corecipient of the 1990 National Academy of Sciences Award for Initiatives in Research by AT&T Bell Laboratories (see ***currents***, vol. 3, no. 2). Professor Fujimoto is also a Visiting Lecturer in Ophthalmology at Harvard Medical School and a consultant for Lincoln Laboratory. He is a member of the American Association for the Advancement of Science, the American Physical Society, the Optical Society of America, Sigma Xi, Tau Beta Pi, and Eta Kappa Nu. *(Photo by John F. Cook)*



Dr. Peter L. Hagelstein (SB/SM '76, PhD '81), Associate Professor of Electrical Engineering and Computer Science. Before joining the MIT faculty in 1986, Professor Hagelstein was a Principal Project Scientist at the Lawrence Livermore National Laboratory. In addition to receiving a tenured faculty position, Professor Hagelstein has been named corecipient of the 1990 Award for Excellence in Plasma Physics Research presented by the American Physical Society's Division of Plasma Physics. Professor Hagelstein shared this honor with his collaborators: Dr. Mordecai D. Rosen, Dr. Dennis I. Matthews, Dr. E. Michael Campbell, all of Lawrence Livermore Laboratory; and Dr. Szymon Suckewer of Princeton University. The Society cited the group for "the first demonstration of a soft x-ray laser, achieved through pioneering laser target design, theoretical modeling of the states of highly ionized atoms in laser-produced plasmas, and novel spectroscopic diagnostics of such plasmas." The award was presented at a meeting of the Society's Division of Plasma Physics in Cincinnati, Ohio, in November. *(Photo by John F. Cook)*

Auditory Physiology Group. A graduate of the University of Utah (BSEE '73, PhD '77), Dr. Eddington has been a Research Scientist with RLE since 1983. He conducts fundamental research and experimentation on the development of auditory neuroprostheses, and is Director of the Cochlear Implant Research Laboratory at the Massachusetts Eye and Ear Infirmary (see ***currents***, vol. 3, no. 1). Dr. Eddington is also an Assistant Professor in the Department of Otology and Laryngology at Harvard Medical School. *(Photo by John F. Cook)*

IN MEMORIAM



Professor Emeritus and Senior Lecturer Joseph C. R. Licklider, 75, died June 26, 1990, following complications from asthma. Born in St. Louis, Missouri, and educated at Washington University and the University of Rochester, Professor Licklider came to MIT in 1950. Previously, he had worked at Harvard University's Psychoacoustics Laboratory, where he discovered that "clipped speech" (produced by limiting the amplitude of speech waves) was 70-90 percent intelligible. Professor Licklider's background was in the psychology of communications, and he played a major role in stimulating linguistics research at MIT while contributing to the study of biological aspects of communication. He lectured on the neurophysiology of vision and hearing, the perception of speech, and the presentation and assimilation of information. At MIT, he was affiliated with RLE, the Acoustics Laboratory, the Department of Electrical Engineering and Computer Science, and the Department of Economics and Social Sciences. He was also co-head of Lincoln Laboratory Group 31. From 1957-62, he worked at Bolt, Beranek, and Newman, where he became a vice president. In 1960, he published the seminal paper *Man-Machine Symbiosis,* which proposed the concept of a greater role for computers; people and machines could interact to solve problems, not only to perform mathematical calculations. Professor Licklider was instrumental in developing computer time-sharing research at MIT, and encouraged the start of computer science studies in the Electrical Engineering Department. His career also included tenures at the Defense Department's Advanced Research Projects Agency, the agency's Information Processing Techniques Office, and IBM Corporation. He returned to MIT and was appointed Associate Director of Project MAC (now the Laboratory for Computer Science), where he subsequently became Director. Professor Licklider retired from the MIT faculty in 1985. Professor Licklider was a former president of the Acoustical Society of America. In March 1990, he received the Common Wealth Award for Distinguished Service from a Delaware humanitarian trust for his work in computer networking and the interaction between humans and computers. *(Photo by Koby-Antupit)*

alumni notes

Frank Amoroso (SB '56, SM '58) has retired after 16 years with Hughes Aircraft. He resides in Santa Ana, California, and keeps busy by serving as an expert witness in patent litigations, publishing research papers in the field of data modulation, and writing non-fiction magazine features (especially on scuba diving).

Wilbur B. Davenport, Jr. (SM '43, ScD '50) sends his regards from Sunriver, Oregon. He taught at the University of Hawaii during the last spring semester ("a freshman computer programming course based on C and a junior course on Fourier stuff using Oppenheim and Willsky"), while his wife Joan was a Docent at the Honolulu Academy of Arts.

Josef Eisinger (PhD '51) is Professor of Biophysics at the Mount Sinai School of Medicine in New York, where his special interest is fluorescence microscopy. Previously, he was at Bell Laboratories for 30 years.

Norman E. Gaut (SM '64, PhD '67), Chief Executive Office and President of Picturetel Corporation of Peabody, Massachusetts, was featured in a business article about the image processing company in *The Boston Sunday Globe,* September 23, 1990.

Michael Helke (PhD '71) has worked since 1975 at the United Nations in New York, where he served as a Senior Political Affairs Officer. Most recently, he has relocated to England, where his wife is a British diplomat.

Jay W. Lathrop (SB '48, SM '49, PhD '52) is Professor Emeritus of Electrical and Computer Engineering at Clemson University. He retired in 1989, and resides in West Union, South Carolina.

Irwin L. Lebow (SB '48, PhD '51) is a consulting engineer in Washington, DC, and has written a book, *The Digital Connection,* published by W. H. Freeman last summer. He was previously a Chief Scientist at DCA in Washington.

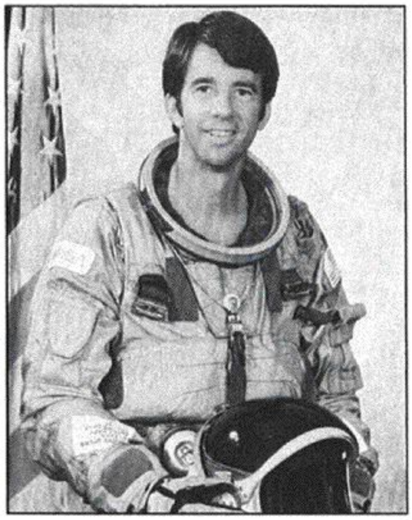
Lawrence R. Rabiner (SB/SM '64, PhD '67), Head of the Speech Research Department at AT&T Bell Labs in Murray Hill, New Jersey, was elected to the

RLE's RIGHT STUFF

RLE alumnus Dr. William B. Lenoir (BS '61, MS '62, PhD '65), a former astronaut, is the Associate Administrator for NASA's Office of Space Flight. Dr. Lenoir is responsible for the development, procurement, and operation of the Space Shuttle and Space Station; management of all U.S. government civil launch capabilities; U.S. Spacelab operation; and planning for future space flight, transportation, and system engineering programs. Dr. Lenoir develops and implements policy for all Space Shuttle System, Space Station, and U.S. launch activities. He is also in charge of the Johnson, Kennedy, Marshall, and Stennis space centers.

A native of Miami, Florida, Dr. Lenoir received his degrees from MIT's Department of Electrical Engineering and Computer Science. He was a Ford Foundation post-doctoral fellow and served two years on the MIT faculty as an Assistant Professor of Electrical Engineering.

Dr. Lenoir's graduate research was performed under Professor Alan H. Barrett in RLE's Radio Astronomy Group. During the 1960s, Professor Barrett successfully showed that microwave atmospheric sensing was possible. As part of his research under Dr. Barrett, Dr. Lenoir designed a 60-gigahertz atmospheric sensing microwave receiver to remotely sense the temperature profile of the Earth's atmosphere at different altitudes. Dr. Lenoir worked with Sponsored Research Technical Staff John W. Barrett to deploy this instrument package on board a high-altitude (125,000 feet average altitude) helium balloon launched from the National Center for Atmospheric Research in Palestine, Texas. These experiments resulted in the new instruments used in the Nimbus series of NASA satellites, which further evolved into elements of today's weather forecasting satellite system of the National Oceanic and Atmospheric Administration.



Dr. William B. Lenoir (Photo courtesy of NASA)

Dr. Lenoir was vice president and a member of the board of directors of Booz, Allen & Hamilton Inc., Bethesda, Maryland, and also managed that company's Space Systems Division until he was selected for his NASA appointment. Prior to joining Booz, Allen, Dr. Lenoir was chief of the mission development group in the Astronaut Office at NASA's Johnson Space Center in Houston. He directed and managed all astronaut activities concerned with mission development and payload operations.

Dr. Lenoir flew in space as a mission specialist on Shuttle Mission STS-5, the first operational flight of the Space Transportation System, in November 1982. He was the first spaceborne launch director to deploy the first communications satellite from the shuttle.

National Academy of Sciences.

Robert J. Shillman (SM '71, PhD '74), founder and CEO of Cognex Corporation in Needham, Massachusetts, was named New England's 1990 Entrepreneur of the Year in High Technology. The award was cosponsored by Ernst & Young's Entrepreneurial Services Division, *Inc.* magazine, and Merrill Lynch. Dr. Shillman was chosen from more than 150 New England entrepreneurs and cited for his company's success in the field of machine vision.

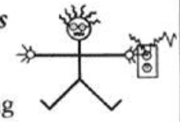
Lamar Washington, Jr., (SB '56) sends his reminiscences of his colleagues at RLE, and writes of his 12 children and 21 grandchildren. He resides in Menands, New York.

We welcome news of accomplishments from RLE graduates. Letters may be addressed to:

Professor Jonathan Allen, Director
Research Laboratory of Electronics
Room 36-413
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139
Telephone: 617-253-2509
Telefax: 617-258-7864

SHORT CIRCUITS

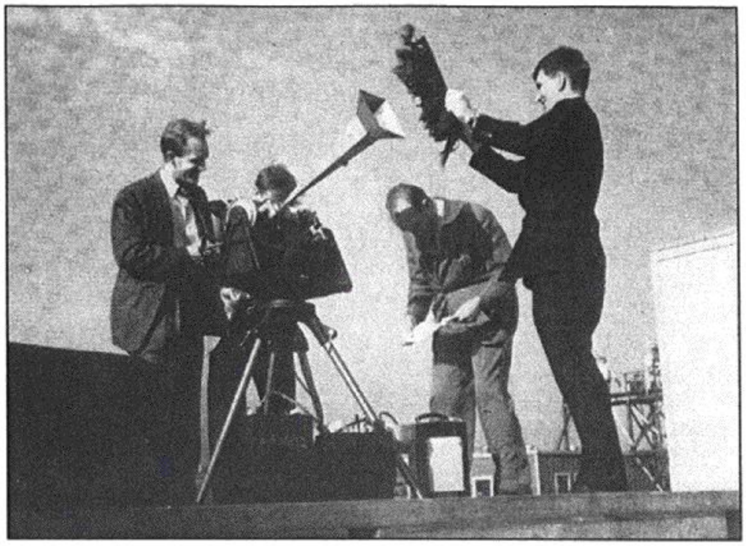
The staff of ***currents*** would like to note the following correction to the Spring 1990 issue:



The 1958 photograph on page 17 mistakenly identified Visiting Scientist Saburo Muroga as Professor Wilbur B. Davenport, Jr.

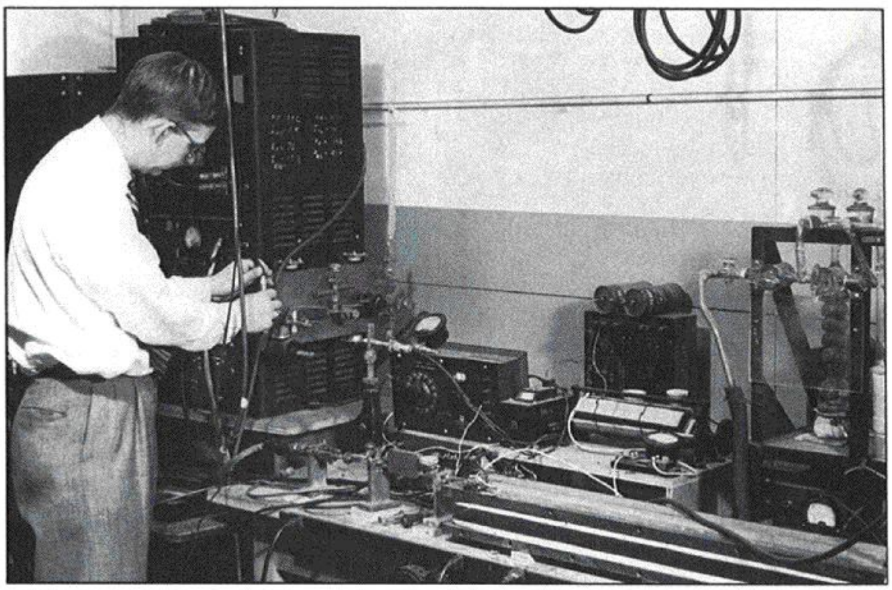
Thanks to both Professor Wilbur Davenport, who checked the error, and to Professor Robert Fano, who correctly identified Dr. Muroga.

History of Radio Astronomy at RLE



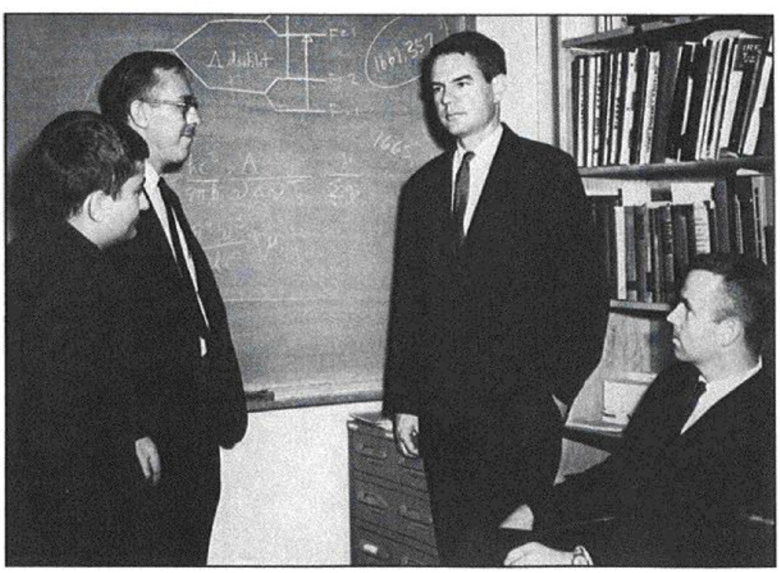
ca. 1945

Radiation Laboratory roof-top crew uses "Shaggy Dog" microwave radiometer equipment pointed at the sun to measure water absorption by the atmosphere. Atop Building 20 (from left): Edward R. Beringer, Robert L. Kyhl, Arthur B. Vane, and Robert H. Dicke. (Photo from Five Years at the Radiation Laboratory)



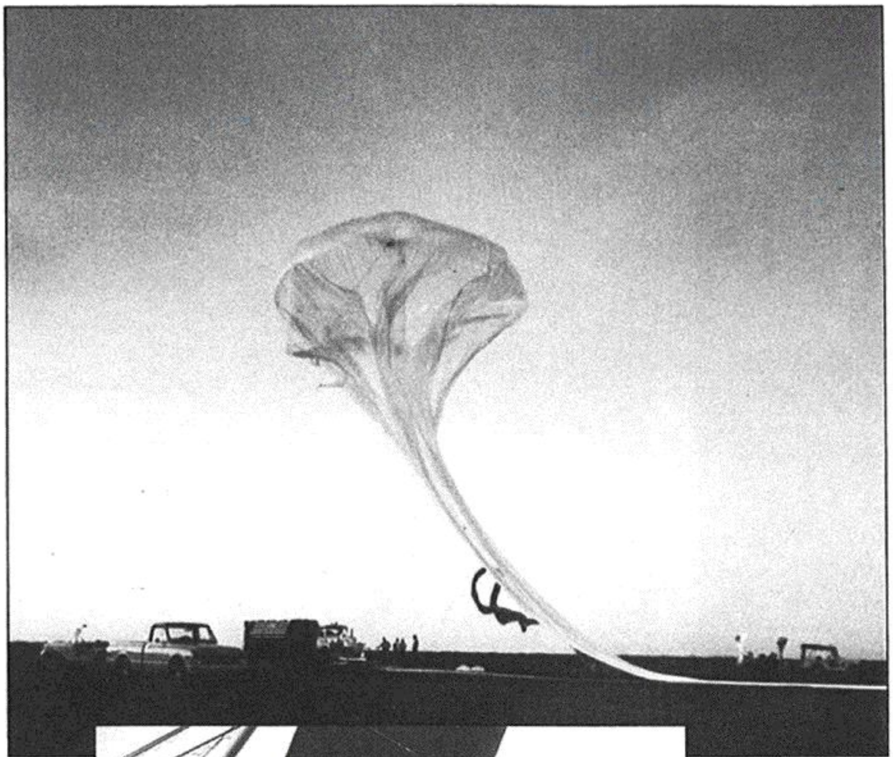
1952

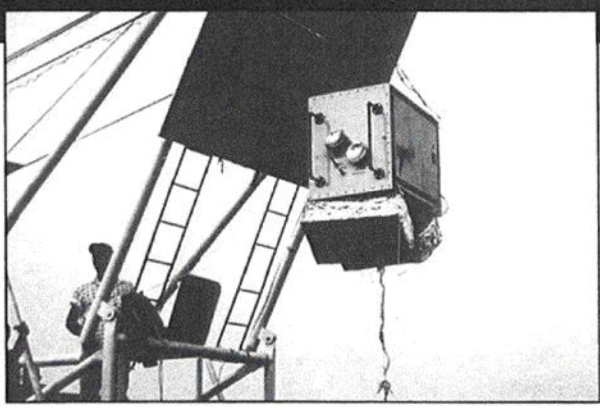
Professor Malcom W. P. "Woody" Strandberg played an active role in applying microwave techniques to laboratory problems and contributed to the understanding of physics in masers and in oxygen absorption. Here, he conducts an experiment of the Zeeman effect in the rotational spectra of molecules. (Photo by Benjamin Diver)



1963

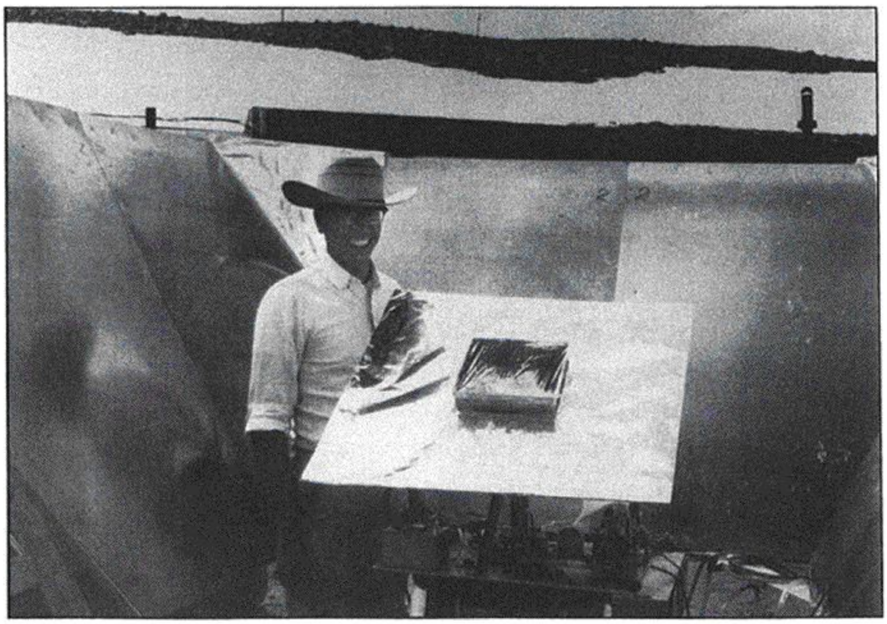
(From left): Graduate student Sander Weinreb, Professor Alan H. Barrett, Dr. M. Littleton Meeks, and graduate student John C. Henry were responsible for the detection, identification, and measurement of the first molecular matter ever found by radio astronomy techniques in interstellar space. Positive radio identification of oxygen-hydrogen molecules (called the hydroxol radical or OH radical) enabled radio astronomers to chart the distribution and abundance of OH as well as oxygen and hydrogen in the galaxy and contributed to a greater understanding of the fundamental astrophysical interactions that lead to the formation of galaxies. (Photo courtesy MIT Museum)





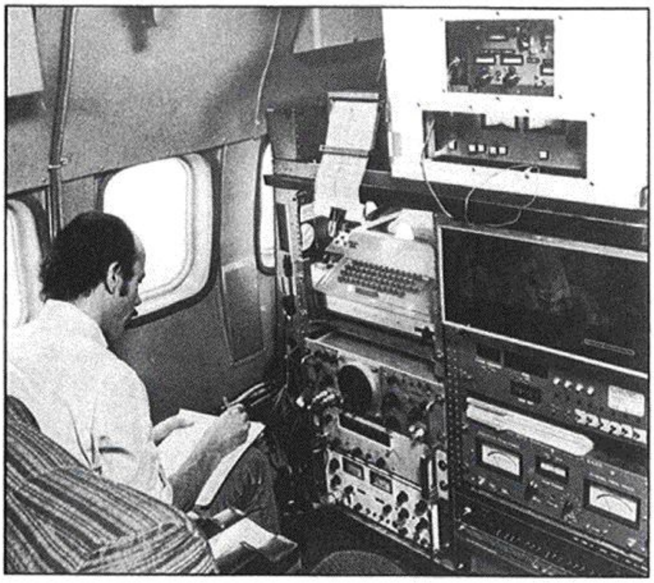
1965

On location at the National Center for Atmospheric Research in Palestine, Texas. A launch crew prepares apparatus that is part of graduate student William B. Lenoir's research—a 60-gigahertz atmospheric sensing receiver (inset). Once lofted airborne by balloon, the receiver remotely sensed the temperature profile at different altitudes. These experiments evolved into the Nimbus series of NASA satellites, which later became part of the National Oceanic and Atmospheric Administration's satellite weather forecasting system. (RLE file photo)



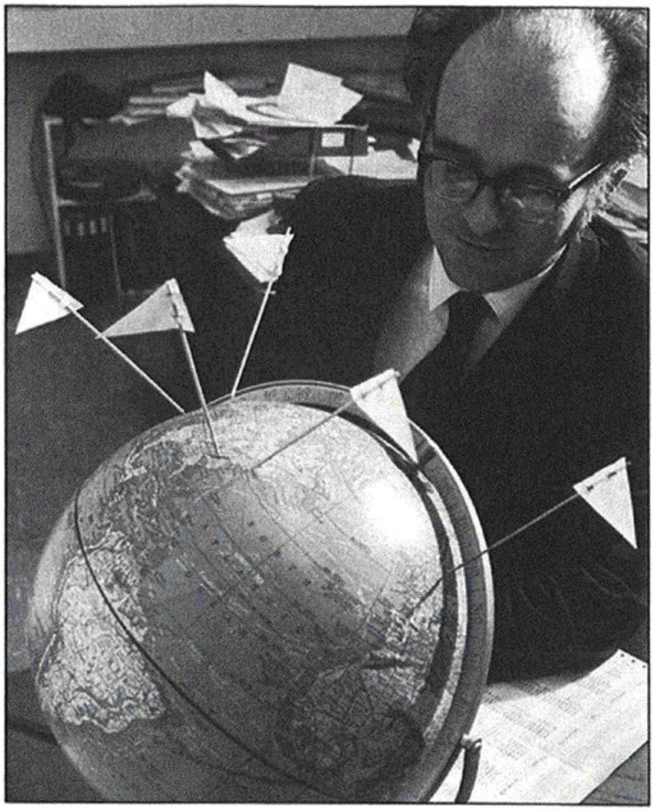
1967

Professor David H. Staelin on location at White Mountain, California, conducts black body radiation experiments in the June snow. The experiments measured cosmic background radiation at 8-millimeter wavelengths. (Photo by Bernard F. Burke)



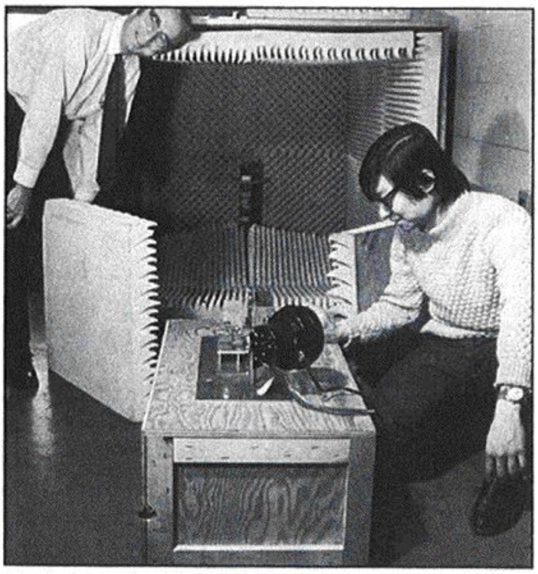
1970

Graduate student Joe W. Waters records information from a 53-gigahertz atmospheric temperature sounding radiometer aboard a NASA high-altitude Convair 990 test aircraft. (RLE file photo)



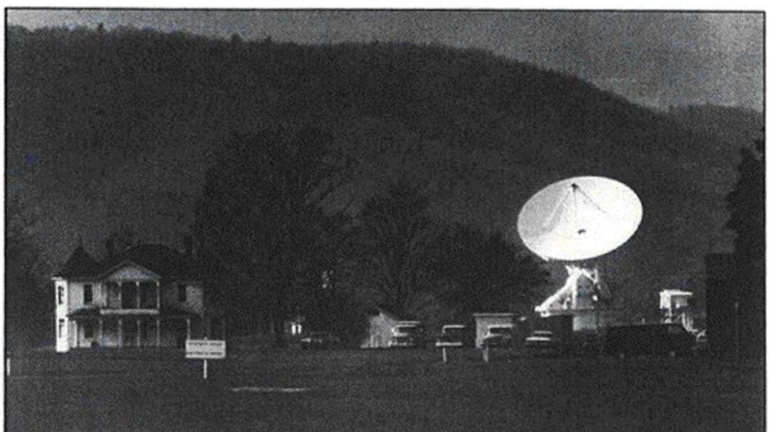
1971

Professor Bernard F. Burke flags locations on the globe that represent the five major VLBI stations in operation at that time: Green Bank, West Virginia; Haystack Observatory, Massachusetts; Hatcreek at the University of California in Berkeley; Onsala at Chalmers University in Sweden; and Owens Valley at the California Institute of Technology. (Photo by John F. Cook)

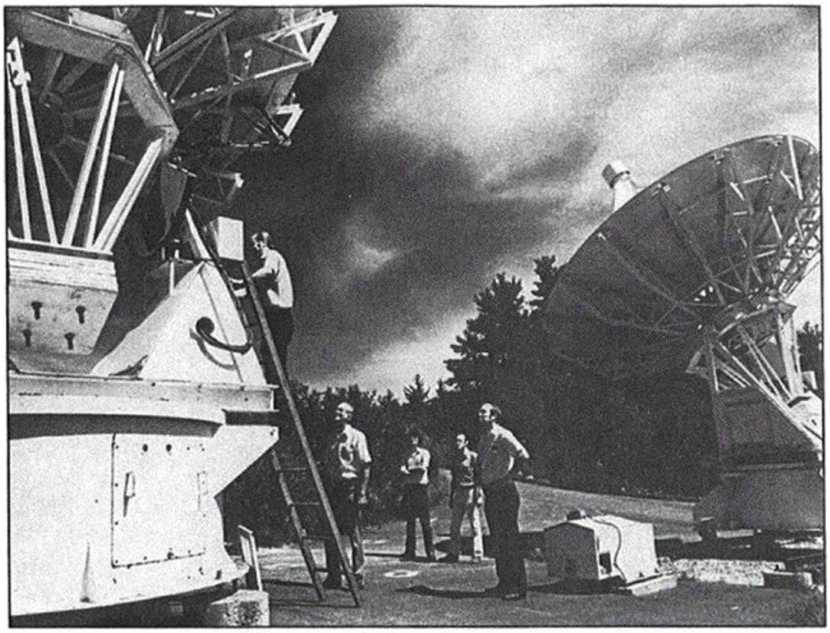


1971

Research Staff member D. Cosmo Papa (left) and graduate student Kai-shue Lam use RLE's anechoic chamber to test the radiation patterns of a 53-gigahertz microwave antenna. (Photo by John F. Cook)

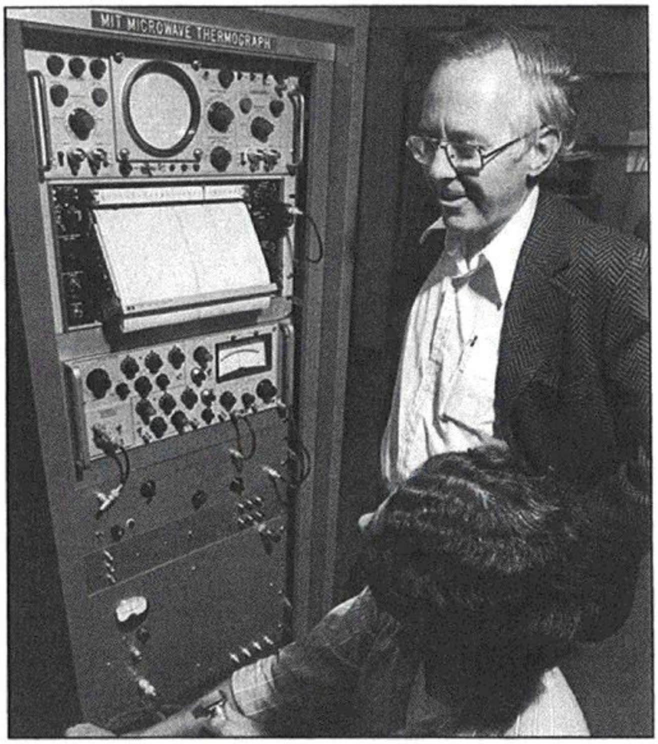


A rustic view of the National Radio Astronomy Observatory in Green Bank, West Virginia. This facility was used by many RLE students for early VLBI operations and to compile the MIT-Green Bank Survey. The 140-foot parabolic antenna collapsed in November 1988 under heavy snow, and a new antenna is planned for the site. (Photo by Bernard F. Burke)



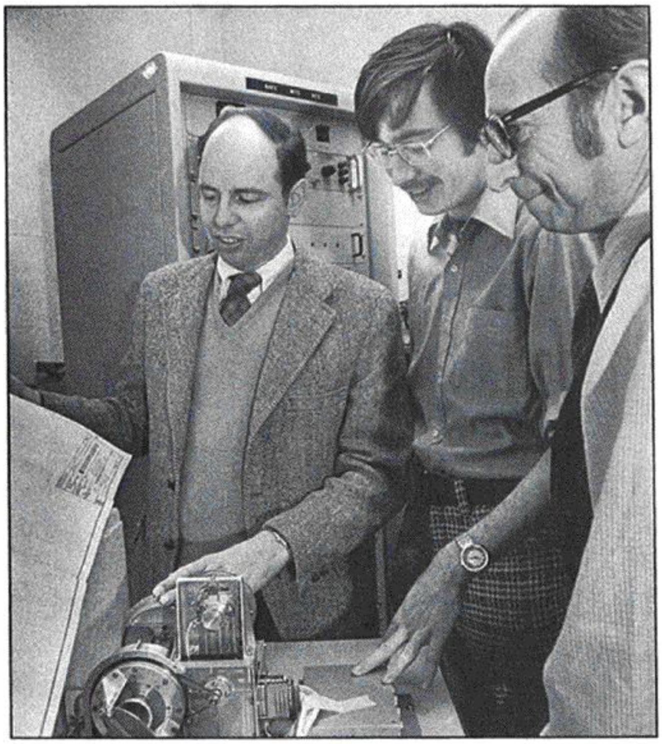
1975

RLE group performs outdoor maintenance on equipment used in experiments involving a three-element interferometer for the aperture synthesis of radio sources. These experiments were the precursor for VLBI development at short wavelengths. Research staff member D. Cosmo Papa ascends ladder while colleagues look on (from left): Professor Bernard F. Burke, graduate students Daniel C. Stancil and Barry R. Allen, and research staff member John W. "Jack" Barrett. (Photo by John F. Cook)



1977

Professors Alan H. Barrett (right) and Philip C. Meyers extend the radio astronomy techniques that detect molecules in space to the diagnosis of breast cancer in humans. Their technique, called microwave thermography, uses microwave radiometers to measure microwaves emitted by human tissue and sense abnormal temperatures. (Photo by John F. Cook)



1977

Checking an instrument that is the direct forerunner of today's operational satellite microwave atmospheric imagers used by the National Oceanic and Atmospheric Administration. From left: Professor David H. Staelin, graduate student Paul G. Steffes, and research staff member D. Cosmo Papa. (Photo by John F. Cook)

UPDATES:

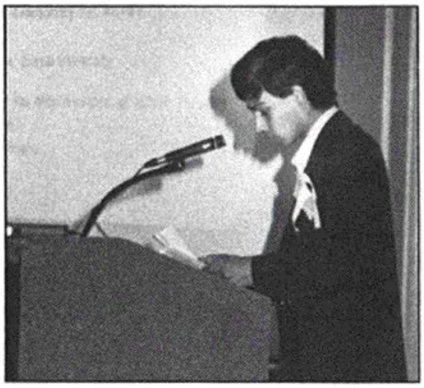
Collegium

The RLE Collegium was established in 1987 to promote innovative relationships between the Laboratory and business organizations. The goal of RLE's Collegium is to increase communication between RLE researchers and industrial professionals in electronics and related fields.

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, educational video programs, RLE patent disclosures, seminars, and laboratory visits.

The RLE Collegium membership fee is $20,000 annually. Members of MIT's Industrial Liaison Program can elect to transfer 25% of their ILP membership fee to the RLE Collegium. Membership benefits are supported by the Collegium fee. In addition, these funds will encourage new research initiatives and build new laboratory facilities within RLE.

For more information on the RLE Collegium, please contact RLE Headquarters or the Industrial Liaison Program at MIT.



Professor Srinivas Devadas presents a talk on logic synthesis, testing, and verification at RLE's Computer-Aided Design Review, held September 20, 1990. The faculty and students of RLE's Circuits and Systems Group invited colleagues from industry to attend this one-day meeting, which served as a forum on computer-aided design. Topics included: logic and finite-state machine synthesis, and synthesis for testability; parallel, serial circuit, and device simulation algorithms; and performance-driven synthesis.

Publications

RLE has recently published the following technical reports:

A Fault-Tolerant Multiprocessor Architecture for Digital Signal Processing Applications, by William S. Song and Bruce R. Musicus. RLE TR No. 552. February 1990. 143 pp. $15.00.

A Receiver-Compatible Noise Reduction System, by Matthew M. Bace. RLE TR No. 553. April 1990. 113 pp. $14.00.

Adaptive Frequency Modulation for Satellite Television Systems, by Julien Piot. RLE TR No. 554. April 1990. 153 pp. $15.00.

Syllable-based Constraints on Properties of English Sounds, by Mark A. Randolph. RLE TR No. 555. May 1990. 219 pp. $17.00.

Estimation and Correction of Geometric Distortions in Side-Scan Sonar Images, by Daniel T. Cobra. RLE TR No. 556. May 1990. 141 pp. $14.00.

Femtosecond Thermomodulation Measurements of Transport and Relaxation in Metals and Superconductors, by Stuart D. Brorson. RLE TR No. 557. June 1990. 171 pp. $17.00.

Channel Equalization and Interference Reduction Using Scrambling and Adaptive Amplitude Modulation, by Adam S. Tom. RLE TR No. 558. June 1990. 122 pp. $14.00.

Transform/Subband Analysis and Synthesis of Signals, by David M. Baylon and Jae S. Lim. RLE TR No. 559. June 1990. 37 pp. $6.00.

In addition, ***RLE Progress Report No. 132*** is available at no charge. The ***Progress Report,*** covering the period January through December 1989, contains a statement of research objectives and a summary of research efforts for each RLE research group. Faculty, staff and students who participated in these projects and sources of funding are identified at the beginning of each chapter. Current RLE personnel is also listed.

Also available at no charge is the ***RLE Publications Update January-June 1990.***

RLE welcomes inquiries regarding our research and publications. Please contact:

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