RLE currents

Volume 1, Number 2 • June 1988

The Research Laboratory of Electronics at the Massachusetts Institute of Technology

FOCUS: OPTIC RESEARCH AT RLE

Few developments have had a more profound impact on the way science is conducted and on the development of new technologies than modern optics. New areas of chemistry, physics, and materials science have been created by the invention of the laser and the advent of modern optics. Virtually no area of science has been left untouched by modern optics.

This impact has been equally dramatic on technology. Fiber optics and a growing legion of optoelectronic devices have revolutionized communications. Manufacturing and materials processing are undergoing similar changes. Lasers and modern optics are now pervasive in national programs for energy, the environment, and national security.

Optics research involves the basic science of light generation, transmission, and detection. This research contributes to the invention of new optical devices (semiconductor lasers, for example). Optical science encompasses both quantum optics (the basic science of light-matter interaction) and spectroscopy in its most general sense (the use of light to study the structure and dynamics of atoms, molecules, and materials).

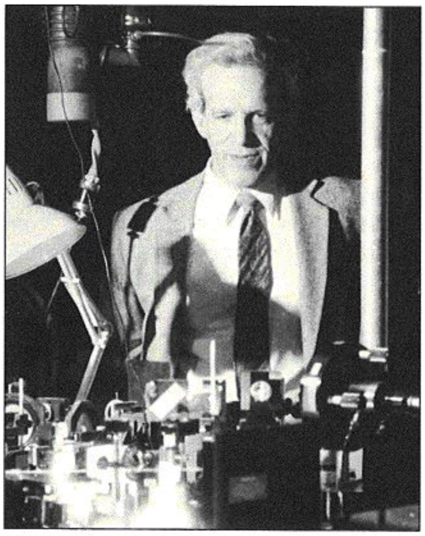
The area of quantum optics can be considered a direct product of the laser revolution. It focuses on the study of quantum and coherent properties in the radiation field, and how radiation can interact with matter. The term "quantum optics" originally referred to the physics of laser-generated radiation. Today, it includes the basic quantum mechanics of the radiation field; atom-cavity effects such as inhibited emission; and communications and metrology at the quantum level. All of these areas involve the interaction of light waves with matter.

Quantum optics normally involves coherent states of light. Now, techniques are being developed to prepare coherent states of atoms for what might be called the "quantum optics of matter." Scientists now anticipate the possibility of conducting "optical" experiments with atomic matter waves instead of optical waves.

The laser itself has had great impact on the field of spectroscopy. Originally, spectroscopy referred to the systematic measurement and interpretation of atomic and molecular spectra. Today, it is also used in a much broader sense. Laser-based methods have increased spectroscopic resolution a million-fold, and have opened the way for measurements of incredible sensitivity and precision. Lasers make it possible to create and study new species (such as free radicals, molecular ions, and Rydberg atoms), to detect them at the single particle level, to prepare them in exactly defined quantum states, and to take "snapshots" that freeze their nuclear motion. Scientists can now view spectral lines with the best resolution possible under the laws of quantum mechanics, and perform processes that allow access to otherwise forbidden states.

Laser spectroscopy also includes the study of how energy is transferred from state to state during molecular collisions; femtosecond studies that provide atomic "movies" of chemical reactions; high-precision tests of fundamental symmetrics, cavity quantum electrodynamics (QED), and weak interactions.

Professor Shaoul Ezekiel did his graduate work at MIT on the develop-



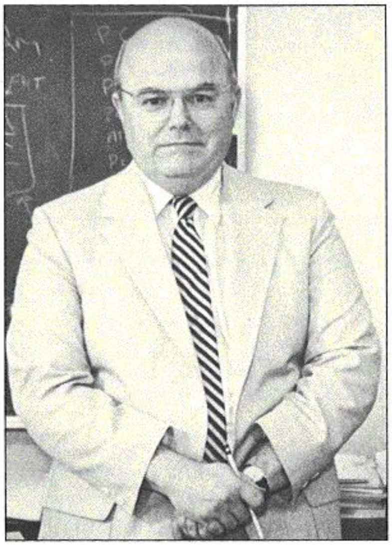
Laser spectroscopy of highly excited atoms in a strong magnetic field is an interest of Professor Daniel Kleppner. This project, which is being conducted in MIT's Spectroscopy Laboratory, seeks a deeper understanding of atomic theory and the connection between quantum mechanics and classical chaos. (Photo by John Cook)

Director's Message

In the scientific quest to understand the world of physical phenomena, there is a continuing need to investigate the smallest structures and to observe the fastest events. The field of modern optics forms part of a new set of tools that are being used to "see" ultra-fast phenomena such as fundamental electronic transport processes in today's high-speed devices. The invention of the laser as a coherent light source has played a central role in these studies, and has permitted the development of a variety of new probe techniques whose use has led, in turn, to new optical phenomena and sources.

A central theme in modern optics research is the exploitation of natural physical phenomena to produce desired signals. When ultrahigh-speed control is needed, no explicit control circuitry will suffice, and ways must be found that will constrain the experimental system in order to produce the signals of interest. RLE researchers have been leaders in the development of such systems to generate extremely short pulses (tens of femtoseconds), which can be used, in turn, for experimental probes as well as signal processing tasks.

New materials are vital to today's optics research, and RLE is greatly increasing its activities in this area. Quantum phenomena abound, and are exploited to discover new modes of communication and to elucidate novel light-matter interactions. Ultra-precise measurements are now possible with optical techniques that promise several orders of magnitude of improvement over contemporary methods. Optical interconnection between electronic systems is central to improvements in computing performance, as is the use of optically controlled waveguide technology to directly perform logical computations, including the possibility of massive parallelism.



Professor Jonathan Allen, Director, Research Laboratory of Electronics. (Photo by John Cook)

Optics research in RLE is an excellent example of interdisciplinary studies, ranging from the fundamental scientific studies to the innovative engineering solutions to many demanding problems. The excitement in the field is widespread, and the influence of optical techniques is increasingly pervasive in the Laboratory. It is no wonder that optics and electronics together form the basis for future systems of astounding performance.

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ment of ultrahigh-resolution laser spectroscopy and laser frequency standards based on atomic beam techniques. Currently, he uses laser atomic beam techniques to uncover the details of atom-field interactions, particularly in intense fields. He has also performed very high-resolution studies of the structure of iodine, and has pioneered the development of atom beam stabilized lasers.

In atomic physics, laser light has been used to trap molecules and cool them to temperatures within one millikelvin of absolute zero. The recent creation of two new types of atom traps will contribute to the study of atomic phenomena at microkelvin temperatures with ultrahigh precision. This enables the study of matter in a new quantum regime, spectroscopy at a resolution higher than anything yet achieved, and the creation of new devices (such as optical clocks) of unprecedented accuracy.

Professor Daniel Kleppner did his graduate research at Harvard University, where he co-invented the hydrogen maser with Norman F. Ramsey in 1959. After coming to MIT in 1966, he pursued research on precision measurements in hydrogen, conducted one of the earliest experiments on differential scattering of excited atoms, and pioneered the field of Rydberg atom research. His recent research focuses on the structure of atoms in strong fields, trapped hydrogen, inhibited spontaneous emission, and associated radiative studies.

Professor David E. Pritchard pioneered studies in high-resolution two-photon laser spectroscopy in addition to radio frequency and optical spectroscopy on van der Waal molecules. He also introduced the application of high-resolution lasers to atomic line broadening. Currently, his research is concerned with the forces of light on atoms, traps for neutral atoms that use either magnetic fields or light forces for confinement, and precise mass measurements of trapped ions. Recently, the duality between light and matter was exploited to diffract a matter wave from a "grating" made of light.

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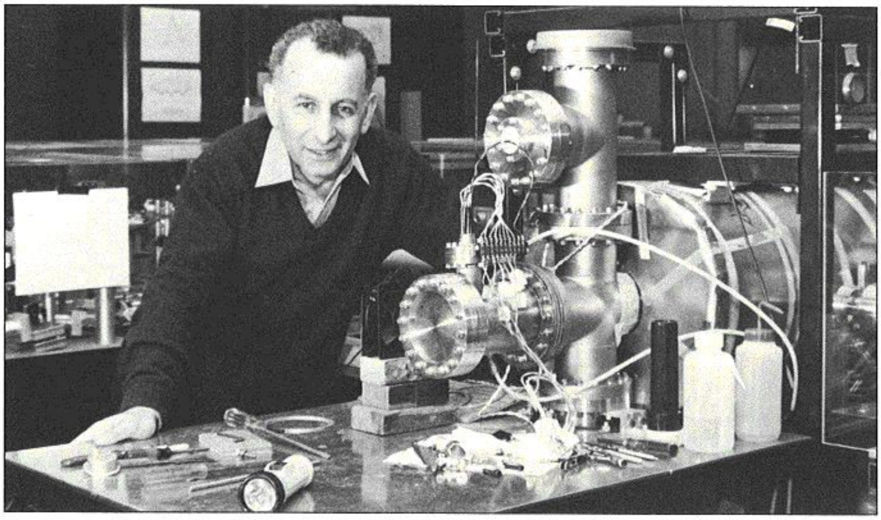
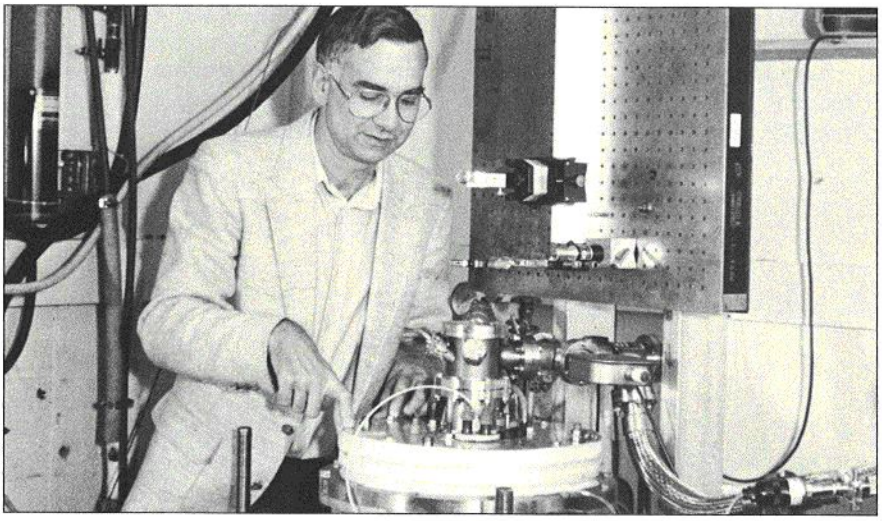
Nonlinear optics would not exist if it were not for the development of intense laser light. "Nonlinear" refers to the radiation-matter interaction where the variables that describe the response of the matter (such as electric polarization) are not proportional to the variables that describe the radiation (such as electric field strength). Light of ordinary intensity emerges from a transparent medium with the same wavelength as it did before it passed through the medium. But, high-intensity laser light can alter the optical properties of a medium, and cause intense beams of new wavelengths to be generated.

Molecules, surfaces, and con-



Professor Shaoul Ezekiel describes a sodium atomic beam apparatus used to detect laser Raman interaction for the development of new atomic clocks. The laser Raman atomic clock is based on the pioneer work of Professor Jerrold R. Zacharias, who developed atomic clocks using direct microwave excitation. (Photo by John Cook)



Professor David E. Pritchard points out a feature at the top end of a trap for neutral atoms. The trap uses superconducting magnets and laser light to cool and confine over 10 billion sodium atoms at millikelvin temperatures. The magnets were constructed from low-temperature superconducting wires with assistance from MIT's Francis Bitter National Magnet Laboratory. (Photo by John Cook)

densed matter can also be modified by intense light. Femtosecond lasers now make it possible to create and study excitations on a time scale shorter than that of fast internal relaxation phenomena. Nonequilibrium states of matter produced in this way permit the study of dynamical processes in matter within a regime never before witnessed. Scientists anticipate the discovery of new kinds of nonlinear optical interactions, and possibly, the creation of new photochemical and photophysical techniques for materials processing.

Professor Jeffrey H. Shapiro conducted his doctoral research under the supervision of Professor Robert S. Kennedy in 1970. His dissertation provided one of the first analyses of atmospheric turbulence compensation via adaptive optics. In collaboration with MIT Professor Cardinal Warde, he invented the microchannel-plate spatial light modulator. He has also pursued research on atmospheric optical propagation, communication, and imaging on coherent laser radars and on squeezed states of light. His RLE research group was the first to generate squeezed-state light in a Doppler-broadened atomic medium. The fundamental radiative properties of squeezed light are altered in order to permit measurements beyond the limit of the Uncertainty Principle.

Senior Research Scientist Dr. Robert H. Rediker is currently investigating the high-power communications by coherently combining semiconductor lasers in an external cavity.

Research Scientist Dr. Ngai Chuen Wong investigates squeezed state generation by degenerate optical parametric oscillation. This technique generates a novel light source whose intensity noise is below the usual classical shot noise.

* * *

Some of the techniques and concepts developed for materials and structures in solid-state optics at MIT include light scattering by carriers in solids; large, fast nonlinearities; and theories of modelocking. In the future, the area of optical signal processing will need more efficient materials and devices for practical applications.

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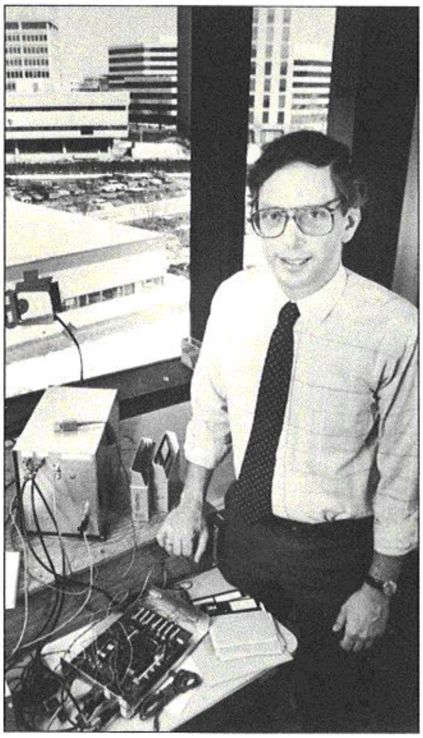
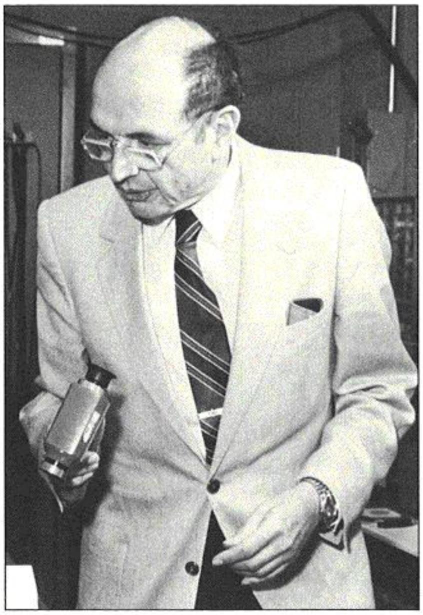


Professor Jeffrey H. Shapiro explains the operation of an experiment to study atmospheric optical communications for local area computer networks (see related article on page 4). (Photo by John Cook)



In his laboratory at RLE, Senior Research Scientist Dr. Robert H. Rediker works to combine semiconductor lasers coherently in an external cavity in order to achieve the production of higher power for communication applications. (Photo by John Cook)

FOCUS

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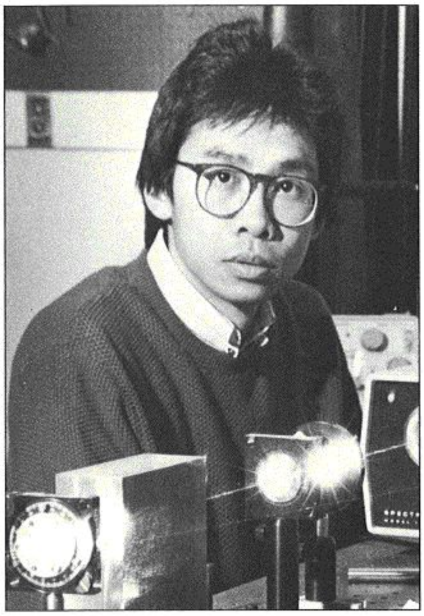
Professor Clifton G. Fonstad studies the growth and characterization of III-V ternary and quaternary compounds including InGaAlAs and InGaAsP, and the fabrication of heterostructure devices such as bipolar transistors and guided wave optical circuitry from these materials. He is also concerned with the lattice-matched Pb-salt heterostructure system PbSnTe/PbTeSe, and the fabrication and modeling of single-mode diode lasers in Pb salts.

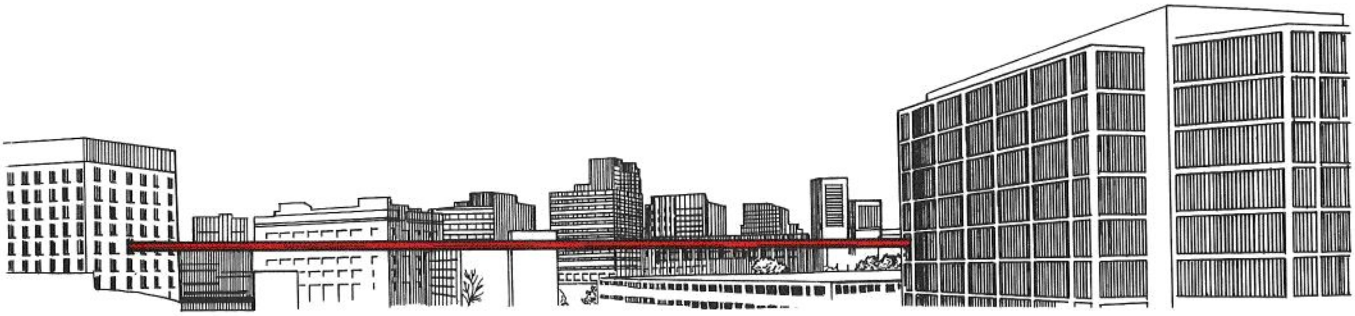
The development of new optical materials contributes to new optoelectronic devices such as spatial light modulators and subpicosecond switches. Related research exploits laser spectroscopy techniques and femtosecond methods that help to study molecular dynamics in gas and condensed phases.

Professors Hermann A. Haus, Erich P. Ippen, and James G. Fujimoto are concerned with the development of all-



Research Scientist Dr. Ngai Chuen Wong investigates squeezed state generation by degenerate optical parametric oscillation. A novel source of light is generated where the intensity noise is below the usual classic shot noise. (Photo by John Cook)

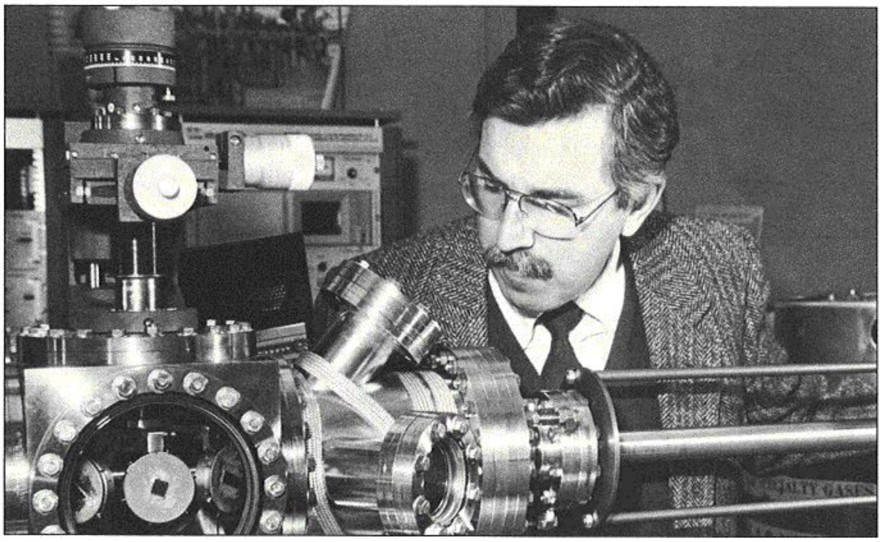
LOOK! Up in the Sky—It's LAN!



An investigation is currently being led by Professor Jeffrey H. Shapiro to study atmospheric optical communications for local area computer networks by using through-the-air laser communications that connect buildings containing cable subnetworks. The equipment, built by his students, consists of an infrared laser transmitter with a small spotting telescope mounted on top to facilitate alignment. The data is transmitted at 10 mbps from the fourth floor of 50 Vassar Street (Building 36) to a receiver on the fifth floor at 545 Technology Square, a distance of 170 meters. An infrared laser receiver in Building 36 is used to receive data transmitted from the same location at Tech Square.

In conjunction with two microcomputers and the appropriate software, these two laser transceivers form an experimental token-ring local area network or LAN. This experimental atmospheric optical LAN may lead to applications to bridge buildings that are almost a kilometer apart, or to temporarily and quickly connect new network users who cannot be immediately cabled.

The viability of these applications hinges on problems created by adverse weather conditions, because they can result in outages in through-the-air laser communication links. Currently, the experiment is collecting measurements of network performance under various weather conditions in order to improve link and network design.



Professor Clifton G. Fonstad inspects samples loaded into the introduction chamber carousel of a molecular beam epitaxy system that produces III-V heterostructures and multiple quantum wells for guided wave optics and laser diode applications. (Photo by John Cook)

optical switches and logic gates capable of processing picosecond pulses for application in high-rate optical communication systems. A recent focus of the group has been on fiber interferometer switches which permit long, large nonlinear interaction. All-optical nonlinear systems play an important role in the quantum theory of measurement.

In the 1950s, Professor Hermann A. Haus initially investigated noise in microwave tubes, and collaborated with MIT Professor Richard B. Adler on the circuit theory of linear noisy networks. In the early 60s, he became involved with the theoretical and experimental determination of quantum noise in lasers and the electrodynamics of moving media. His other studies have included nonlinear optical phenomena, CO and HF lasers, and noise in microwave solid-state oscillators. He achieved the first explanation of modelocking of a semiconductor diode laser in 1978, and the first all-optical waveguide modulator in 1983.

Professor Erich P. Ippen came to RLE from Bell Laboratories in 1980. His research interests include nonlinear interaction in optical fibers, dye lasers, semiconductor diode lasers, picosecond and femtosecond optical techniques, and studies of ultrafast processes. He was the first to demonstrate subpicosecond optical pulses.

Professor James G. Fujimoto is concerned with femtosecond laser generation and measurement techniques, studies of ultrafast processes in electronic and optoelectronic materials and devices, and time-resolved spectroscopic techniques in laser medicine. In collaboration with investigators at the Massachusetts General Hospital and the Massachusetts Eye and Ear Infirmary, the first studies of laser-tissue interaction were made in the femtosecond regime.

New sources of light are the driving force behind modern optical science and technology. Following the invention of the first laser, numerous light sources were developed such as ion and excimer lasers, molecular lasers, tunable dye lasers, semiconductor lasers, and sources based on various nonlinear techniques. New light sources must be developed to enable research within frequency and time regimes that are beyond the capability of existing optical devices.

Professor Peter L. Hagelstein, an MIT graduate, recently returned to MIT from the Lawrence Livermore National Laboratory in California where his research focused on the theory, design, simulation, and atomic physics of laboratory soft x-ray lasers. His invention of an x-ray laser driven by a nuclear explosion sparked new interest in defense applications at Livermore. He organized an effort to develop laboratory soft x-rays at Livermore, and began work that led to the demonstration of amplification in the extreme ultraviolet (EUV) regime. His current interests include laboratory EUV and soft x-ray lasers, relativistic atomic physics, large-scale physics simulation, and quantum-cavity electrodynamics.

Following the creation of a new laser source, research is usually directed toward the improvement of the source's frequency purity, or short pulse generation for diagnostic applications or communications. Through the use of nonlinear optical techniques, pulses less than 10 femtoseconds have been generated with dye lasers. These pulses are used for time-resolved studies of nonlinear optical processes in a broad range of materials. Short pulses also permit the use of nonlinear processes to generate a spectral continuum of subpicosecond duration for time-resolved spectral diagnostics. These pulses can be made even shorter

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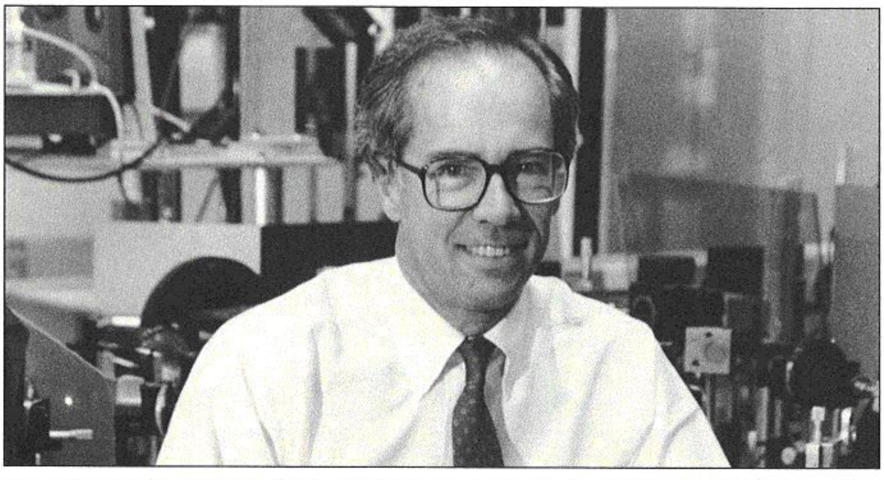
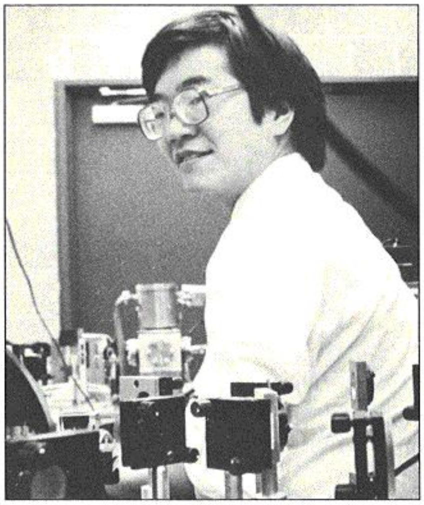


Professor Erich P. Ippen studies ultrafast phenomena in materials and devices with the help of picosecond and femtosecond laser pulses. (Photo by John Cook)



Professor James G. Fujimoto works with a high-intensity femtosecond laser amplifier. His research group studies ultrafast phenomena in electronic and optoelectronic materials and devices. He is also interested in the application of short pulse lasers in medicine. (Photo by John Cook)

by spectral broadening in an optical fiber, followed by compression with a dispersive grating or prism pair. The development of high-power, high-repetition rate femtosecond pulse sources will open new areas of study in time-resolved nonlinear optical processes in materials.

Professor Peter A. Wolff, a former Director of RLE, has broad interests in solid-state physics. He has investigated magnetism, local moments, semimetals, semiconductors, solid-state plasmas, and light scattering in solids. In recent years, his research has focused on semiconductor nonlinear optics and diluted magnetic semiconductors.

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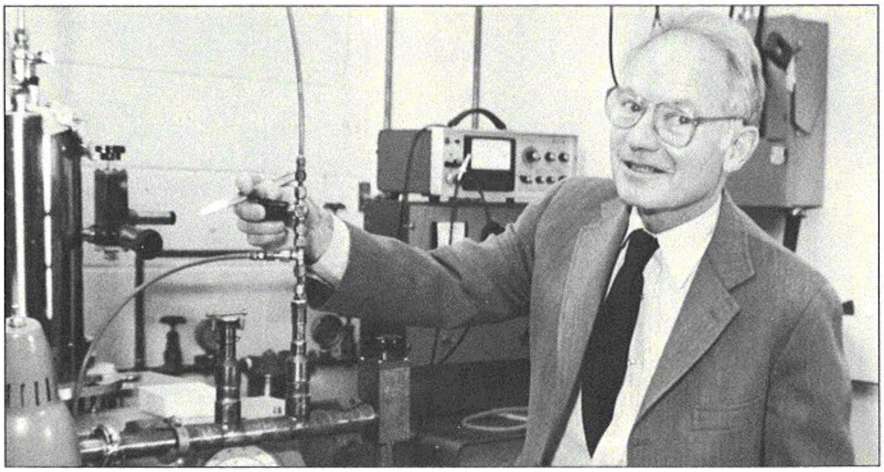
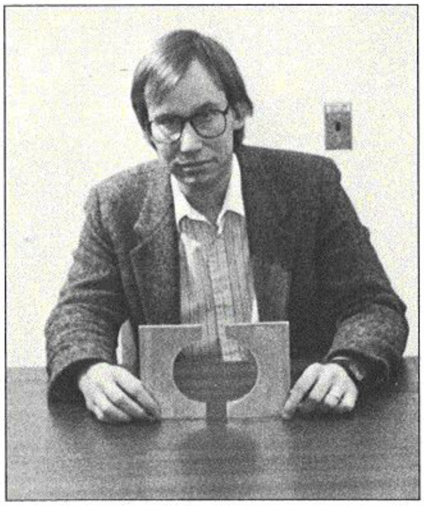
In contrast to laser technology, optical device technology is still in its early stages. While optical communications is already a large industry, the impact of optical information processing on society has been minimal. Scientists anticipate the creation of high-speed optical processors for special purpose computing, for all-optical switching systems, and for the implementation of neural network concepts. Fundamental research into new optical devices must be conducted before these optical processors become a reality. These devices exploit either the enormous "parallelism" afforded by optics or the incredible switching speed available with short optical pulses.

Because of their two-dimensional nature, parallel optical processors are ideal for tasks such as pattern recognition and complex matrix interconnection. Scientists anticipate that optical neural networks, composed of many highly interconnected simple thresholding processors, or "neurons," will tackle symbolic processing tasks and estimation problems. Applications of neural network processors include robotic vision systems and inference engines. Looking into the future, a medical diagnostic procedure can be envisioned where a neural network processor can diagnose a patient by simultaneously processing information associated with the symptoms, the patient's medical history, a set of "medical algorithms" developed by a team of doctors, and a library of medical literature.



Professor Peter A. Wolff's interests include the nonlinear optics of semiconductors for optical signal processing and picosecond electron kinetics. (Photo by John Cook)



Professor Peter L. Hagelstein's current project is the construction of a table-top soft x-ray laser. Here, he shows the whisper gallery mode mirrors which are part of the device. Together with a pump laser, the device will fit on top of a 4x12-foot optical table. In contrast, the pump laser at the Lawrence Livermore National Laboratory occupies a room the size of a football field. (Photo by John Cook)

Ultrafast serial processors will be required for high-capacity, time-multiplexed communication networks and interconnects. Picosecond all-optical switches are also needed in these systems to perform in-line logic and signal processing functions. These switches must also provide the multiplexing and demultiplexing necessary to interface with slower electronic systems.

Future technological innovations can be anticipated by looking at today's research. Coherent light sources in the far ultraviolet and soft x-ray regime are expected to have a dramatic impact on surface science, materials science, and biology. The development of new optical materials will make possible optoelectronic devices such as spatial light modulators and subpicosecond switches. These new devices may lead to the creation of optical neural network architectures that can simultaneously process information from many data banks, and produce the type of intelligence suited to perceptual tasks such as pattern recognition and complex decision making.

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The staff of ***currents*** would like to thank Professor Daniel Kleppner for his contribution to this article.

FACULTY PROFILE:

Hermann A. Haus

Institute Professor Hermann A. Haus was born in Ljubljana, Yugoslavia, in 1925. After attending the Technische Hochschule, Graz, and the Technische Hochschule, Wien, in Austria, he received his Bachelor of Science degree from Union College in Schenectady, New York, in 1949. In 1951, he graduated Rensselaer Polytechnic Institute with a Master of Science in Electrical Engineering, and came to MIT, where he earned his Doctorate of Science and joined the faculty in 1954. He was promoted to Associate Professor in 1958, to Professor in 1962, and to Elihu Thomson Professor in 1973. In 1987, he was conferred the honor of Institute Professor. In over thirty years on the MIT faculty, he has been a prolific contributor to the emerging technologies in the field of optics.

I heard about Norbert Weiner's theories on statistical phenomena when I was attending Union College. These phenomena fascinated me because they could be described deterministically, just as things can be characterized mathematically. I applied to MIT from Union and was not accepted. Instead, I went to RPI, and came to MIT in 1950 for a summer job with Professor Louis Smullin in the Tube Lab. Shortly after that, I was accepted to MIT. I guess Professor Smullin put in a good word for me.

In January, 1951, I came to MIT as a doctoral student and continued to work with Professor Smullin in the Tube Lab. We studied electron beams, and that's when I became aware of the work of Cutler and Quates. So, the "trigger" was Norbert Weiner, and then came Cutler and Quates. They studied noise in electron beams and reported on it after seeing standing waves. It was not all that surprising because they looked at noise in a very narrow band range, and few frequencies were picked up. But, the noise came from one place and imposed a distinct spatial pattern.

Professor Hermann A. Haus was the recipient of the 1987 Charles Hard Townes Award for his analysis of laser noise, the development of the modelocked semiconductor laser, and contributions to the understanding of nonlinear waveguide interactions. (Photo by John Cook)

That mystery was cleared up, but the question arose: How does noise in the electron beam affect traveling-wave tube noise? That was the topic of my thesis which was supervised by Professor Lan Jen Chu. Professor Smullin was my thesis reader, but he was much more than the traditional thesis reader, because I worked under him on the experimental part. Once the thesis was finished, we asked if what we had learned about traveling-wave tube noise could be applied to *any* physical system, such as an amplifier system with transistors, but not necessarily traveling-wave tubes. In other words, it wasn't an electron beam traveling-wave system, but it might be what is known today as a transistor. In those days, transistors had just been invented, and I didn't think about them that much.

As a physical device, transistors did not affect my work because I never went into semiconductor physics. Richard Adler was more involved with that. But, it was not a coincidence that we got together to ask questions about noise in linear circuits: How do you characterize a linear system in terms of its noise properties? How many parameters do you have to specify? Once those parameters are specified, what can you tell about the amplifier and how good will it be when all the components are put together? We called our paper "Circuit Theory of Linear Noisy Networks."

There was an interlude in my work on noise. I worked with Paul Penfield on electrodynamics, and I also worked on plasma physics with Will Allis and George Bekefi. That work never got me very far because the others were better at it and I never got involved enough to make any significant contributions. It was the same with magnetohydrodynamics, which was a possible source of power at one time. It still hasn't taken off, partly because it is materials-dependent, and we don't have the materials. Also, there was not enough money for magnetohydrodynamic power generation. That research was done in connection with William Jackson. I never got far with that either.

But, my work on noise got me interested in another question: Is there any fundamental limit? If we were to spend a lot of money on improving a device, would anything prevent us from making it better and better in terms of lower and lower noise? In a sense, we were not at the fundamental limit. We then asked: What other truly fundamental limits are there? It was obvious that quantum effects became more pronounced only at optical frequencies. At microwave frequencies, they are weak because of background thermal noise. If you cool it enough though, you can eliminate this thermal noise. Even at microwave frequencies, quantum noise tends to be at equivalent temperatures of a few degrees Kelvin. It would have to get that cold before you could notice quantum effects. At optical frequencies, the equivalent temperatures are in thousands of degrees.

Then, why do we communicate optically? To the lowest order, optical communication is bad in terms of noise. It is absolutely amazing! We have regressed to the lowest order because we live with larger noise! The speed of the transmission medium (the optical fiber) is so fantastic that it greatly overwhelms the disadvantages of increased noise. It took years to realize that. Optical communications didn't appear until the mid-'70s, long after the laser's invention. But, it was clear that the laser had obvious fundamental noise limits.

That started the measurements which Charles Freed and I worked on in 1964 and 1965. These were the first measurements of quantum noise effects in laser oscillators. We tried to demonstrate that laser noise was truly quantum noise. If a laser is in a general environment, it will be very noisy. Things have improved since then, but in the early days, we had to run the laser off of batteries. If you ran it off of a conventional power source, it was extremely noisy because the energy source was noisy. We also had to turn off all the lights in the building at Lincoln Laboratory where we conducted the experiment so we wouldn't get interference.

Although these effects were much larger than quantum effects, they were hard to find. At the time, people asked, "Why bother? If the noise is so hard to find, will it ever be important?" Of course it was important! Today, communication systems run at the quantum limit. Why? Because of improvements in noise performance and the highly increased bandwidth that we use. With increased bandwidth, some of those noises that plagued us have turned out to be important. Now, if you look at the characterization of communication systems, they are very close to the quantum limit.

We are limited by quantum theory as to how far we can go. However, we did anticipate that quantum noise would come to the fore and dominate optical communications. That was long before the optical fiber. At that time, it was not clear if optical communications would ever be as important as it is today, because you take a tremendous beating in terms of noise when going to optical frequencies. Now, it is enormously compensated by optical fibers.

- ***Did you have a mentor for this work?***

In 1962, I was close to Charlie Townes' group in the Physics Department, and I wrote a joint paper with him on noise problems.

- ***How did the study of optics develop at RLE?***

Many people from the older generation entered optics from microwave research. Very few were actually from op-

Shedding Light on Lasers

On July 7, 1960, in New York's Hotel Delmonico, Dr. Theodore Maiman, a research scientist from Hughes Research Laboratories in California, demonstrated a new light that created temperatures hotter than the sun. This atomic radio light, as it was called then, is used today in science, art, industry, medicine, communications, and defense applications.

Today, the laser (acronym for light amplification by stimulated emission of radiation) can drill diamonds, steel, and teeth. It can weld microscopic electronic components on computer chips and enormous steel plates on ships and buildings; read UPC codes printed on retail merchandise; print computerized documents; play audio/video discs; and create holograms and spectacular light shows. Lasers are instrumental in medical applications because they allow faster healing, less bleeding, and fewer complications. They are also the controversial focal point of President Reagan's "Star Wars" missile defense program.

In its simplest sense, a laser is a tube (or resonator) with mirrors on both ends that contains a material (for example, ruby crystal, or carbon dioxide gas, or chemicals). A source of energy (light, electricity, or a nuclear explosion) "pumps" and excites the material's electrons. As the excited electrons return to their normal (ground) state, energy particles (photons) are released at the same frequency (modulation). These photons bounce between the mirrored ends of the resonator (amplification) and stimulate other photons. A chain reaction is created by this stimulated emission of radiation. One semi-transparent mirror on the end of the laser tube permits the photons to escape when their intensity reaches a certain level. This results in an emerging laser beam.

Under various circumstances, light possesses different properties. It can behave as a stream of particles or as a series of waves. Today, scientists describe light as being made of energy particles (photons) that travel in waves. Ordinary light is characterized by various wavelengths (the distance between the waves' highest points), amplitudes (the top-to-bottom distance of each wave), and frequencies (the number of waves that pass through a given point in a specified time). Ordinary light is polychromatic (as witnessed through a prism) and of lower intensity than laser light. In a laser light, the highly concentrated photons travel at incredible speeds along a narrow beam. Light waves from a single laser are almost the same frequency and, hence, are monochromatic. Ordinary light waves can be compared to a scrambling football team, or a teeming mob of people on a city street moving in different directions. In contrast, laser light waves can be characterized as a precision marching band or soldiers marching in step.

In 1951, Nobel laureate Dr. Charles H. Townes developed plans for the precursor of the laser—the maser (microwave amplification by stimulated emission of radiation). In collaboration with his associate, Nobel laureate Dr. Arnold Schawlow, he published a paper on how a maser might work. In 1954, Townes developed a device that controlled high-frequency microwaves by exciting ammonia gas molecules with electromagnetic wave energy. His device screened out the low-energy molecules, and struck the remaining

A sufficient justification should be that the problem is interesting and challenging. Never mind if it's useful, because it may be useful in ways that you just can't anticipate. I think that attempts to make research relevant is just not research.

tics. Of course, optics was defined differently then. There was an influx of physicists interested in optical media and the development of lasers. If you were to ask who really made contributions to the development of new laser sources, it was generally the physicists and spectroscopists who understood the media. Laser sources were developed by the physicists, and were a practical part of the theory. In other words, you had to build the thing and show that it worked. Electrical engineers didn't know enough spectroscopy then. Now, they know more because they need to, but that wasn't the case then. The people interested in fiber optics and optical communications had a strong footing in microwaves, particularly at Bell Laboratories.

• ***How would you describe the transition of your work from noise in linear amplifiers to lasers and optics?***

Some of it was very much the same. It was helpful that noise turned out to be important. Instinctively, it was just interesting. That's a lesson everyone should circumscribe future research in, because you can't anticipate what's going to happen. A sufficient justification should be that the problem is interesting and challenging. Never mind if it's useful, because it may be useful in ways that you just can't anticipate. I think that attempts to make research relevant is just not research. It should be challenging, and that's the main criterion you ought to have.

You can get interested in something and work hard on it. I can remember times when I've walked down a corridor somewhere, and I got an insight. That's how it works. You work really hard on something and it doesn't pan

(continued on pg. 10)

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high-energy molecules with waves traveling at the same frequency and phase. This stimulated each ammonia molecule to give up its excess energy in a wave of exactly the same frequency as the molecule that struck it. Each wave would strike another molecule, and the result was a continuous doubling in the number of these high-energy molecules. The molecules converted all the energy that had been pumped into them into one frequency, and the molecules emerged in a much greater quantity at a single frequency. Thus, the molecules were modulated and their quantity vastly increased.

Although Townes' maser produced microwaves that were higher in frequency than radio waves, it was not high enough to be light. Thus, the name "maser." The maser amplifier, because of its high sensitivity and low noise levels, could detect extremely weak signals and furthered studies in radio astronomy, long-distance radar, and microwave communications. But, since light waves have a much higher frequency than microwaves, the laser's capabilities far outweigh those of the maser.

In 1958, Townes designed a type of maser to amplify light waves. This device featured two mirrors at opposite ends of a tube made of a ruby-like solid that could produce a frequency of red light. Light energy was pumped into the tube, and molecules were stimulated to release their excess energy at the exact frequency of the light waves pumped in. Similar to the ammonia gas maser, the released energy waves hit other molecules and continuously doubled their number. All molecules that were struck sent out waves parallel to the length of the tube at exactly the same frequency. Once the parallel waves struck a mirror at one end, they were repeatedly reflected back and forth between the two mirrors at each end of the tube. All nonparallel waves were absorbed by the tube walls or escaped through them. Once enough energy was built up, the remaining parallel waves shot out through one of the mirrors, and created a brilliant flash of coherent light (which consists of parallel rays).

Different materials lase at different frequencies, and produce lasers in a variety of almost pure colors within the light spectrum. The ruby was the first material used because of the crystal's atomic structure, which suggested that it might be easier to excite than other materials. Almost any material will lase if pumped with enough energy. Theodore Maiman successfully demonstrated the first laser in 1960 because he used more energy than anyone else.

Dr. Arthur Schawlow demonstrated the selectivity of the laser beam by aiming it at a blue balloon inside a clear balloon. The blue balloon exploded while the clear one was unharmed. This property of the laser enables surgeons to target specific tissues in laser surgery since the light beam treats only those tissues that absorb the specific color of the laser light used.

Today, lasers come in a broad range of sizes, types, and capabilities. Semiconductor lasers are smaller than grains of sand, while lasers that create fusion power are larger than a house. Medical applications include the treatment of detached retinas, glaucoma, and techniques to stop internal bleeding. In the future, scientists anticipate that lasers will assist in the production of energy from seawater, treatments for arteriosclerosis, holographic transmissions, high-precision genetic engineering using live cells, and spectroscopic analysis to determine the purity of materials.

out. Then suddenly you realize—AH HA! Of course, you don't realize it until you've spent many hours in frustration getting to the bottom of it. There were instances like that in my noise work. This is how you pick things up. Because you think about it or other people may comment on it. Suddenly, you realize—AH HA!—there might be a fruitful approach or something that I've overlooked.

• *What was the direction of your research under your Guggenheim Fellowship in 1959?*

It was my attempt to get deeper into plasma physics, although it didn't quite pan out. If you look at the papers I wrote as a result of the Guggenheim, they were in the plasma physics area. But, not everything you attempt works out.

• *How has the interdisciplinary research tradition at RLE affected your work?*

It was very important in the past. Unfortunately, I believe that we have gotten much more compartmentalized because of the support structure. Today, the specificity of proposal writing that details what you've contributed is counter-productive to interaction. In the old days, we didn't have to justify what we were doing. By not having to justify what we were doing, we were freer and that encouraged more interaction. You walked around to people who had little to do with your own research, but they provided perspective and you knew that they were experts in something else. I can remember talking to either Manny Cerrillo or Walter Pitts about a mathematical problem. You talked to people who tended to be outside of your particular interest because, partly, it was expected of you and you didn't have to render an account to your source of support that you worked on this specific proposal. This greatly encouraged interaction. Today, the interaction within our group is excellent, but that is by design and location.

It would be beneficial if we received block funding as a laboratory. Ultimately, you shouldn't judge people by what they say they will do, you should judge people on what they've done. Give them five or six years of grace, and do not expect anything from them for five or six years. Then, see what happens. You'll find much more interaction, creativity, and open-endedness. If I had promised to work on noise, I couldn't have justified it! But twenty years later, it proved to be important.

• *Can you describe your theories and experiments in the modelocking of lasers for short pulse generation?*

In 1968, I was involved with CO_2 lasers with my student Paul Hoff. We were modelocking CO_2 lasers to get shorter pulses out of them. Using a continuous-wave (cw) laser that gives a constant output, you can produce pulses by dividing time-dependent attenuation. In other words, at one instant of time there is no attenuation. Modelocking is a word to describe this, but it is based on a time-intensity domain. It's much simpler to say that modelocking is a form of *time-dependent attenuation*. So, at one point and one instance of time, there is no attenuation. But, to the left and to the right of that instant (before and after), there is attenuation.

It is similar to a *shutter*. Imagine if you had a mechanical shutter that opened and closed at the exact time when a pulse came through. Remember that optical radiation travels at a constant speed. The shutter opens only at an exact instant of time, and that time can be synchronized with the time the pulse goes through. So, here comes the pulse, it gets through, and then you close the shutter again so that nothing else gets through. The laser will then emit pulses, not continuous waves. That's what femtosecond optics is all about—pulses.

The tremendous advantage is that you can build electronic shutters which don't have to be very good. They must be precise in timing, but they don't have to be good in terms of blocking. If it blocks a little bit, that's all that is needed. In other words, you must have perfect transmission at one point and block off a little to either side. So, each time you cut off a little bit of radiation, and next time you cut off a little bit more. With a very poor shutter, you can get very good pulses. That's really the basic idea. Because it's resonant.

It's like pushing a child on a swing. Each time you push a little bit, but you do it at the right time, and it builds up. That's the same idea here. You shorten the pulse a little bit more each time, and you keep shortening it until other mechanisms (such as bandwidth) affect it. The gain can't handle unusually short pulses. That's when it stops. The shortening and the broadening keep each other in balance.

In 1975, another idea was born: the mystery of *how* the laser modelocked. This was solved by realizing that there was a double shutter. One shutter was the saturable absorber which opened but didn't close when a high pulse came in. The other shutter was the gain which closed after the pulse passed, because the pulse pulled down the gain. It used all the active particles and pulled the gain down. So, it was a combination shutter. That was the answer. Dye lasers which use dye for absorption are similar. So, absorber and gain must be similar. If they don't work properly, or if they are mismatched, they wouldn't do that. So, they must be matched.

• *What is the goal of producing the shortest, fastest pulses?*

You can use those pulses to build switches that have wonderful optical properties to check electronic circuits. Electronic circuits have switching times of 10 or 15 picoseconds, so you can look at them electronically. But, if you tried to look at a pulse of that speed on a scope, you would have to load the circuit enormously, and the circuit won't respond the way it does when it's not loaded. Optically, you can send pulses and look at that circuit without loading it. Now you can find out what is going on. The diagnostics that you have enable you to look at electronic circuits and make them perform faster.

From the optical viewpoint, if you want to look at some interesting optical material properties, it's usually important to disturb the medium, and then watch the disturbance (by exciting carriers or electrons in the medium). Or, you can excite the atoms in the medium and watch them. The wonderful thing is that the excitation can be made quite large since you can have enormous intensities but small images. If you make the pulse half as long and twice as intense, the energy stays the same. So, with femtosecond pulses you can achieve extremely high intensities and very nonlinear responses of the medium that you can study.

You can study anything longer than what the pulse occupies in time. Anything slower than the pulse will give you very nice results. Here is an analogy: You know those beautiful photographs of bullets by Edgerton? He stopped bullets at microseconds (a microsecond is 10^{-6}). Now, you can open the laser's shutters to fifty femtoseconds. Fifty femtoseconds is another factor of twenty. That's six orders of magnitude. So, it's twenty multiplied by 10^6 times faster than Edgerton's camera. Of course, nothing microscopic moves that fast. No one can stop individual electrons because you can't see them. But, you can observe clusters of electrons in action and you can stop the smallest particles.

• *Can you describe your development of the saturable absorber theory?*

We were working on CO_2 lasers, modelocking, and short pulses. Still thinking about how these short pulses are generated, I listened to a Joint Services talk in California by Andy Dienes, who was at Bell Labs at the time. He had just achieved picosecond pulses with dye lasers, and posed the following problem about modelocking with gain and a saturable absorber.

An ideal saturable absorber is a perfect shutter because it is a medium which will absorb less for highly intense pulses and more for less intense pulses. A saturable absorber was used to operate the shutter. So, intense pulses were now automatic. The shutter doesn't have to be operated by anyone, because the pulse itself operates the shutter—wonderful! So, the pulse goes through. Where it's high, it doesn't get attenuated. Where it's low, it gets attenuated and chopped off. This leaves you with the center portion of the pulse. They put this system together and got picosecond pulses.

Then, they took the absorber (how it worked was unknown at the time), put it in front of the laser, and asked how it worked. The problem was that the shutter was opening but not closing. If it only opened and did not close, it chopped off the front and not the back. If it didn't chop off the back, there would be no reason for the pulses to form.

That's the question Dienes asked. How does it work? If they had known that the absorber was slow, they would never have tried it. But, they didn't know it was slow, they made it work, they found out that it was slow, and they didn't know how the system worked!

Dienes gave that talk in 1962, if I remember correctly, which triggered my interest in modelocking. I had already thought about modelocking in connection with CO_2 lasers. So, I asked Dienes why does it work. In 1964, I worked out a theory and presented it at Bell Laboratories. Chuck Chang and Erich Ippen, who were in the audience at the time, cornered me and said, "Have you really got it? Have you left something out?" Indeed, I did leave something out. Then, with their input, I developed the theory of the saturable absorber.

> The trouble was that no one could build the lasers that we proposed in 1975, because it entailed quarter-wave shifted lasers. The technology wasn't ready for our new idea.

Imperial College in London worked on the same problem. They were running problems on computers as opposed to getting analytic expressions. They got to the bottom of things, but their theories were not useable because they were on computer. Whereas, mine were useable because they were analytic. The problem with computers is they tend to be problem-specific. First, you have to write a program, and then it only works for a particular problem. If you have an analytic theory, it is very flexible and can be transferred.

In 1974, I was at Bell Labs for a one-year sabbatical, and I wrote my paper on the saturable absorber theory. If you were to ask about a highlight in my professional career, I am proud of that because that's what brought Erich Ippen to MIT. It marked the beginning of our acquaintance.

• *Can you describe your involvement with the distributed feedback laser?*

In 1974, when I was at Bell Labs, Chuck Chang came to me and inquired about the distributed feedback laser which was invented around 1971. This is now a common way to fabricate lasers since it replaces the mirrors with a grating that acts as a mirror. What's the advantage? We get better spectral purity of the laser. Chuck said that we couldn't anticipate the frequency at which the distributed feedback laser would oscillate. Once it is built, there are two possible frequencies on which it can operate. But, the two frequencies are random, depending on how the chip was processed. That's not good because half of the laser is, in a sense, not in spec because the other half oscillates on another frequency. He asked me to think about how to make it operate on a single frequency. We did some research, wrote a paper, and took out a patent. The trouble was that no one could build the lasers that we proposed in 1975, because it entailed quarter-wave shifted lasers. The technology wasn't ready for our new idea.

Then, in 1983, I attended talks in Tokyo on distributed feedback lasers where people complained about the two frequencies. After attending these talks, I was asked to visit KDD, the international telephone company in Tokyo. I gave them a proposal on how to solve the distributed feedback laser problem. Shigeyuki Akiba, who was spending a year there, took up the challenge and tried my idea. At that time, he wasn't able to make it work. In the interim, NEC made it work. But, Akiba got a clever new idea—how to *build* the distributed feedback laser! Now, they are commercially available.

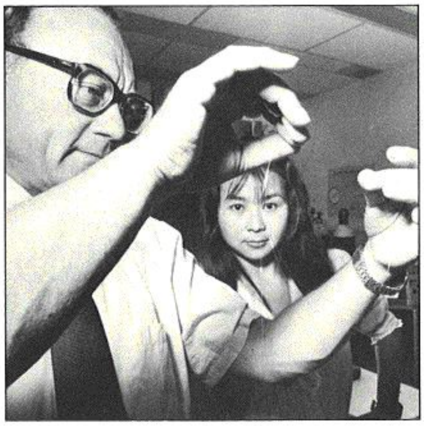
In 1988, the quarter-wave shifted laser demonstrated a million hours (114 years) anticipated life. Twenty years is the normal half-life for a laser. They claim that it will be *THE* laser of the future because it has 95% yield, while others have 50% yield. These lasers also demonstrate much greater stability and accuracy in the frequency.

• *How did you become interested in nonlinear optical waveguides?*

When I was at Bell Labs, I asked what happened to integrated optics, and the answer was: almost nothing. Integrated optics was discontinued at Bell Labs, and I asked myself why. What could integrated optics do for you? In one sense, it did nothing that you couldn't already do with electronics. Integrated optics appealed to me as a theoretical challenge with some nice problems. What would revive integrated optics? I thought—speed! In other words, if you could use short pulses in integrated optics, and if you had a source of short pulses that was integratable, then integrated optics would be useful.

What's the source of a semiconductor laser? Let's get short pulses out of semiconductor lasers. (A semiconductor laser with a semiconductor absorber looks very much like a dye laser with a dye absorber.) That was the idea of modelocked semiconductor lasers. In 1975, Ping-Tong Ho was a student of mine, and I gave that to him as a problem. In 1978, we were the first to modelock a semiconductor laser. At that time, Erich Ippen was a visiting professor, and he helped with the diagnostics. So, we wrote a joint paper on modelocked semiconductor lasers. Well, a lot has happened in the meantime, and other people have improved it. But, we were the first to demonstrate it. Now, we can get picosecond pulses from semiconductor lasers.

So, now that you have integrated optics with semiconductor laser pulses, how do you switch the pulses? That's how we started research in 1983 on the nonlinear optical waveguide, which still occupies us today. We also demonstrated the first all-optical waveguide modulator, where one optical pulse switches, or modulates, another optical pulse. We are still at it because the media are not there. But, we have done the same thing with optical fibers. The nice thing about an optical fiber is that it can be much longer, so it can interact longer. In fact, you can do pulse switching with much lower intensities in fibers than in waveguides. We have demonstrated that.



Professor Haus and graduate student Dilys Kit-Ling Wong examine a fiber used for optical interferometric switching. (Photo by John Cook)

The problem is that there is a delay if you have a long fiber. You can send in two pulses, but you must wait until they get to the other end before you can see your result. That doesn't mean the switch itself must have a low throughput, because you can send two pulses right afterwards. It can still be a very high-rate switch with a delay. I think we have a reasonable chance to demonstrate very good switching. We have demonstrated switching at two watts peak optical power which is extremely low. For optical switching, you usually need megawatts! But, that's what you can do with long fibers.

Currently, for Draper Laboratory, we are investigating the fiber laser gyroscope. A laser gyro implies that you have to consider noise again, so we are proposing a soliton laser gyro.

• *What are the details behind your development of the soliton laser theory?*

We are developing the soliton laser theory right now by studying the quantum noise of solitons. A soliton is a optical pulse that can maintain itself on an optical fiber without deterioration. If you were to send in a normal low-power pulse, the different frequency components disperse. But, if it's intense enough, and if the fiber is in what is known as an analogous dispersion regime (where the wavelength is generally greater than 1.3 microns), then the nonlinearity of the fiber compensates precisely for that spreading or dispersion. They keep each other in balance.

It is very much like the modelocked laser. The analogy is that two mechanisms are fighting each other. In the modelocked laser, the saturable absorber, or shutter, squeezes the pulse while the gain medium spreads the pulse. The two work against each other. The same thing takes place in the soliton laser. The dispersion spreads out the pulse, and the nonlinearity compresses the pulse. Together, the two actions keep each other balanced. Soliton pulses can travel over large distances without dispersing.

We are interested in solitons for two reasons. One is for Draper Lab, and the other is for the switches that I described. They can be rather long, but would only work with short pulses if you made them solitons. Otherwise, the pulses would disperse. So, the ideal fiber switch would have solitons because they stay together.

How do you switch solitons? That brings you to the nonlinear theory of solitons. Another question is how do you use them in laser gyros? That brings you to the quantum theory of solitons. In optical communications, you are concerned about signals sent over long distances because you are dealing with attenuations of 10^4 and 10^5. That's not true in the case of solitons.

At first, you might say why bother with noise? Because, after all, you have powerful pulses here. But, in the laser gyro configuration, you can design it so that all the classical noise is balanced out. It is only quantum noise that you must worry about. So, we are right back where we started twenty-five years ago. Quantum noise, but now in a nonlinear environment.

• *Can you describe your work on the quantum theory of phase-sensitive systems?*

It is the quantum theory of nonlinear systems. I have researched it in the past, and I still work on it with Yoshihisa Yamamoto from Japan. We've written a couple of papers on it. It is related to the soliton because solitons are phase-sensitive systems that display some of these properties. Professor Jeffrey Shapiro and I have speculated that it would be interesting to determine how to build systems that generate desired quantum states. In a sense, you could dial a quantum state and build your system to produce that state. This is related to phase-sensitive systems because it is a kind of quantum state.

• *What are the limitations of optical technology?*

It is definitely the *topology*. I would like to clarify some misconceptions. People have talked about integrated optics since the 1970s, and that conjures up images of integrated circuits where you can put a million transistors on a chip, and the development of all-optical computers. I think optical computers, as they are bandied about, will not exist. There are certain optical properties that must be used in computers. But, they are talking about all-optical computers, everything optical.

• *What about the possibility of using light to switch light?*

That is possible, but not on a large scale, not with millions of transistors. Maybe with ten or fifteen. That's why I say that integrated optics is a misnomer because it conjures up a picture of a very large computer. I prefer to call it waveguide optics because it doesn't conjure up that image. I think waveguide optics will be important because, let's face it, optical signals are already optical. It's not as if we have to transform them because they are already in optical form.

• *But what about switching from optics to electronics?*

That's what is being done today, and that's the other way to go. It is a roundabout way to do certain functions. There will always be optical processes. But, on what scale? Optics is very fast, and to some extent, parallel (image processing is parallel processing). But, this has been highly overdone . . . talking about millions of pixels when the devices don't exist. I don't think they can deliver massive parallel processing. We should use the best properties of both electronics and optics to come up with a design. That's what is basically wrong with an all-optical computer. It tries to use some of the advantages of optics, but the enormous disadvantage is that there are no devices or equipment in optics that can compare with the transistor. In the foreseeable future, there won't be. An optical beam must be a few microns in diameter. Transistors are now submicron and much smaller than electron beams. In order to get an optical beam from one place to another you must use a waveguide (which is three microns wide and fairly long). Using wires, you can get electrons around corners. It will never be possible to integrate optics and electronics just by the laws of nature, no matter what happens to materials. But, optics will always be faster than electronics, and that you can always predict. So, where speed and optical interconnects in computers come into play, I can see that because you can change those interconnects in real-time. Interconnects that would replace cables are also obvious. Replacing coaxial cable with an optical fiber is the natural thing to do. So, computer cable connections will disappear.

• *What does the future success in optics depend on?*

Materials. At RLE, we seem to be planning for that. I am pleased to see that two new materials people have come on board (Leslie Kolodziejski and Jesus del Alamo). The bottleneck in materials development will impact on the direction of optics. The big, uncharted territory is high-speed optical properties. There are lots of ideas around, but they are all limited by the fact that we don't have optical materials with the properties that we need.

• *Why have you chosen to stay at MIT for over thirty years?*

It's fun. I have never been frustrated. Well, maybe at times . . . In that respect, it is a good environment for people like me. But, I would be the first to admit that I'm not sure if I could develop an industrial product that would sell. I have high respect for people who do. On the other hand, it would be nice if we could provide that kind of perspective to our students.

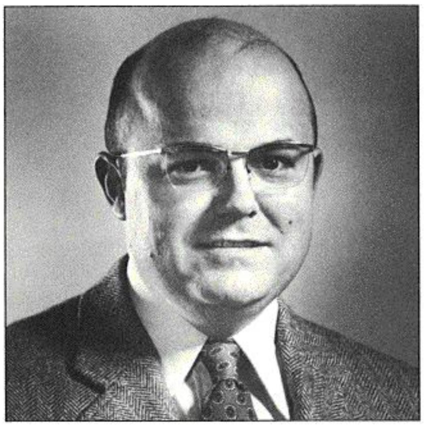
I think we should encourage industry ties with universities, encourage student exchange, and raise the awareness of students at MIT. We shouldn't discourage students from research and development. It is a very challenging field. But, how can we teach development if we never do it? It's a chicken/egg problem. On the other hand, how can you hire great developers from industry to work in the university? I think they would be frustrated because they want to see their products developed. The universities are not a good environment for someone who is gungho on getting a system to work. It is not an easy problem.

• *Do you have a philosophy of life?*

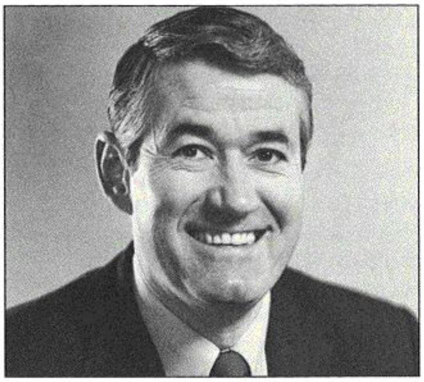
Have fun working with ideas. I've never stayed far from experiments. I did experimental work as a thesis student, and there was my experimental work with Charles Freed, the CO_2 experiments, the modelocking experiments, the work with Ping-Tong Ho on semiconductor modelocking, and experiments with waveguides. Although I don't consider myself an experimentalist, I have high respect for the experimentalist. I believe that your theory needs realism by being involved and being in close touch with experimentalists. Have fun with ideas, work very hard with them. Don't stay far from the experiments if you are working on theory, and if you have any talent for experiments, do them.

Try to do your best, because that's all part of the fun. The greatest thing is that once in a while something clicks. It happens every three or four years. It can't happen more often than that, except for some exceptional people.

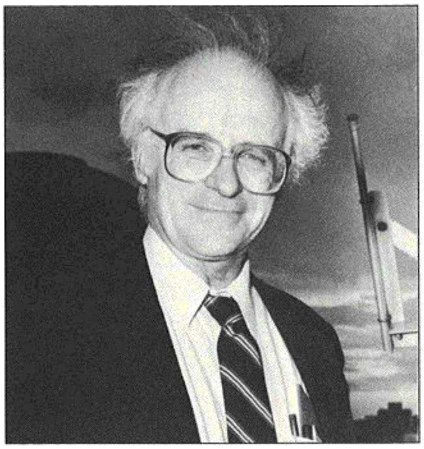
circuit breakers



Dr. Jonathan Allen, Director of RLE and Professor of Electrical Engineering and Computer Science, was awarded the IEEE Acoustic, Speech, and Signal Processing Society's 1987 Technical Achievement Award for his valued contributions and work in the signal processing area. The award was made at ICCASP-88 in New York City on April 12, 1988. *(Photo by John Cook)*

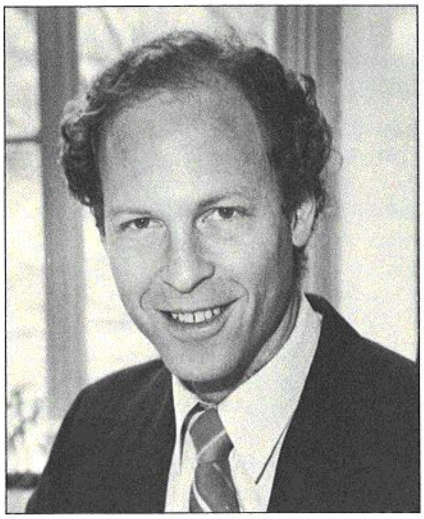


Dr. Robert J. Birgeneau, Cecil and Ida Green Professor of Physics, was appointed head of MIT's Physics Department, effective July 1, 1988. Professor Birgeneau came to MIT in 1975. From 1983-1986, he was Associate Director of RLE. Recently, Professor Birgeneau was selected as co-recipient of the 1988 Bertram Eugene Warren Award from the American Crystallographic Association. The award will be presented to Professor Birgeneau and collaborator Dr. Paul Horn, Director of Statistical and Quantum Physics at IBM, at the annual ACA meeting in Philadelphia. The award is presented in recognition of their studies in two-dimensional phases and phase transitions by diffraction methods. *(Photo by John Cook)*



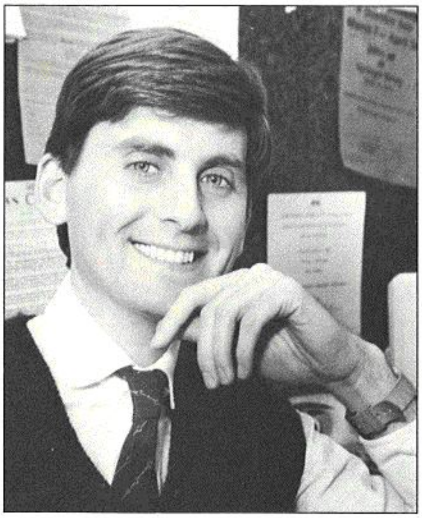
The MIT Physics Department and Haystack Observatory co-sponsored a one-day conference on gravitational lenses and their impact on astrophysics in honor of ***Professor Bernard F. Burke's*** 60th birthday on June 20, 1988, at MIT. *(Photo by John Cook)*

Recently, Physics ***Professor Bruno Coppi*** was honored with three distinguished awards. At the Annual Meeting of the Division of Plasma Physics in November, 1987 in San Diego, he was named recipient of the 1987 James Clerk Maxwell Prize for Plasma Physics, sponsored by the Maxwell Laboratories, for his outstanding contributions to fundamental theory, experimental interpretation, and engineering design in fusion research. Also in 1987, he received the Dante Gold Medal awarded by the Dante Alighieri Society for excellence in physics and education. In addition, he will receive the European Biancamano Prize in honor of his work to foster the ideals of European and international solidarity. *(Photo by John Cook)*

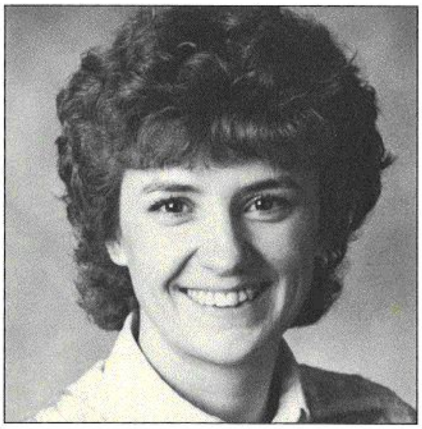


Chemistry ***Professor Keith A. Nelson*** was named recipient of the Coblentz Award, which honors outstanding work in spectroscopy by a scientist under the age of 36. The award will be presented by the Coblentz Society, which fosters the understanding and application of infrared spectroscopy and related fields, at an Ohio State University symposium in June, 1988. *(Photo by John Cook)*

Dr. William M. Siebert, Ford Professor of Engineering in the Department of Electrical Engineering and Computer Science, was named co-recipient of the 1988 Pioneer Award of the Aerospace and Electronic Systems Society. Professor Siebert is being recognized for his achievements in the development of pulse-compression radar, specifically in the origination of the phase-coding principle within the radar pulse. *(Photo by John Cook)*



Dr. Jesus A. del Alamo was recently appointed Assistant Professor of Electrical Engineering at MIT and has joined the RLE faculty. A Stanford University graduate, Professor del Alamo was employed as a Research Engineer at the Nippon Telegraph and Telephone Corporation in Atsugi, Japan, where he initiated a research project on the fabrication of heterostructure field-effect transistors by molecular beam epitaxy using InGaAs and InP active layers for telecommunication applications. He is currently starting a research program on high-performance semiconductor devices for microwave and optical telecommunications. *(Photo by John Cook)*



Dr. Leslie A. Kolodziejski was appointed Assistant Professor of Electrical Engineering at MIT, and will join the RLE faculty in the fall of 1988. A graduate of Purdue University, Professor Kolodziejski also served as Assistant Professor of Electrical Engineering at Purdue. Her research involves the fabrication of semiconductor lasers based on II-VI compounds.

In Memoriam

Dr. Manuel V. Cerillo, 81, died at his home in Mexico City on August 26, 1987, following a lengthy illness.

Dr. Cerrillo received his degree in electrical engineering from the Escuela Superior de Ingenieria Mechanica y Electrica in 1928, and went on to become an Assistant Professor and Director of his alma mater. In 1940, he was named President of the National Polytechnic Institute of Mexico. He came to MIT in 1945 to resume his doctoral studies, and completed his Ph.D. thesis entitled *Transient Phenomena in Wave Guides* in 1947. For the next few years, he worked with Professor Ernst Guillemin on problems in time-domain network synthesis.

He served as a Research Associate in RLE from 1945-1953, and again from 1959-1965. He was appointed Guest of the Laboratory from 1968 to the time of his death. During his distinguished career, he made substantial contributions to high-voltage and lightning research, electromagnetic theory, time-domain network synthesis, linear operator theory, as well as signal processing and its relation to perceptual phenomena. His research interests since the early 1950s were devoted to signal processing in man and machine using both auditory and visual signals as media. He was a pioneer in the application of mathematics and engineering to the study of art and music.

Dr. George G. Harvey, 80, Professor Emeritus of Physics, died April 9, 1988, after a lengthy illness. Professor Harvey had been associated with RLE for 42 years, and served as Assistant Director in 1950, and Associate Director in 1952.

He attended Washington University in St. Louis and received a Bachelor's degree in 1928, a Master's degree in 1930, and a Doctorate in Physics in 1932. He was a National Research Council Fellow in 1932 at the University of Chicago, and joined MIT as a physics instructor in 1934. He was promoted to associate professor in 1943 and full professor in 1961.

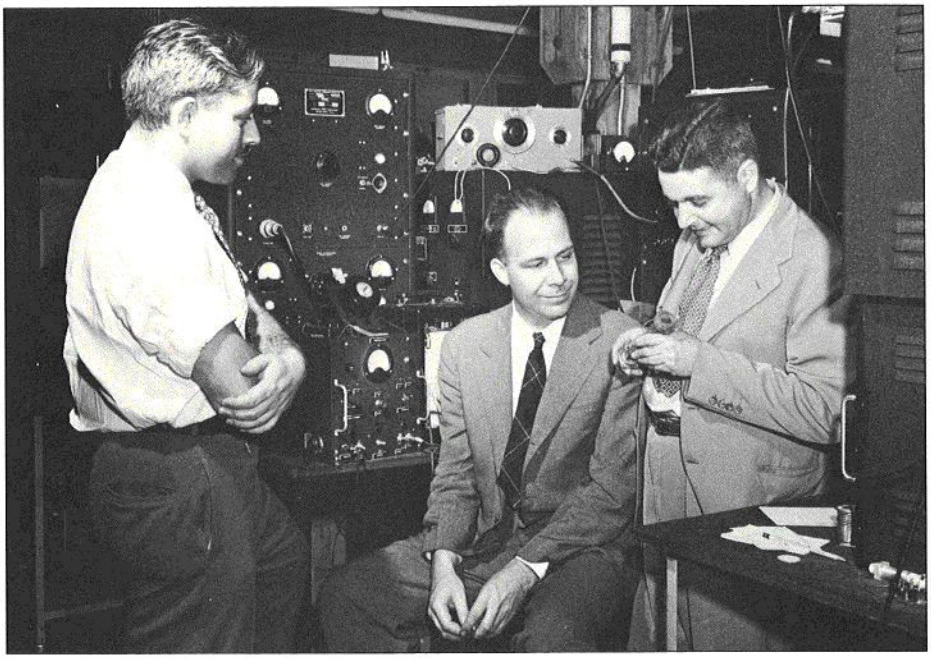
During World War II, Dr. Harvey was a staff member of the Radiation Laboratory for four years. As a scientist consultant for the armed forces from 1944-45, he served in Australia, the Phillipines, and the Pacific islands. In 1948, he was awarded a Certificate of Appreciation for outstanding contributions as a member of the Office of Scientific Research and Development during the war. He is also acknowledged as the the person responsible for securing much of the electronic equipment that was transferred from the old Radiation Laboratory to RLE .

Dr. Harvey is well-known for his contributions to x-ray spectroscopy and atomic structure. He built one of the first high-resolution electron microscopes, and held patents for microwave antennas with novel properties.

History of Optics at RLE

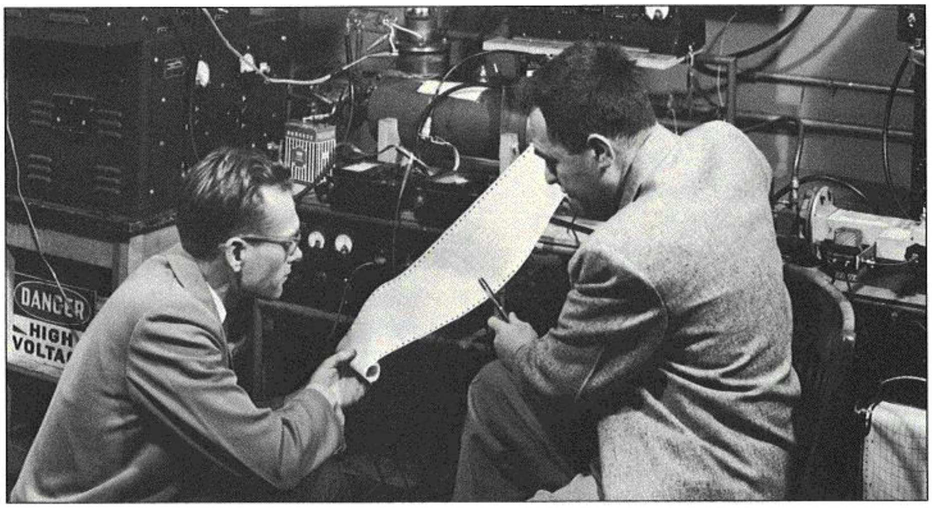
1945

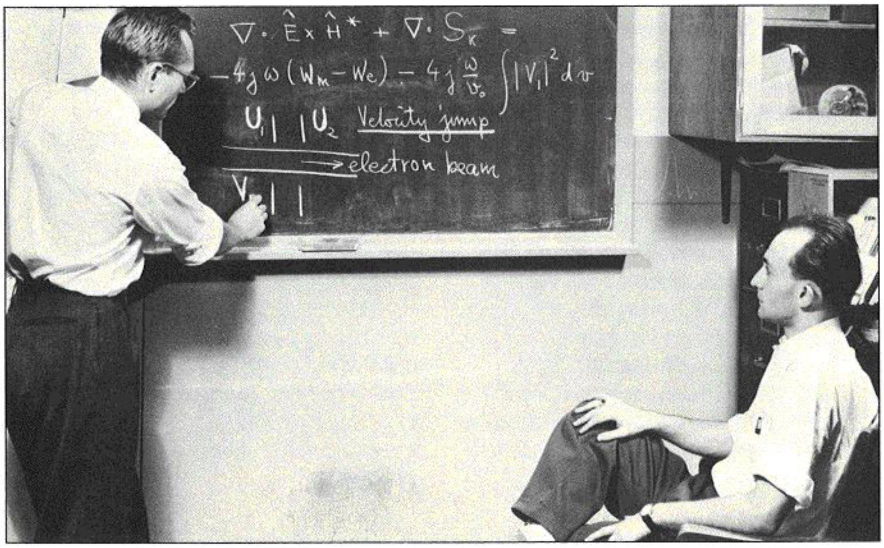
Today's millimeter-wave and optical techniques used in RLE stem from the MIT Radiation Laboratory's microwave tradition. G. B. Collins, Albert G. Hill, and Jerrold R. Zacharias (left to right) examine the features of a microwave waveguide. (Photo: Historical Collections)



1954

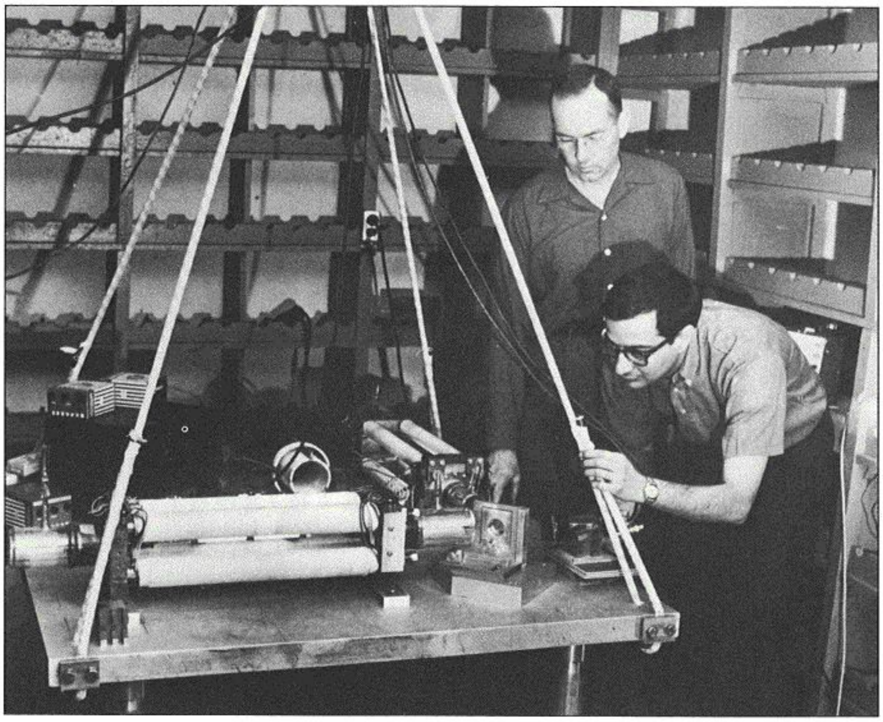
Associate Professor Hermann A. Haus (left) and Professor Louis D. Smullin (right) examine measurements of high-frequency noise in microwave vacuum tubes. (Photo: Ben Diver)





1956

Associate Professor Hermann A. Haus (left) discusses the properties of noise in microwaves tubes with graduate student Abraham Bers (right). (Photo: Ben Diver)



1962

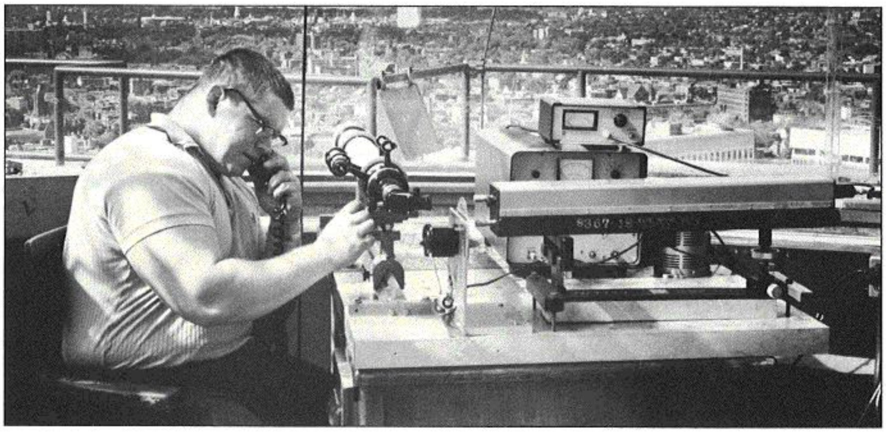
MIT Provost (and soon-to-be Nobel laureate) Charles H. Townes (left) and Associate Professor Ali Javan position two helium-neon masers in an experiment designed to examine properties of the theory of relativity (specifically, the variation in length with velocity). Their laboratory, located at MIT's Round Hill Field Station in South Dartmouth, Massachusetts, was situated in a former wine cellar because it was free from distorting vibrations. (Photo: MIT Historical Collections)

1962

Project "Luna See," headed by RLE Professor Louis D. Smullin (left) and Dr. Giorgio Fiocco (right), successfully demonstrated high-power optical maser technology by being the first to bounce a laser beam off the moon's surface. High-intensity red light flashes were created by an optical maser (laser), sent through a transmitting telescope to the moon's surface, and detected with an optical receiver. This was the first time space had been spanned by a laser light. Dr. Stanley Kass from Raytheon (center) discusses the experiment with Professor Smullin. (Photo: MIT Historical Collections)

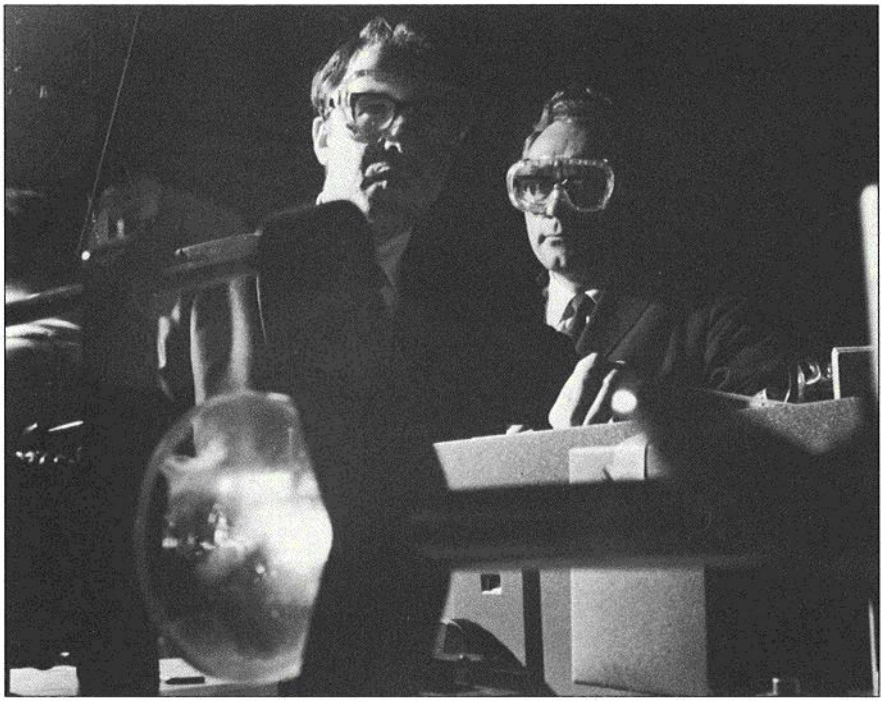
1966

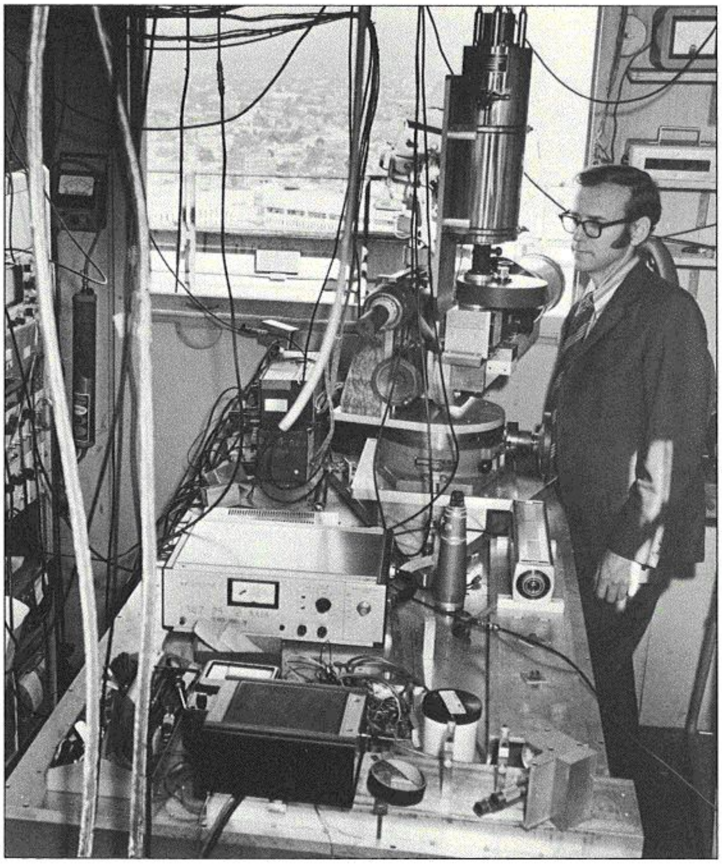
Graduate student James E. Roberson uses a helium-neon laser to study atmospheric turbulence effects on optical signals. The experimental signals were beamed 4000 meters to the Harvard Observatory. (Photo: John Cook)



1970

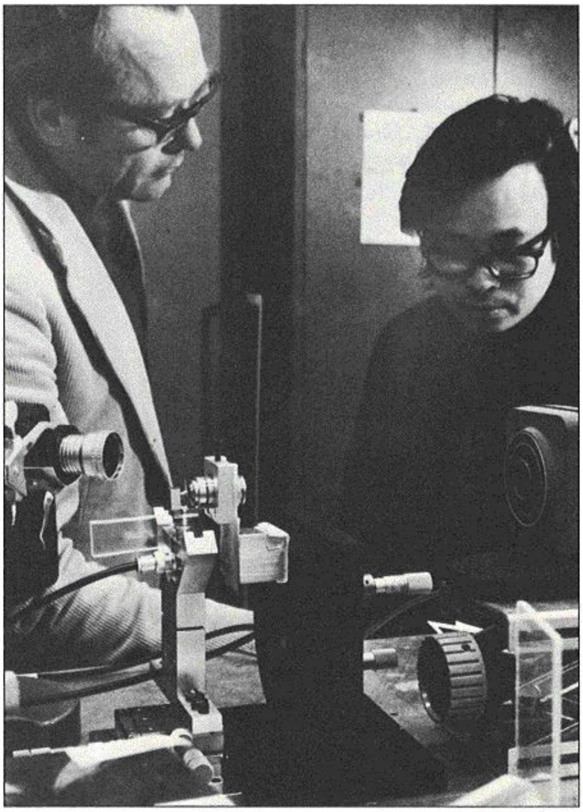
Professors E. Victor George (left) and Hermann A. Haus (right) use a high-pressure carbon dioxide laser to observe the characteristics of self-pulsing, a form of self-mode-locking in a laser. (Photo: John Cook)





1971

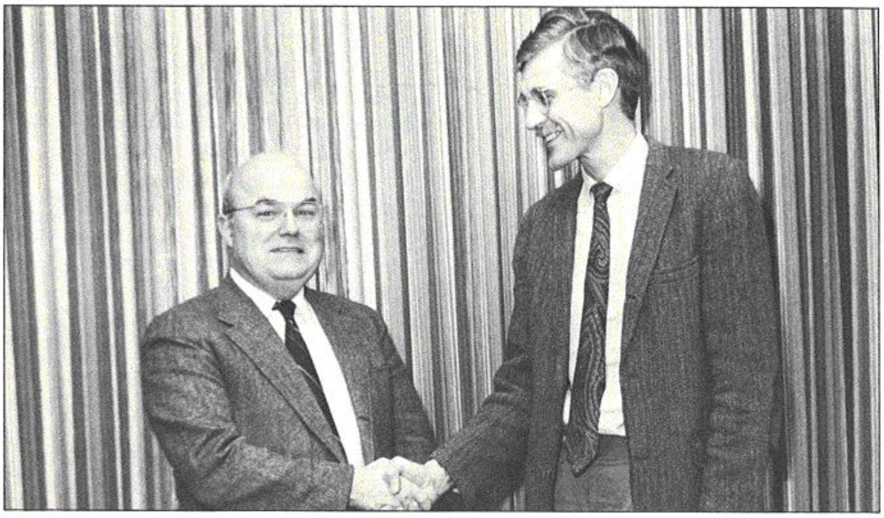
Professor Robert S. Kennedy with an optical communication receiver used in propagation experiments to determine the fundamental performance capabilities of optical communication systems. (Photo: John Cook)



1978

The world's shortest light pulses from a semiconductor device were achieved by Professor Hermann A. Haus (left) and graduate student Ping-Tong Ho (right). Here, they discuss the operation of a gallium arsenide diode laser in an external resonator. (Photo: MIT Electrical Engineering Department)

UPDATE: RLE Collegium



Professor Jonathan Allen (left), Director of RLE, congratulates Dennis Buss (right), Director of Technology at Analog Devices, on Analog's membership in the RLE Collegium. (Photo by John Cook)

Collegium Symposia

The Research Laboratory of Electronics Collegium and the MIT Industrial Liaison Program hosted two symposia this past academic year. The first, Speech Communication and Processing, was held on December 14, 1987; and the second, Opto-Electronics: Devices and Applications, was held on April 13, 1988.

Professor Kenneth N. Stevens chaired the December symposium and spoke on "Speech Production, Speech Perception and Linguistic Units." Other RLE speakers were Senior Research Scientist Dr. Dennis H. Klatt on "Speech Synthesis: State of the Art, Current Research at MIT, Future Prospects"; Principal Research Scientist Dr. Victor W. Zue on "Speech Recognition: State of the Art, Current Research at MIT, Future Prospects"; Professor Jae S. Lim on "Coding, Enhancement, and Time State Modification of Speech"; and Professor Louis D. Braida on "Speech Processing Aids for the Handicapped." One hundred fifty-six participants from thirty-eight companies attended.

Institute Professor Hermann A. Haus chaired the April symposium and spoke on "Opto-Electronics in Perspective." Other RLE speakers were Professor Clifton G. Fonstad, Jr. on semiconductor lasers; Professor James G. Fujimoto on femtosecond optics; Professor Cardinal Warde on optical computation; and Professor Shaoul Ezekiel on optical sensors. Speakers from MIT Lincoln Laboratory were Dr. James N. Walpole on new structures; Dr. Leonard M. Johnson on integrated optics; and Dr. Vincent W. S. Chan on space coherent optical communication systems. One hundred seventy-three participants from sixty companies attended.

Videotapes of the speech symposium are currently available through the MIT Center for Advanced Engineering Study. Videotapes of the optics symposium will be available shortly.

Collegium Membership

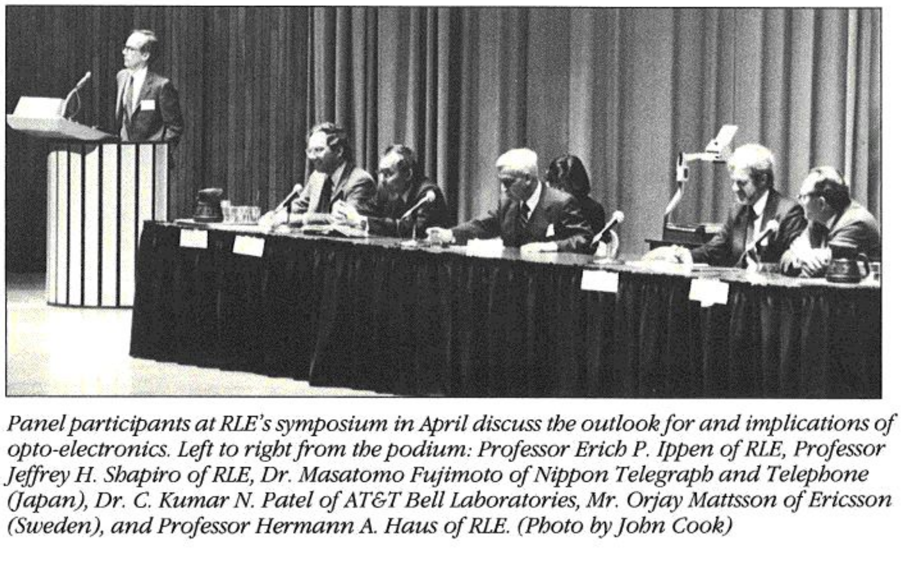
The Research Laboratory of Electronics is pleased to welcome six new member companies to the Collegium: Analog Devices, EG&G, IBM, Lockheed, Pitney Bowes, and NCR. The Collegium was established in 1987 to promote innovative relationships between the Laboratory and business organizations. The goal of 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. This kind of increased 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 publications, educational video programs, RLE patent disclosures, seminars, laboratory visits, and an on-line calendar of events.

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. After an initial one-year membership, a three-year commitment will be required. 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.



Panel participants at RLE's symposium in April discuss the outlook for and implications of opto-electronics. Left to right from the podium: Professor Erich P. Ippen of RLE, Professor Jeffrey H. Shapiro of RLE, Dr. Masatomo Fujimoto of Nippon Telegraph and Telephone (Japan), Dr. C. Kumar N. Patel of AT&T Bell Laboratories, Mr. Orjay Mattsson of Ericsson (Sweden), and Professor Hermann A. Haus of RLE. (Photo by John Cook)

UPDATE: Communications

Publications

The annual ***RLE Progress Report*** will be available in July, 1988. ***Progress Report #130***, covering the period January 1 through December 31, 1987, contains both a statement of research objectives and summary of research efforts for each research group in RLE. Faculty, staff, and students who participated in these projects and sources of funding are identified at the beginning of each chapter.

Also available in July will be ***RLE Publications Update*** which lists abstracts of reports published by RLE from January, 1987 through June, 1988.

In addition, RLE has published the following reports since the last issue of ***currents:***

III-V Waveguides and Couplers for Integrated Optics, by Nadir Dagli. RLE TR No. 533. September, 1987. 225 pp. $12.00.

Reconstruction of Multidimensional Signals from Multiple Level Threshold Crossings, by Avideh Zahkor. RLE TR No. 534. January, 1988. 184 pp. $11.00.

Generating Efficient Layouts from Optimized MOS Circuit Schematics, by David George Baltus. RLE TR No. 535. February, 1988. 193 pp. $11.00.

Speech Communication Group Working Papers. Volume VI. January, 1988. 262 pp. $8.00.

Other publications include ***RLE Progress Report #129*** (which covers 1986), the ***RLE Brochure***, ***Collegium Prospectus***, and the first issue of ***currents*** (December, 1987).

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

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Videotapes

RLE, in cooperation with MIT's Center for Advanced Engineering Study and the Industrial Liaison Program, has videotaped research presentations from two recent symposia, ***Speech Communication and Processing*** (December, 1987), and ***Future Directions in Electronics: 40th Anniversary Symposium of RLE*** (November, 1986). These color videotapes can be purchased or rented at the prices listed below. For further information, please contact Carolyn B. Johnson, MIT Center for Advanced Engineering Study, Room 9-234, Cambridge, MA 02139 (617) 253-7444.

• Speech Communication Processing

With the increasingly pervasive use of computers by all segments of society, the need for natural and reliable man-machine interaction has become pressing. Audio response devices, text-to-speech capabilities, and speech recognition systems are available or are being developed to satisfy these needs. To design such systems, the knowledge of many disciplines must be combined.

In the Speech Communication and Processing Symposium, researchers from RLE described advances and discuss future directions in the following key areas: signal processing, coding theory, human speech production and perception, acoustics, phonetics, linguistics, experimental computer systems, and VLSI technology.

Catalog #639-1100
(8 color videocassettes)
Purchase: $2,200
Two-week rental: $950
Five-day Executive Preview
(1 representative videotape): $95

• Future Directions in Electronics

On October 31, 1986, RLE celebrated its 40th anniversary with an exceptional symposium called Future Directions in Electronics. RLE faculty presentations included: submicron structures technology and future electronics; quantum transport and fluctuations in small devices; signal processing and representation; the links between language, speech, and hearing; radio astronomy: Fourier transforming the universe; plasma: space physics and fusion research; atomic physics and the frontiers of high precision; and high-speed optics. Invited guest speakers were Dr. Ralph E. Gomory, Senior Vice President and Chief Scientist, IBM, whose talk focused on university research and its relationship to industry, and David Packard, Chairman, Hewlett-Packard Corporation, who discussed the future of university research.

Catalog #634-1100
(11 color videocassettes)
Purchase: $1,200
Two-week rental: $600

RLE *currents*

RLE ***currents*** is a biannual publication of the Research Laboratory of Electronics at the Massachusetts Institute of Technology.

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