RLE currents

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The Research Laboratory of Electronics at the Massachusetts Institute of Technology

On the Road to Success with RLE's Alumni Company Founders

Welcome once again to ***RLE currents!*** You may have missed us over the last two years, but we have been busy creating our next two special issues. Our previous issues focused on research areas in RLE, and usually included interviews with our faculty, historical perspectives, and news of RLE achievements. With the spring 1994 issue, we completed coverage of all RLE's current research groups and were considering format changes to provide a new emphasis for upcoming issues.

Although the laboratory has remained intellectually strong and financially healthy, in recent years there have been changing patterns of research sponsorship and an increased need to document the contributions of research universities. As a result, we need to justify spending taxpayer dollars on research—to the public, to our sponsors, and to Congress. Increasingly, we are asked to demonstrate productivity on a cost-benefit basis. Because 1996 is also the laboratory's fiftieth anniversary, we want to mark this occasion by highlighting our five decades of innovation and impact. We want to emphasize how RLE has contributed not only to the economy but also to the needs of society, and to describe our current focus on developing solutions to many critical problems.

RLE Celebrating 50 Years of Impact & Innovation 1946-1996

Over the past fifty years, more than 3,000 students who have graduated from MIT also conducted research in RLE. Many of them have gone on to form significant companies that have introduced new technologies and products while bolstering the economy. So it seems appropriate, as we celebrate our fiftieth anniversary, to point out the accomplishments of these alumni and relate how RLE has played a role in their success. Of course, we do not take total credit, but I have found that our alumni company founders have exceptionally positive feelings about their RLE experiences, and there is a strong correlation between RLE's style and the companies that our alumni have established.

In preparing these two special issues of ***RLE currents,*** we reviewed our alumni database and discussed our plans with our faculty. From so many possibilities, we finally selected twenty RLE alumni company founders to be interviewed. The interviews themselves turned out to be a major project, and I traveled from one coast to the other in order to personally meet with and interview our alumni. All of them were extremely helpful and gave generously of their time. Once the interviews were taped, the detailed process of transcribing, condensing, and revising began. In this issue of ***RLE currents,*** we present ten of those interviews, with ten more to follow in our upcoming fall 1996 issue.

Many recurring themes caught my attention during the interviews. Remarkably, several alumni knew from an early age that they wanted to form their own companies. A strong sense of independence and a desire to follow

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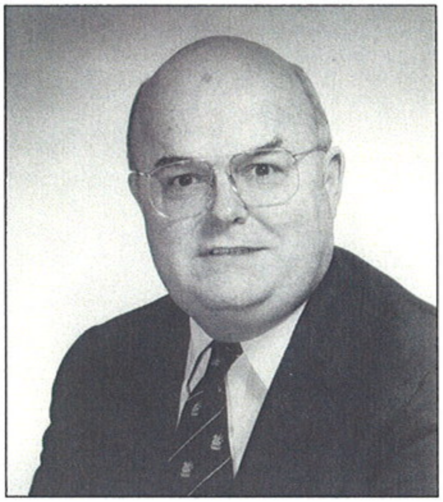
Inside This Issue



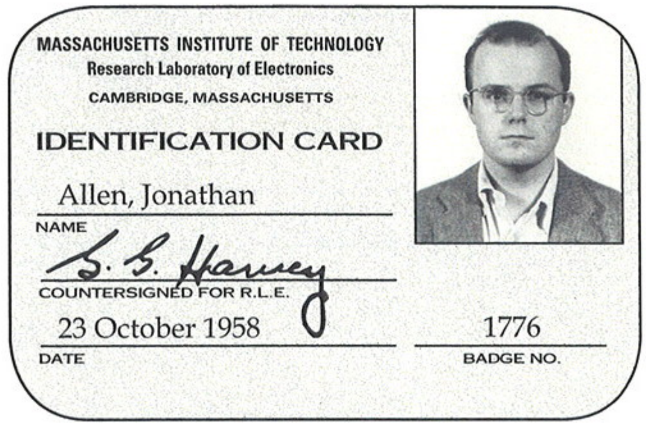
Professor Jonathan Allen, Director Research Laboratory of Electronics

one's own direction was evident. Not surprisingly, there was also a clear sense of self-confidence and a mature view toward success and failure. Our alumni company founders have a realistic view of their plans, a patience for results, and a determination to actually profit from the experience of failure. They are good judges of opportunity and how their skills relate to the needs of the economy. Many have also been fearless in penetrating foreign markets, sometimes while facing substantial resistance. Their confidence to succeed internationally, despite the difficulties of foreign trade barriers, is impressive.

They have high standards and only want to do the best by creating products and services that set the high-water mark in their industries. This strong personal sense of commitment, tenacity, and determination to set new standards is apparent in all our alumni who were interviewed. They are not content to design and build "just another product." They want to create and satisfy a need while delivering the best to their markets. With such top-notch products and services, they are confident in leading their particular industries, even in the face of challenging obstacles.

We often hear that engineers do not make good business people, but our alumni company founders have demonstrated their success as technical executives. Some have elected to emphasize technical activities and research while attracting other colleagues to manage their business; but they retain leadership and a sense of high-level direction that is crucial to their companies' success. They also have a strong commitment to people and have sought out others to complement their talents and perspectives.

While all successful companies contribute to the economy, many of our alumni company founders have made a direct contribution to society. Some have addressed the needs of the handicapped, while others have provided world leadership in environmental instrumentation. These interviews demonstrate the motivation provided by strong connections to individuals who benefit directly from the companies' products or services, as well as the commitment and satisfaction that these relationships foster in the companies' employees.



In many cases, academicians have formed their companies while maintaining strong ties to their universities. Some still teach, lead research, and contribute to major new educational initiatives. Among our alumni company founders, attitudes vary about the need for basic research. For some companies, it is crucial. For others, there is the expectation that new basic research will come from the universities rather than their own companies' laboratories.

It is heartening to know that several of these alumni see university research as an investment rather than an expense, even though it can take more than a decade to see it pay off. The new industries and employees spawned by this research pay back the cost of government's research sponsorship in the form of taxes and by creating new jobs. Indeed, there are often many spin-offs from the businesses formed by our alumni, and the entrepreneurial spirit shown by these companies provides the momentum for other businesses.

These alumni see people as the best way to realize technology transfer. They are quick to utilize outside experts in order to bring new ideas into their companies and to encourage their employees to form new enterprises from the parent company. Because of their background, many alumni have strong engineering departments in their companies and have fostered a sense of "intellectual turmoil" and openness to new ideas that challenge existing practices.

In their companies, an engineering style permeates the enterprise, from product development to technical marketing. There is a belief among these alumni that engineers can and should be central to understanding customer needs and that they can provide direction in highly innovative projects. These alumni are often multidisciplinary in

RLE currents

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The staff of *currents* would like to thank the RLE alumni who appear in this special issue for contributing their time and effort.

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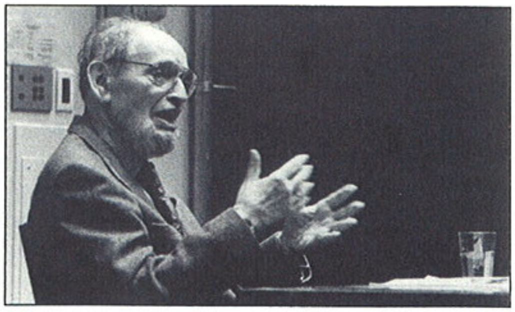
their approach. Many have taken the needs of their industries into academia in such a way as to put a necessary focus on research directions. One example is how the needs of human-machine interfaces have driven research in specialized circuit development, which is now thriving in universities.

Finally, our alumni company founders voice a great fondness for both the MIT and RLE cultures. They relish the atmosphere of bright, energetic students who are intensely involved with their research, often forsaking many nights of sleep to pursue their dreams. Not knowing what can't be done, they go ahead and do it. They have clearly carried that spirit with them when they left RLE and went on to build new enterprises in the same style that they had so much enjoyed.

In addition to the two special issues of ***RLE currents,*** we have also been busy planning for the laboratory's 50th anniversary celebration. On Friday, November 1 and Saturday, November 2, 1996, RLE will host a series of events that will examine our past, illustrate our current research activities, and explore our future. Guests and returning alumni will be welcomed by RLE's faculty, students, and staff at a laboratory-wide open house on Friday. In addition, a gala reception will be held on Friday evening to accompany the opening of a museum exhibit in MIT's Compton Gallery that will showcase 50 years of RLE's impact and innovation. On Saturday, following a reunion breakfast at the Faculty Club, where we hope to provide an opportunity for a remembrance of things past, a series of presentations on RLE's research will be given at MIT's new Tang Center. Saturday's technical program will be highlighted by both MIT President Charles Vest, who will speak on the relationship of research universities to contemporary society, and by well-known television series host and writer James Burke, who will trace the development of communications over the centuries, including recent contributions from RLE. The two-day celebration will conclude on Saturday evening with a jubilee dinner party.

RLE's 50th anniversary will be a wonderful opportunity to renew old friendships, to see how the laboratory has changed over the years, and to meet our faculty, staff, and students. The bright fall colors of New England also should provide a marvelous backdrop to our festivities. I know you will find our 50th anniversary event to be exciting as well as entertaining, and we look forward to seeing you here.

RECENT SYMPOSIUMS AT MIT

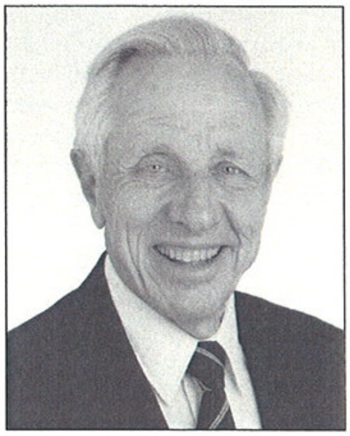


Above: An International Symposium on Physics of Laboratory and Space Plasmas was held at MIT in honor of Dr. Bruno Coppi, Professor of Physics, on January 19 and 20, 1995. During the proceedings, Professor Coppi (left) shares a personal moment with his mentor Professor Marshall N. Rosenbluth of the University of California at San Diego. The two scientists collaborated earlier in their careers at Princeton University and at General Atomics in San Diego. *(Photo by John F. Cook)*

Left: A symposium to commemorate the 100th anniversary of the birth of Professor Norbert Wiener was held at MIT from October 8 through 14, 1994. As part of the event, three speakers from RLE reflect on their experiences with the inimitable Professor Wiener (from top left): Professor Emeritus Jerome Y. Lettvin, Professor Amar G. Bose, and Institute Professor Walter A. Rosenblith. *(Photos by John F. Cook)*

JOHN G. LINVILL

Chairman of the Board, TeleSensory Corporation



John G. Linvill

John G. Linvill (SB '43, SM '45, ScD '49) is cofounder of TeleSensory Corporation of Mountain View, California. Dr. Linvill worked with Professor Ernst Guillemin in RLE and later served on the MIT faculty from 1949 to 1951. After four years on the technical staff at Bell Labs, he was appointed to the electrical engineering faculty at Stanford University in 1955. Dr. Linvill is the inventor of the Optacon reading system for the blind. The inspiration for his award-winning invention came from his daughter Candy, who is blind. In collaboration with Dr. James C. Bliss (PhD '61) at Stanford, their work on the Optacon resulted in the establishment of Telesensory Systems, Inc. (now TeleSensory Corporation) in 1970. Today, the Optacon is sold worldwide, and approximately 12,000 have been produced. Candy, who participated in the early experiments for the device, continues to rely on it in her work as a clinical psychologist.

At Stanford, Dr. Linvill has served as chairman of the Department of Electrical Engineering from 1964 to 1980, and associate dean of the School of Engineering from 1972 to 1980. He helped to establish Stanford's Center for Integrated Systems and served as its director from 1981 until his retirement in 1990. He is currently Canon USA Professor of Engineering Emeritus.

MEMORIES . . . As a farm boy in Missouri, I built model airplanes. By the time I was in high school, I wanted to be an aeronautical engineer. MIT was a mecca to my brother Bill (SM'45, ScD'49) and me, but we figured there was no way to get there from our graduating class of seventeen. We went to William Jewell College, a small liberal arts college near our home, where we studied math and physics. We didn't have undergraduate degrees when we applied to MIT for graduate school, but we did have good references. Karl Wildes and Bill Timbie decided we could make it in MIT's VI-A co-op program, and we started in 1941.

No one faculty member at MIT dominated the intellectual atmosphere. There was a collection of self-aspiring people to excellence. That's what made MIT interesting. I did my master's and doctoral theses with Ernst Guillemin, who was a superb teacher and mentor. He was self-directed and provincial to some degree. He'd say, "Why should I publish or present papers at meetings? I have the best students and I tell them about my new results in class." The Guillemaniacs, who were working on network theory, were probably in their ascendance then, but new ideas were emerging. Information theory was coming, and computers had just started. My brother worked on Project Whirlwind, and Guillemin was his advisor as well. The caricature, "Tech is hell," depicts bright students with great energy and little sleep who pursue topics of intense interest. The students are as important as the faculty in that environment. Everyone who goes through it is a different ingredient in the sauce that's splashed over everybody else.

MOTIVATION . . . In 1962, my family and I visited IBM's research lab near Stuttgart. We saw a high-speed printer driven against a fast-moving paper with carbon. It occurred to me that you could probably feel this. The fact was it could have drilled a hole in your hand. On the way back, I told my family, "I have a great idea to help Candy read." Our daughter Candy was blind and, ever since she was in kindergarten, my wife Marjorie had been her Braille teacher. She spent four hours a day preparing material for Candy, who went to regular school. I told Arnold Shostak at the Office of Naval Research about my idea. The navy had people working underwater, and tactile communication seemed like a reasonable thing to work on. That was the beginning of the Optacon, and Candy became its principal guinea pig. Today, she's a clinical psychologist.

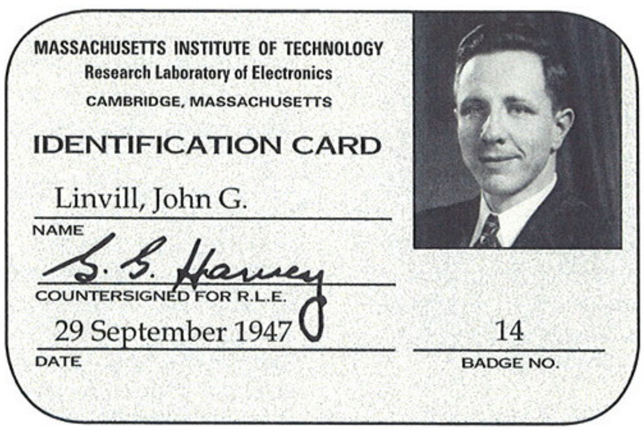
BEGINNINGS . . . Joel Moses has said that the Optacon put Stanford ahead in integrated circuits. At the time, it turned out that the integrated circuit problems were absolutely of the right scale for a university lab. In 1968, we made one of the first integrated circuits, a photosensor with an array of phototransistors on one chip. Jim Meindl, who set up our integrated circuit facility, decided we should have a back-up strategy to put all 144 phototransistors on one chip. The back-up was small chips with six transistors. To make the image sensor, twenty-four of these chips were bonded to a substrate in what was called a hybrid arrangement. Making connections in this arrangement proved to be a difficult task, but the 144-transistor chip was promptly successful.

About ten Optacons were made at Stanford and the Stanford Research Institute (SRI) for reading experiments. Then the United States Office of Education wanted fifty units for a field trial. Since Stanford and SRI weren't configured for such a task, Jim Bliss and I discussed manufacture with nearby companies. None were interested, so we set up a company to do it. That's how TeleSensory came into being in 1970. Its goal was to put into production what we had made one at a time. Jim Bliss recruited and developed a first-class set of people. Our ongoing connection with Stanford gave TeleSensory a good base to do that. There were four of us from Stanford—Jim Bliss, Jim Meindl, my doctoral student Steve Brugler, and myself. Jim Meindl and I remained at Stanford while Steve and Jim were full time at TeleSensory. For our first contract, we produced fifty Optacons for the Office of Education at $5,000 each. The Optacon was expensive, but it was worth more than it cost.

TeleSensory

CORPORATE CULTURE . . . TeleSensory made a strong commitment to people, particularly to blind persons. Many of them came to us as employees to develop training materials, and their contribution was unique and important. It's a powerful and rewarding experience to observe blind persons being able to independently read material with something you've produced. To engage in such a socially desirable enterprise and to do it in a financially sound way is doubly rewarding.

GROWTH . . . With the increases in both the population's longevity and the incidence of sight loss with aging, the low-vision population is growing more rapidly than the blind population. Consequently, TeleSensory's low-vision business is growing more rapidly than its blindness business. The rapid development of personal computers has strongly influenced sensory aids. About fifteen years ago, we produced a personal information system for blind users called VersaBraille. It had a Braille keyboard as the input port and a twenty-character line of refreshable Braille as the output port. Between these ports was a microprocessor, a magnetic tape cassette memory, and software to permit navigation through the text. The middle part was essentially what is found in personal computers. Now TeleSensory produces PowerBraille, in which a line of refreshable Braille is connected to any PC that runs DOS. Six keys on the keyboard now play the role of the Braille keyboard. The result is that the blind user has a more powerful and less expensive information system.



Computer-generated speech has also played an important role in sensory aids for the blind. TeleSensory entered this field with help from Professor Jonathan Allen at RLE in the late 1970s. Many applications, particularly those using PCs, are carried out more effectively with speech output rather than refreshable Braille output. Moreover, the coupling of scanners, recognition machines, and text-to-speech machines provides faster text-reading systems than the Optacon, although they're not as portable. Thus, newer machines and their combinations perform functions that earlier were only possible with the Optacon, and they perform them faster. Optacons are now used for tasks where portability and flexibility are needed, while faster equipment is used for other tasks.

ISSUES . . . The Optacon was the earliest in a series of technological products to help blind persons live in a sighted world, where the ultimate rehabilitation is competitive employment. The Sensory Access Foundation (SAF) of Palo Alto, organized by my wife Marjorie, has placed 1,200 blind and partially sighted persons in competitive employment. Convincing potential employers that a blind person will be a good and independent employee isn't simple. For several years, SAF did an annual return-on-investment analysis, where the investment is the cost of the equipment and placement services. The return is the income tax paid by the visually impaired person who is now employed, plus any diminution of subsistence that's no longer needed. Over the past several years, SAF placements paid off the investments in about a year. In addition, the social benefits to both the blind person and the community are great.

FUNDAMENTAL SCIENCE VS. ENGINEERING APPLICATIONS . . . Interesting applications are a fertile ground for doctoral dissertations, but I learned that the hard way. When one of my students did a magnificent engineer's thesis on the Optacon and wanted to continue with doctoral study, I didn't believe he could get a doctor's degree from something so simple-minded. I suggested that he look at problems related to semiconductor physics. Later, it became clear to me that we weren't going to get experimental instruments unless doctoral students were involved. So I had two students take problems related to the Optacon. The problems focused on optimum design. Why was it done that way and what were the fundamental physical limits? I told them that if it didn't work, don't worry. Just prove it's impossible; a sound conclusion in any of these cases would be an interesting contribution to knowledge. That process was so successful that thirteen dissertations came out of the Optacon project. Moreover, hands-on involvement with a working aid for the handicapped was attractive to the Optacon team.

TECHNOLOGY TRANSFER . . . I once talked to Robert Noyce about how to foster industry support for university research. He said Gresham's law also applies to industry's support of university research. As long as you can get something free from the government, Gresham's law says you'll never get it from industry. Cheap money always drives out dear money; that's Gresham's law. With constriction of government funding, "cheap" money from the government is disappearing, so academia must work with industry. Both sectors will be challenged to succeed in this changing environment, and a new openness will be required on both sides. Academia must provide services of value to industry. Industry must preserve features of the academic environment that are essential to its unique products. With understanding and imagination, new paradigms of cooperation attractive to both sectors will evolve, and we'll wonder why we didn't work them out long ago.

SIGNIFICANT ACHIEVEMENT . . . I've probably had more impact as chairman of Stanford's Department of Electrical Engineering than anything else I've done. There's an academic misperception about administrative roles – that they're dull and unrewarding. My administrative roles at Stanford and the personal contact with colleagues arising from them have been professionally and personally exciting and rewarding.

GEORGE N. HATSOPOULOS

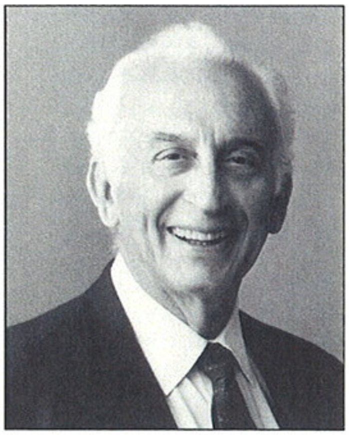
Chairman and President, Thermo Electron Corporation

George N. Hatsopoulos (SB '49, SM '51, ScD '56) is founder, chairman, and president of Thermo Electron Corporation of Waltham, Massachusetts. Since its founding in 1956, Thermo Electron has become a world leader in environmental monitoring and analysis equipment. The company's fourteen publicly traded subsidiaries have earned Thermo Electron a reputation for employee entrepreneurship. These technology-based enterprises address many societal issues including environmental quality, health, and safety.

A native of Athens, Greece, Dr. Hatsopoulos served on the MIT faculty from 1956 to 1962. During the early 1960s, Dr. Hatsopoulos contributed research to RLE's Plasma Magnetohydrodynamics and Energy Conversion Group. He was appointed MIT's first senior lecturer from 1964 to 1990. His association continues with MIT as a member of the corporation.

MOTIVATION . . . I knew what I wanted to do when I was in grammar school. I was going to become an engineer, teach, and form a technology-oriented company. There were several uncles in my family who had succeeded in academia. One was the president of Athens Polytechnic, the most prestigious university in Greece. Two or three were also well-known scientists. The whole family was proud of them, and I wanted to emulate them. One thing that struck me was that several of them had tried business and failed. I had also read that when my idol Thomas Edison founded General Electric, he lost control of the company after several years. He didn't make a lot of money, but he was world-famous for his inventions. From all this, I thought that a good technologist could not be a good business executive. So my uncles and Edison gave me the incentive to think that maybe I could do better.

MEMORIES . . . At the end of my third year at Athens Polytechnic, I was offered a scholarship to MIT and came as a transfer student in 1948. When I started my thesis, I had one purpose in mind; namely to start a company. My thesis topic was selected in an unconventional way. Usually you go to your thesis advisor with several topics and ask which is more appropriate. Instead, I went to venture capitalists and asked which topic was more likely to attract venture capital. I did my thesis on thermionic emission, and the only facilities at MIT for that were located in RLE. Jerry Wiesner was also a friend of my thesis advisor Professor Joseph Kaye in the Department of Mechanical Engineering. There was a thermoelectrics group headed by Dave White, and Herb Woodson eventually split off from that group to work on hydrodynamics. I worked on thermionic conversion in his group. My work on magnetohydrodynamics appeared in the *RLE Quarterly Progress Reports*. At that time, there was a tremendous aura of success and new high-tech companies were springing out of MIT. My environment at MIT was fertile enough to do what I wanted to do, which was to build an enterprise, and the institute was very supportive.



George N. Hatsopoulos
(Photo courtesy Thermo Electron)

When I founded Thermo Electron, MIT turned over our jointly owned patents so I could use them in my company.

GOALS . . . I started Thermo Electron with a specific invention that I had made. Although one of my goals was to make my invention successful and to improve the way electricity was generated, my ambition was broader than that. My goal was not to create a company in any specific field, but to have a collection of outstanding engineers and scientists and to see what was needed in society. I believed then, as I do now, that technology is a major tool that can be used to solve social problems. My ambition has always been to form a company that would continue to address society's needs through technical solutions. That's Thermo Electron's major focus, and it helps everybody. It's also good business practice. It's good for our stockholders, not only because they're more likely to be successful financially, but also because they take pride in having the company do something useful. Our employees take pride in that as well.

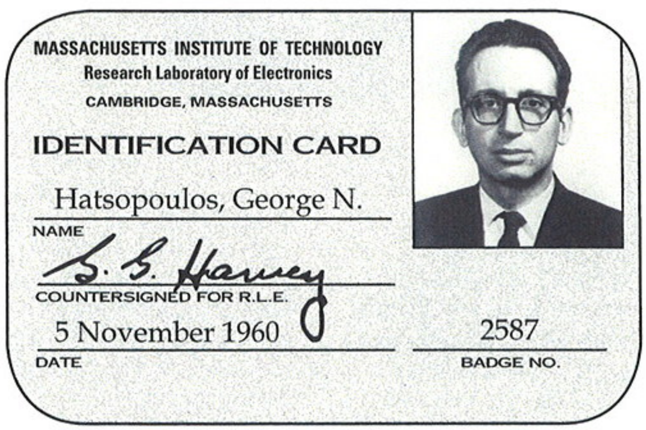
FIRSTS . . . Some of our firsts didn't go anywhere, although they made a lot of splash. Thermo Electron was first to produce electricity from heat by using electron evaporation from a surface. Eventually that made a lot of splash. But it wasn't useful for terrestrial applications, and since the space program hasn't gone anywhere, it hasn't found much use. That was an unsuccessful first, but some of our other firsts were successful and more interesting. We introduced the first instrument using chemiluminescence. It essentially replaced wet chemistry to detect air and water pollution. Now it's used to measure oxides of nitrogen and sulfur in the atmosphere and other pollutants. As a result of that, we've become the biggest environmental instrument company in the world. We also introduced an instrument to measure explosives. It's used in Europe to prevent terrorism, primarily in airports, and in the Chunnel tunnel. Unfortunately, it's not used much in the United States because nobody wants to pay for it. One of our most intriguing firsts is our mechanical heart, which has received FDA approval. We've also had firsts of a more cosmetic nature, including a new laser method to remove unwanted hair.

Thermo Electron

SUCCESS . . . Thermo Electron's success has been in the area of new ventures. One type of new venture is technology initiated. For example, my initial invention used a new phenomenon and I tried to find applications for it. A second type of new venture is market initiated. During the oil embargo in 1973, there was a need to improve energy efficiency and that indicated a market-oriented venture. For the last thirty-eight years, statistics have shown the chances for a technology-initiated venture to succeed are less likely than for a market-initiated venture. So my advice to entrepreneurs is that they should start with a problem, not with a solution.

HALLMARKS . . . Thermo Electron differs from other technology companies because we are very diversified. We're in all sorts of fields and we provide all sorts of services, from the medical to the instrumentation fields. No other company is so diversified, even companies like General Electric, and we're much smaller. Our philosophy is that we can get into any business where there is an enormous need and we have a solution. We don't say, "We can't do this because we're not in this business." We have several thousand very bright engineers and scientists like other companies, but the difference is we have more entrepreneurs. We cultivate this by creating an environment to attract, develop, and promote entrepreneurship. Few of our competitors do that. We also charge more for our products because they're better than our competitors. People buy our products; sometimes at a significantly higher cost. However, our production costs are many times less than our competitors. So our prices are higher and our costs are lower. Therefore, our profitability is greater than our competitors.

CORPORATE CULTURE . . . Entrepreneurship is the main theme of Thermo Electron's corporate culture, but there's more to it. Everybody supports each other, and no backbiting is permitted. People can make out well financially and professionally without building empires. There's also tremendous freedom in transferring information, and everybody is asked their opinion. We don't follow everybody's opinion, but we do listen.



ISSUES . . . The biggest issue facing Thermo Electron is preserving our culture while the company grows. We have 15,000 people, and the company's sales are growing at the rate of more than 20 percent a year.

PRODUCTIVITY . . . The only way you can measure productivity is to compare your costs to your competitors' costs. In everything we make there is competition. We're more productive than our competitors for two reasons. Our people are very productive in terms of output per hour. However, our biggest advantage is that our overhead and general administrative expenses are lower when compared to our competitors. This is because we don't waste time with costly procedures. Every company has procedures that are costly and instead of helping productivity they hinder it. This means we can take more of a risk while other companies have costly procedures and forms in order to minimize their risk.

FOREIGN COMPETITION . . . We've never had problems competing with foreign companies. We compete with foreign companies in their own countries, and they go to great lengths through regulation to prevent us from doing that. There's protectionism everywhere in the world, even in this country, but nothing like it is in Japan. Every inefficient industry wants protection, but that's bad for the world's standard of living.

TECHNOLOGY TRANSFER . . . It's rare that technology transfer occurs without people. When we employ faculty as consultants, technology transfer is going on there. When people from MIT set up a company, that's technology transfer. But if somebody at MIT tells me about an interesting idea, and I try to persuade our lab to buy that idea, I find resistance because it wasn't their idea. Usually, I hire the person with that idea to work as a consultant with our people. That's when technology transfer happens. I also take students who have worked on their research with me and hire them.

REWARDS . . . My job has been different every year for the past thirty-eight years. I love the fact that I deal with different problems that make me study something else. One year I may study accounting, and another year I may study economics or law. The advantage of being a CEO at a substantial company is that I can have the best private teachers. I might want to learn law because we have a difficult legal problem, and I have the best lawyer. I can spend time with the lawyer and ask questions, and then I can learn law. It's a fantastic luxury. Every year I learn more things, but I never learn them in isolation. I want to learn them as they relate to a particular problem.

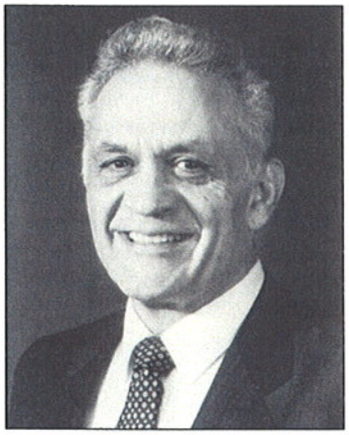
CHALLENGES . . . We have a tremendously capable staff. They're getting older now, along with me, and eventually we'll have to replace them. It's difficult to find people with the right combination of intelligence, expertise, passion, and people skills. When we built Thermo Electron, after a lot of trial and error, we found exceptional people who could command these attributes. You can always find brilliant physicists who are terrible in human relations, or they might not be interested in entrepreneurship. You can also find capable people who have two of those attributes I mentioned, but don't have the vision. Brilliant entrepreneurs who are also good engineers and scientists are difficult to come by.

DANGER IN SUCCESS . . . Some CEOs take one thing with enormous potential and ride that horse. They don't have a chance to fail, and that can be a great weakness. Thermo Electron has had failures from the beginning. We tried one thing and it didn't work, so we tried something else. Because of the proliferation of our activities there have been some successes, but while those were riding, we tried something else and failed. You must have some failures, otherwise you lose your sense of reality. We've been fortunate that we've had both failures and successes.

Amar G. Bose

Chairman, Bose Corporation

Amar G. Bose (SB/SM '52, ScD '56) is founder, technical director, and chairman of Bose® Corporation of Framingham, Massachusetts. Dr. Bose joined RLE in 1953 and worked with Professors Yuk Wing Lee and Norbert Wiener on statistical communication theory. In 1956, Dr. Bose began research in physical acoustics and psychoacoustics. His research and patents in acoustics, electronics, nonlinear systems' and communication theory led to the formation of Bose Corporation in 1964. Today Bose designs and manufactures high-quality audio products for consumer and professional use, and conducts research in several fields. As a result of developing a strong research team, Bose is the leader in creating sound systems that approach the realism of live performances. In addition to his work at Bose Corporation, Dr. Bose has served on the MIT faculty since 1957.



Amar G. Bose
(Photo courtesy Bose Corporation)

Memories . . . I joined RLE as a research assistant with Professor Ernst Guillemin in 1953. However, in the fall, Professor Wiesner insisted that I work on some ideas Norbert Wiener had which Wiesner felt were applicable to electrical engineering. Even with a minor in math, I didn't have the slightest idea about Wiener's mathematics. Professor Yuk Wing Lee, the project's supervisor, gave me Professor Wiener's notes and instructed me to read them. I couldn't make head or tail of them. In February, Lee said there was going to be a mathematics conference at MIT in June. I was to speak on Wiener's theory! Two weeks before the conference, everything suddenly became clear. I was scared because it was my first talk, and everyone at the conference was a renowned mathematician. It went well until Wiener raised his hand. I answered his question incorrectly, and calmly he repeated the question. Fortunately this time, I was able to answer correctly. Following the conference, we developed a close relationship and met in my office at RLE almost daily for the next ten years.

After my thesis exam, Jerry Wiesner asked about my plans and if I was interested in teaching. I told him that I was recruiting for a research position in industry which I intended to pursue after spending a year in India on a Fulbright fellowship. I explained that I had no interest in teaching. Jerry offered to bypass the teaching assistant and instructor positions. He asked if I would be interested in joining the faculty directly. I thanked him, but declined. After his kind offer, I decided it might be appropriate to ask for something I really wanted.

I had recently purchased a hi-fi loudspeaker based upon what I thought were meaningful specifications. My engineering knowledge told me the specifications were good, but my musical training told me the performance was not. I asked Jerry if I could stay at MIT over the summer without pay and use RLE's equipment and anechoic chamber to resolve my dilemma before leaving for India in September. He agreed. That summer, I arranged with Radio Shack to borrow all the brands of speakers they carried at that time. I wanted to measure them for my own knowledge, and I offered them a copy of the measurements in return. I didn't know it at the time, but those measurements became the basis for their Realistic speaker line.

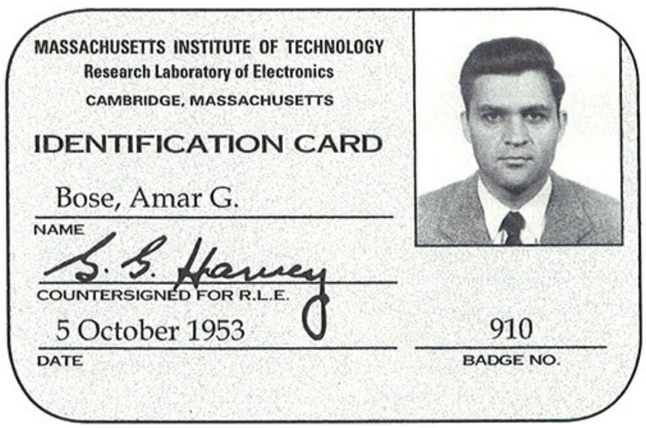
Two weeks before leaving for India, I was swimming in the MIT pool when a colleague informed me that the fall catalogue listed me on the faculty with a one-year leave of absence. Before leaving the building, I decided that I probably wouldn't lose all my research ability if I taught for just two years upon my return from India. During the next year, I taught statistical communication theory at the National Physical Laboratory in Delhi, India. In the evenings, I read acoustics books since my experiment from the previous summer didn't resolve my problem, and I had never taken an acoustics course. When I returned to MIT in 1957, my first teaching assignment was in electromagnetic field theory.

In 1959, we started an experiment in RLE to determine if the many cone resonances of closely coupled loudspeakers produced audible sound coloration. We compared an array of twenty-two closely coupled loudspeakers on an eighth of a sphere mounted in the corner of a room to a similarly mounted ideal pulsating eighth of a sphere. Although the latter can't be constructed, its impulse response through the room to a microphone can be determined. It is the integral of the response to an electrical spark discharge at the apex of a room's corner. The experiment took four years to complete because there were many obstacles. Tom Stockham convolved the impulse response with musical signals into the TX-2 computer at Lincoln Lab, where he made the first digital recordings of high-fidelity sound. Over four years, he reduced the computation time from twenty hours per second of music to seven minutes per second. This was the basis of his contributions to digital signal processing and fast Fourier transforms.

Beginnings . . . By 1963, I had several patents in electronics and power processing, amplification through switching techniques, and acoustics. MIT gave me the patents, and I tried unsuccessfully to license them. One day, Yuk Wing Lee called me into his office and wanted to tell me of his experiences during World War II. I didn't know why he wanted to do this, but he always made his point by describing a situation and then allowing the student to draw his or her own conclusion. He said that he had returned to China in 1929 after receiving his doctorate at MIT. He was teaching in Peking, and in 1939 he sensed the impending war and decided to return to the United States. He arrived in Shanghai three days before the scheduled ship, but the Japanese arrived the next day. In order to survive, he became a curio dealer. He then explained the dream of curio dealers: One day, an object of value would come into their hands, that they would recognize it, and not let it pass through their fingers. At that point, he thanked me for coming to his office. After I left, I realized he was telling me that my patents were such objects of value; that I shouldn't let them slip away through licensing, but that I should form a company.

In the spring of 1964, I started meeting once a month with Professor Lee, my college roommate Chuck Hieken (SB/SM'51), and Sherwin Greenblatt (SB'62, SM'64), a master's student in electronics. None of us knew anything about business, and we were not particularly interested in the aspects of a corporation. However, our meetings resulted in the formation of Bose Corporation in August 1964. When Dr. Wiesner and RLE's business manager Ralph Sayers learned we were hunting for a building, they offered us the use of RLE's facilities for the company's work on an honor system until we found a proper location. Bose Corporation actually existed in RLE through November 1964.

In 1965, we realized that in order to produce a superior loudspeaker we needed a better understanding of the recording process. To this end, we spent two years recording the Boston Symphony and Boston Pops orchestras. In 1967, we produced a speaker that was an eighth of a sphere with a power amplifier and equalization located inside. It was very advanced for its time, but it required two unobstructed corners in a room. Despite a marketing survey that said we would sell a million dollars of these speakers in the first year, we made sixty units and sold only forty. We realized that we needed to design something more practical that still used the technology we had developed to produce better sound. We did just that, and the result was the model 901® loudspeaker.



HALLMARKS . . . When we formed Bose, there were about 450 companies in our field, but they did virtually no research. Our interest was the research, and we believed that would be a reason for us to succeed. We didn't know anything about business or production, but research was to be our distinguishing factor.

GROWTH . . . Our largest area of growth has been in consumer products such as complete hi-fi systems. Our original equipment manufacturing business for automobiles and our professional sound business are also growing. We found that it's possible to produce better sound in an automobile than in the average home. In the home, there are three factors that we can't control which have a significant impact on the perceived quality of sound. They are the acoustics of a room, the location of loudspeakers, and where a listener sits. In automobiles, these factors are known, and we can design for them.

We're also doing fundamental research on automobile suspensions. A car that is smooth over bumps can generally roll and pitch. If it has good roadability, you need a chiropractor in the back seat. Searching for a theoretical limit on performance, I spent five years on purely mathematical analysis. In 1985, we began work on the hardware. We now have the first car. It's not completely outfitted with its algorithms yet, but it's quite promising.

Our new instrument called Auditioner® can let one experience the actual sound in a building or public space during its architectural design stage. The architect gives us the blueprints and tells us what materials will be used. If it's an auditorium, you can select a specific seat and hear the sound that will exist when the building is constructed. When the building is completed, we put the Auditioner in the seat you originally specified. You can then compare the sound it produced to the actual sound. It will switch between the two, and it's so accurate that you probably won't be able to hear the difference. With the Auditioner, if we don't like the sound, the designer can change it with a pencil and paper instead of concrete and steel. There's no longer an excuse for designing poor acoustics or installing poor sound systems.

SUCCESS . . . The key is having the nucleus of a company that's competent in its profession and has high integrity. Without character and integrity, you can make a lot of money, but I don't think you can be proud of it. People will tell you that I impose extremely high standards, not only for them, but for myself as well. No matter how well we're doing today, we must do better tomorrow.

UNIVERSITY-INDUSTRY RELATIONS . . . Most of Bose's educational activities are with MIT. We give awards to senior MIT professors and support research and students. But our support isn't just financial. There's also interaction between our engineers and MIT students. I've observed the excitement resulting from this on both sides. In fact, Al Oppenheim's group at RLE gets together regularly with Bose engineers to discuss research.

MIT will have to persuade industry that their future depends on research. Industry can supply the funds to do challenging projects, but they will require that certain information remain proprietary, and they want the patents that arise from the work. Universities will have to compromise when industry sponsors research. When they get funding on that basis, universities will be able to do great things and students will be highly motivated.

ETC. . . . Every September when I start teaching, I wonder how I'm going to get through everything on my agenda. By December, when I see my students' faces and their ability and enthusiasm, I say to myself, "C'mon, we're gonna do it for another year." I've been saying that for thirty-eight years.

L. Dennis Shapiro

Chairman, Lifeline Systems, Inc.

L. Dennis Shapiro
(Photo courtesy Lifeline Systems)

L. Dennis Shapiro (SB '55, SM '57) is chairman of Lifeline Systems, Inc., of Cambridge, Massachusetts. Mr. Shapiro worked with Professor Elie Baghdady in RLE from 1955 to 1957. In 1960, he founded Aerospace Research (later renamed Aritech), a manufacturer of ultrasonic intrusion detection equipment and a distributor of alarm products. Aritech was sold to ADT Company in 1975. In 1978, he left ADT and joined Lifeline Systems as CEO.

Lifeline Systems designs, manufactures, and markets personal response products. It also provides monitoring and other services associated with those products. Through its central monitoring facility, the company provides twenty-four-hour monitoring to its subscribers, who are primarily elderly individuals with medical or age-related conditions, as well as physically challenged individuals. Subscribers communicate with Lifeline® primarily through a personal help button worn by the subscriber and a communicator that connects to the telephone line in the subscriber's home. The communicator becomes a speakerphone when activated by the help button, enabling the Lifeline monitor to speak to and hear the subscriber.

Lifeline was founded in 1974 by Drs. Andrew and Susan Dibner to address the important human needs of elderly and disabled people who want to live an independent lifestyle. The company works with the healthcare industry to pioneer personal response services as an effective and cost-efficient option. Lifeline's network includes hospitals, physicians, community agencies, American Red Cross chapters, and other organizations that sponsor or serve as referral sources to locally managed Lifeline programs across the United States and Canada.

MEMORIES . . . I came to MIT as a freshman in 1951 and stayed on for my master's degree. In those days, RLE was synonymous with Building 20. It was a good place to work, study, and talk to people. The building had a life of its own, and it went on twenty-four hours a day. I was a teaching assistant in Ernie Guillemin's 6.01 course and taught measurement lab sections for Tom Jones' course. I was interested in radio and communications, which wasn't a hot topic at the time. More people were involved with the digital revolution. Transistors were also coming into the mainstream, so people were becoming interested in solid state and things other than point-to-point radio transmission. Elie Baghdady was my master's thesis advisor. My thesis tested and measured the use of positive feedback in FM receiver limiters to improve the capture-effect capability of FM. It actually worked, and it seemed useful, but no one ever knocked on my door wanting to put it in FM car radios.

BEGINNINGS . . . After graduating from MIT, I became a research and development officer in the air force. It was an exciting time, especially in radio and propagation because 1957 through 1959 was the International Geophysical Year. I was originally assigned to the laboratories at Hanscom Field. Later, I was selected as a member of the International Geophysical Year team. That sounded fine until they told me that I was to be based in Thule, Greenland. I decided if I were going to be in Greenland for a year, I might as well work at enjoying it, and it was truly a fascinating experience. I set up an experimental measurements laboratory for ionospheric physics that involved research on the aurora borealis, cosmic rays, radio propagation, and ionospheric absorption. We were near the geomagnetic pole, and it was a great opportunity to learn how all of these phenomena interacted. In 1958, I was sent to Hawaii to set up radio links for high-altitude nuclear tests that I monitored from Johnston Island. Those were the first nuclear explosions in the ionosphere. We found that when we fiddled around with the ionosphere like that, high-frequency propagation, which the Strategic Air Command relied upon, disappeared.

I briefly worked for a small company after the air force, then started my own company called Aerospace Research. We did field measurements and built prototypes chiefly connected to radio propagation studies, but we didn't have a major product. I became interested in very precise timing using LORAN-C transmissions. We developed equipment to synchronize clocks using LORAN-C and won the main contract with NASA to use it for synchronizing their tracking stations. Our other work continued what I had been doing in the air force with monitoring nuclear and ionospheric effects. We became involved with radar and signal processing when Aaron Galvin (SB/SM '55) joined us from Lincoln Lab. We worked for various government agencies on radar signal processing, particularly adaptive processing using directionally sensitive Doppler techniques and selective and variable analog filters. Our goal was to maximize the ability to detect a target through foliage under varying wind conditions.

After Vietnam was settled politically, we took radar signal processing technology and began making very low false-alarm-rate intrusion detectors for the alarm industry. Our products were well accepted, and we did business with the best and largest alarm companies. One of them was ADT, which acquired us in 1975. In 1978, I left ADT after having been a vice president and director of the parent company, as well as president of the Aritech subsidiary.

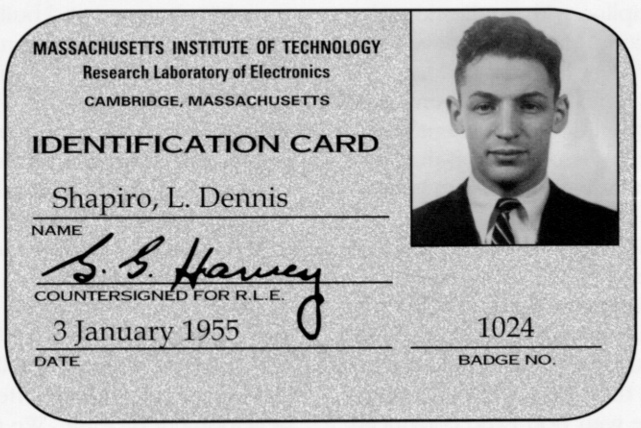
LIFELINE®

NEW DIRECTIONS . . . I was introduced to the founder of a small company called Lifeline. They had no full-time employees, but were doing innovative R&D on the efficacy of personal response systems and people's needs for short- and long-term care. They found that personal response systems delayed the need for long-term care, and the period of long-term care would likely be shortened as well. I thought this was important new research and something you could build a company on. So I invested in Lifeline and joined the company as CEO.

MISSION . . . Lifeline's mission is to provide a unique, quality service that will help elderly and disabled people to continue to live independently in their own homes. By providing this service to this fastest growing segment of the population, we can create value for our subscribers, our employees, and our shareholders.

MARKETS . . . Initially we marketed Lifeline through hospitals. We undertook what I thought would be not a simple but a doable task. After overcoming considerable reluctance at the beginning, we succeeded in signing up more than 2,000 hospitals across the United States and Canada. As the company was developing, we provided equipment to hospitals to monitor their own subscribers. In the late 1980s, we established our own twenty-four-hour monitoring station, Lifeline Central.™ It currently monitors over 125,000 subscribers as a service to many of our local providers and provides us with an important recurring revenue.

Over the years, we've explored additional ways to market Lifeline. For a while, we had a retail program called AT&T Lifeline, which was sold at AT&T stores. We also tried selling in department stores across the country, but retail sales were not successful. We currently have a national program in which local Red Cross chapters can become Lifeline providers. We do the monitoring, and when our monitors answer a help call, they identify as "Red Cross Lifeline." We've found that the best way for Lifeline to be accepted is through personal or professional referrals. So we concentrate on providing information on our services to doctors, nurses, and social service people.



HALLMARKS . . . Lifeline is a quality product that's well known and recognized in the healthcare field. We're the leader in terms of sales volume, the number of subscribers, and the quality and capability of our product. We are the standard for comparison. When people talk about our type of service, they call it a "lifeline," whether it's ours or somebody else's. We're concerned that our registered trademark will become generic. Our people also enjoy growing with a top-quality company. We take pride in the quality and success of Lifeline, and the industry recognizes this. We received national recognition for our pioneering work when Lifeline's founders received a commendation from the Charles Dana Foundation in 1986. The company was also awarded the 1991 Shingo Prize for excellence in manufacturing.

INNOVATION . . . In the early 1980s, we developed equipment for sending information on pulse rate, electrocardiogram, and blood pressure from the home to the monitor. We found that there wasn't an urgent need for it in the medical community, and third parties weren't willing to pay for it. We continued to look into other applications for our product and services that people would find useful. One idea that enhanced our product is the use of the Lifeline button to put any incoming call automatically on the speakerphone. The subscriber can then talk without having to pick up the receiver. Another innovation is our voice-assist feature to enhance user friendliness. We're looking for more ideas along those lines. Digital signal processing is an area we're investigating to see if we can improve the clarity of our subscribers' voices at Lifeline Central. The ability of our central monitoring station to provide the best service is a function of how well our monitors can hear the subscriber at the other end through the speakerphone.

We want Lifeline to be something that the elderly seek out for themselves, rather than having them go through the process of being referred to us by a healthcare provider. If we can make the Lifeline unit more useful in an everyday way, this will happen.

The company also supports an active patent program to encourage innovation. I enjoy participating in that and continue to be an inventor. The most recent patent issued to me was written up in the *New York Times* "Patent" column in May 1995.

ISSUES . . . We see Lifeline continuing to grow at a greater than normal rate for companies. We think we're good at managing this growth and, under CEO Ron Feinstein, we have the right team in place to do it. In the area of growth, we stick to what we do best and have made two successful acquisitions of companies in our field.

LIMITATIONS . . . Technology continues to race ahead giving us expanded opportunities. We used to kid about a global positioning system on a chip that could enable a wide-ranging service rather than one tied to our home communicator unit.

REWARDS . . . When I left ADT, there was no question that I would go into business again, and Lifeline was a fortunate choice. It's rewarding to see a company form and become valuable. For me, as an engineer, it's especially rewarding to be able to invent and innovate and continue to contribute to the company's product area. And with Lifeline and its services geared to improving the quality of life for our subscribers, it's rewarding for its employees and shareholders to do good and do well at the same time.

Irwin M. Jacobs

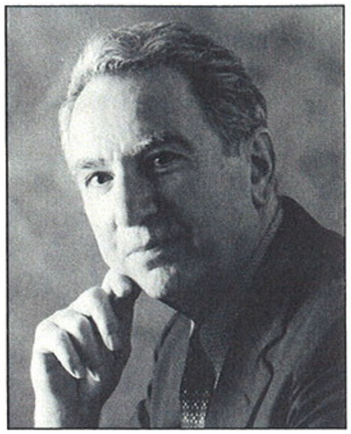
Chairman and CEO, Qualcomm, Inc.

Irwin M. Jacobs (SM '57, ScD '59) was a student in RLE's Statistical Communication Theory Group in the mid-1950s and was affiliated with the laboratory as a faculty member in the early 1960s. He left to join the faculty at the University of California at San Diego in 1966 and cofounded Linkabit Corporation in 1968. Following Linkabit's sale in 1980 to M/A-COM, Inc., Dr. Jacobs remained with the company until 1985. He then established Qualcomm, Inc., where today he is chairman and CEO. Qualcomm, headquartered in San Diego, develops and manufactures advanced communication systems and products based on its proprietary wireless digital technologies. A graduate of Cornell University (BEE '56), Dr. Jacobs holds eight patents for innovations in wireless digital communication through Qualcomm.

Memories . . . It was an exciting time to be involved with information theory and communication theory at MIT. At first, everybody saw information theory as exciting mathematics. Then it gradually changed to a discipline with applications that are central to practical communications. Many early developments occurred at RLE. The people were first rate and the bureaucracy was minimal. RLE was a model for what enlightened government support of research and development can do in the university. It had so much more of a payoff than its investment; more than the government realized. It's an ideal way to support university research.

I took a course with Norbert Wiener, which was an education in its own right. I also took a probability course with Stanislaus Ulam, who was visiting from Los Alamos and explained probability theory in an intuitive fashion. The mathematics may be complicated, but you have to find an intuitive way to think about it. I've followed that approach to life ever since. My information theory course with Bob Fano convinced me to remain with information theory for my career. In my life, MIT has been the basis for much success and satisfaction. It was not only a solid education, but it was also a legacy of rewards for hard work and the excitement of finding clever solutions.

Beginnings . . . In 1964, I took a leave of absence from teaching at MIT to visit California. I discovered San Diego and thought it was a nice location. After I returned, Henry Booker was moving from Cornell to the University of California at San Diego to start the applied electrophysics department. He called to invite me to come along. It was difficult to leave MIT, but it was exciting to think about a new university and the opportunities there. Once in San Diego, I received more consulting requests than I could handle, so I suggested to Professors Andy Viterbi and Len Kleinrock (both then at UCLA) that we form a company and pool our consulting. We started Linkabit as a day-a-week consulting business without plans to grow it very far. After several months, Len moved on to other activities, but Andy and I continued with Linkabit and we hired



Irwin M. Jacobs
(Photo courtesy Qualcomm, Inc.)

our first full-time employee. I took a leave of absence from teaching in 1971 to spend a year getting the company organized. It was so much fun that I became an academic dropout.

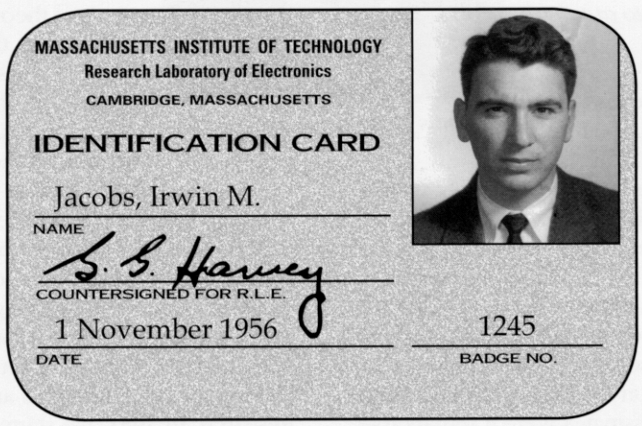
Goals . . . Linkabit started in the information theory coding-decoding arena, but quickly moved to satellite communications and time-division multiple access (TDMA) systems. Early on, when we worked with IBM on a request for proposals, we thought of using multiple distributed small computers to implement a satellite system. IBM wanted to use only one computer. Although microprocessors didn't exist yet, it made sense to do the various distributed tasks with different processors. We finally found a successful application for this when we were awarded an air force contract. We designed and built perhaps one of the first reduced instruction set computer processors. It was a four-stack machine with a thirty-two-instruction set that went into a dual-modem satellite terminal. It was a development program, but it was so successful that we beat the competition and went into production. It's still in production today for strategic military communications. That got things off and running.

Linkabit went from research development and consulting, to development, and then into systems and building equipment. We became involved with NASA's program in digital television compression and transmission. Later, we turned that work into our VideoCipher™ product, which was a commercial system for C-band satellite television direct broadcast. We continued to introduce different ideas and products into our development pipeline. We moved quickly from development to manufacture so we'd have a good spot in the marketplace. Linkabit was sold to M/A-COM, and Andy and I left in 1985.

Firsts . . . Linkabit developed the first satellite terminal where all the communication signal processing was done by a microprocessor. We built it from components since single-chip processors weren't available yet. The Viterbi decoder that we implemented with VLSI circuitry and applied to military systems was also a first. The VideoCipher was the first system to provide a reasonable level of security for satellite television transmission. There, we made a commercial product by using early silicon compiler software that came from universities or was home grown. We were experimenting with this technology, when suddenly we had to apply it in order to rapidly produce several chips successfully for a cost-reduced VideoCipher for consumer use. Another first was an encrypted high-capacity TDMA satellite communication system. We also developed the first commercial wireless-loop TDMA telephone.

NEW DIRECTIONS . . . We formed Qualcomm in July 1985, and focused on digital wireless communications. Our first product, OmniTRACS, was a two-way satellite messaging and position determination system used largely for trucking. The key was to apply existing satellites designed for fixed applications to mobile applications. So we needed a modulation/coding system that wouldn't interfere with the fixed users. We developed a reliable hybrid spread-spectrum terminal and an innovative Ku-band antenna to track the satellite using only the communication signal. OmniTRACS gave us an edge in the mobile communication systems for trucking. We're also developing a low-earth-orbit satellite system called GlobalStar. This includes portable equipment and fixed terminals for its users as well as the gateway equipment to communicate with the satellites and connect them to the public network.

HALLMARKS . . . Qualcomm is known for its work on code-division multiple access (CDMA) for cellular, personal communications, and wireless local loop. Using CDMA, we can take advantage of a mobile user listening or pausing between thoughts or syllables to get higher capacity. CDMA is now standardized and many cellular and PCS (personal communication system) operators in the United States, Hong Kong, Korea, and elsewhere are operating or planning to operate CDMA systems.



SUCCESS . . . Qualcomm has a strong engineering department that's 40 to 45 percent of the company. We try to select good people and support them with good equipment. As a result, we can come up with ideas and get them to market quickly. We always try to take development into manufacture, so that we can obtain growing revenues from our technical efforts. We also try to stay open to new ideas and to keep an intellectual turmoil ongoing in the business by bringing in outside lecturers and faculty who are on sabbatics.

GROWTH . . . Our fastest area of growth is CDMA since both cellular and PCS will be greatly expanded over the next few years. Also, the wireless local loop business that permits basic telephone service to be provided to emerging countries will probably become larger than the mobile business. We're working hard to develop new products, license manufacturers, and to develop integrated circuits in order to make these products less expensive. Our OmniTRACS business continues to grow rapidly, and we're trying to further internationalize it.

CONTRIBUTIONS . . . Developing countries can't attain a good economic base without a good communications infrastructure. Our CDMA technology will allow that infrastructure to be put in place more rapidly at a lower cost. On a more local scale, we encourage our employees to be useful in the community, and we make contributions to education as well as cultural activities. A few years ago, we encouraged the University of California at San Diego to begin a wireless communications institute. We thought it would not only train students in an area with growth potential, but also bring together different disciplines in interesting academic research programs. Qualcomm and several other companies have provided support, and we're looking for good things to come from that effort. Forming two successful companies has demonstrated the value of an engineering education and an engineering approach to entrepreneurship and has had a major impact on our local community. Over twenty spin-offs from Linkabit now make San Diego a major telecommunications center.

FOREIGN COMPETITION . . . Our offices around the world try to influence local governments to use our technology. If you're not active internationally, then your foreign competition will use their home base to build an advantage and come into the United States. International business is a great opportunity, but we must put a lot of resources into it to overcome the advantages foreign corporations enjoy.

FUTURE . . . The analog to digital transition is the basis for our business, and we see that accelerating. We see a large expansion of fixed fiber-based systems with packet switching to provide greater international capabilities for communications. For many applications, access will be wireless. So we'll want to have this tremendous capability interconnected by fiber and the ability to access parts of it with intelligent terminals through wireless technology.

REWARDS . . . It's exciting to see an idea become a useful product. I remember coming up with the idea of applying CDMA to wireless voice communications. It's been a long, difficult development—technically, politically, and economically—but the rewards have been substantial. On a day-to-day basis, the ability to interact with employees is exciting. I try to reserve part of my day for talking with people and getting their point of view; where they're having problems and where I can help. I also enjoy the technical marketing side, which involves interacting with customers and understanding their problems. I suggest solutions using our products, and that in turn makes us think about new products.

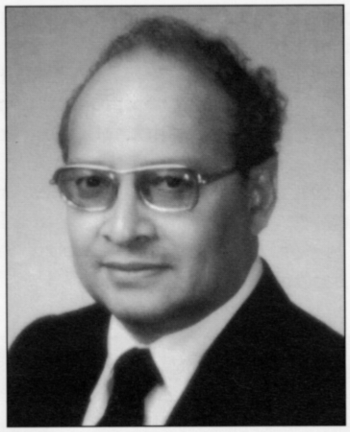
DANGER IN SUCCESS . . . If you become satisfied with your success it would probably kill your entrepreneurial spirit. It's not what you've succeeded in doing yesterday, it's that there are so many challenges to deal with tomorrow that it's difficult to sit back and relax. You're always motivated to remain entrepreneurial because there's so much yet to be accomplished.

THOMAS KAILATH

Board Member, Integrated Systems, Inc.

Thomas Kailath (SM'59, ScD'61) is cofounder of Integrated Systems, Inc. (ISI), of Santa Clara, California. A native of India, Dr. Kailath was a graduate research assistant in RLE's Information Transmission Group from 1957 to 1961. Since 1963, he has been on the faculty of Stanford University, serving as director of its Information Systems Laboratory from 1971 to 1981, and associate chairman of the Electrical Engineering Department from 1981 to 1987. Dr. Kailath is currently Hitachi America Professor of Engineering at Stanford. He also serves on various board committees at Integrated Systems.

Founded in 1980, ISI is a leading provider of software development tools and services for products controlled by hidden, or embedded, computer systems. These embedded computers perform specific functions inside larger systems and are used in a variety of devices ranging from cash registers to automotive engine controls.



Thomas Kailath

MEMORIES . . . Not many students came from India in those pre-Sputnik days. In fact, I became the first student from India to receive a doctorate in electrical engineering at MIT. I probably would have accepted a civil service job if it weren't for the insistence of a family friend and my department chair, Professor Aija. It was a great time to be at MIT. RLE had a remarkable group of faculty and a striking collection of visitors. There was a psychiatrist turned automata theorist known as "Marco Polo"—Marcel Paul Schutzenberger. There was also Benoit Mandelbrot, who had just written his seminal paper on fractals that asked, "How long is the coast of Britain?" My classmates were a remarkable bunch too, including Bob Gallager, Irwin Jacobs, Len Kleinrock, Jim Massey, Howie Yudkin, and Jacob Ziv.

I was Jack Wozencraft's first doctoral student, and he steered me towards the study of time-variant multipath channels. It was a hot area at the time and my master's thesis drew the attention of Bob Price and Paul Green at Lincoln Laboratory. I had a tempting offer from Bell Labs to get my PhD in New York City as a paid employee. Fortunately, Bob and Paul persuaded me to stay at MIT by offering me a summer job at Lincoln. That work led to my first journal paper. Although travel to foreign conferences was a rarity for graduate students then, I also presented a paper at the 1960 London Symposium on Information Theory. There I met Professor Norman Abramson of Stanford, who later persuaded me to join Stanford's faculty as an associate professor in 1963.

BEGINNINGS . . . At Stanford, I worked largely on information and communication theory and stochastic processes. I followed the MIT tradition in which professors worked on their own research while guiding doctoral students along different and separate paths. However the work on feedback communications by my first student led to the need for recursive estimation algorithms that had been developed in control theory. It was more efficient to let my graduate students teach me this, and I realized that joining forces with them on research was more valuable for everyone. This led to a decade of activity in control and linear systems theory. In the late 1970s, the potential to blend integrated circuits and systems became evident. I was inspired by the team projects of my solid-state colleagues, who gathered groups of students to study new areas together. This led to larger group efforts on VLSI and sensor array signal processing in the 1980s. As these new interests developed, I continued mathematical work on building the theory of displacement structure. This was originally inspired by apparently different mathematical and computational questions that appeared in all the areas I had worked in: communications, control, signal processing, computation, and pure mathematics.

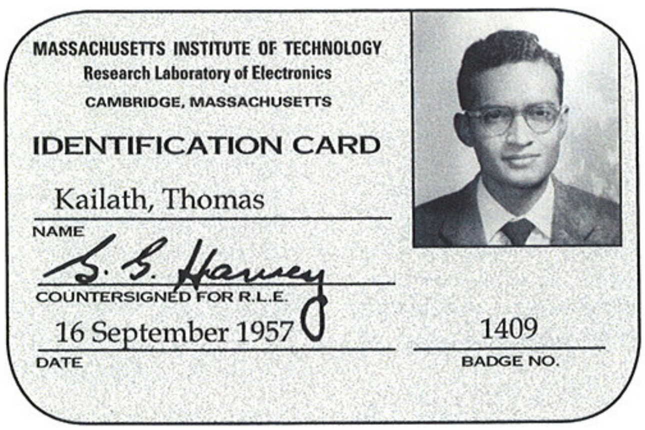
NEW DIRECTIONS . . . In the early 1970s, a few control theorists formed Systems Control, Inc., which was the first commercial group to conduct systems-oriented studies of civilian and military problems. Naren Gupta, a 1971 Stanford PhD in aeronautics, had joined this company and became a successful group leader. Naren had taken all my courses at Stanford and I had consulted for his group. We frequently discussed his going out on his own, and my contribution was to encourage him. Ronald Reagan was about to become president, and it was clear that defense was going to expand. I thought we had a good chance to compete for some of the business that would soon be offered. Naren secured our initial contract from Lockheed, and I arranged another through the Office of Naval Research. In 1981, we started Integrated Systems, Inc., in a two-room office in Palo Alto Square with one employee.

INNOVATION . . . After a few years, we noticed that we were doing jobs well below our estimated costs. This was because we had put together a set of control design simulation software packages that greatly sped up the analysis and design phase of big projects. We bundled these packages together with user-friendly interfaces and offered it as MATRIXx, which was the first integrated higher level control analysis and design package. It was designed to exploit the strengths of the workstations that were beginning to appear.

integrated systems

GROWTH . . . ISI's growth was almost entirely due to Naren. He always put the company's growth first, and its founders and early directors took no special perquisites. By 1984, we had about a million dollars in the bank, but felt the need for deeper managerial expertise in order to grow the company. We initiated discussions with a few venture groups, but we were out of our depth here. We were persuaded that it would be best for us to surrender a major share of the company to a leading venture capital firm for $1 million and their managerial help. At the last minute, the venture group pulled out. A few years later, SUMMIT Partners of Boston sought us out, and we accepted an investment for a much smaller share of the company. We didn't need the money, but we felt that it was good insurance and it would give us access to other opportunities. In fact, one of their partners who joined our board suggested that we go public in 1990, when we had about $12 million in revenue.

A year or so later, we acquired a company with a real-time operating system (RTOS) called pSOS. Although there were some hiccups when we tried to fit the companies together, Naren made major investments in the RTOS area. It's now our major area of growth. The key target is embedded microprocessors or microcontrollers. They're not as visible in workstations or PCs, but they're much more numerous. They're found increasingly in all kinds of devices; from microwave ovens and dishwashers to hand-held phone sets, fax machines, automobiles, and aircraft. These used to be four- or eight-bit devices, and they were relatively easy to program, but the complexity grows exponentially as we go to sixteen- and thirty-two-bit microprocessors. These are now cheap enough to be widely used.


MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Research Laboratory of Electronics
CAMBRIDGE, MASSACHUSETTS
IDENTIFICATION CARD
Kailath, Thomas
NAME
COUNTERSIGNED FOR R.L.E.
16 September 1957
DATE
1409
BADGE NO.

This market is growing over 50 percent a year, but the programming tools are lagging behind. That's where ISI comes in. We now have a set of four or five products that spans the range from design to implementation. ISI currently has over 400 engineers and a revenue rate approaching $100 million a year. Naren is now chairman, and David St. Charles, an alumnus of MIT's Sloan School, joined us as president and CEO nearly three years ago. Together they have put ISI on the fast track. Currently, I'm only involved on the board, although I do encourage activity in semiconductor manufacturing, which is one of my recent research interests.

FUNDAMENTAL SCIENCE VS. ENGINEERING APPLICATIONS . . . After devoting about a decade each to theoretical work in communications, control, and signal processing, my work is turning towards applying these ideas to problems in semiconductor manufacturing and more generally in materials processing. Surprisingly, few ideas in what might be called mathematical engineering have been used in semiconductor manufacturing. There's a different way of thinking on the device side of electrical engineering. There, they start with physics and invent a system for doing something like rapid thermal annealing. After that, their approach is much more empirical and database-oriented. For various reasons, they don't use the approaches and results of modern control, signal processing, or optimization. So from our viewpoint, many of their procedures are inefficient. Volume is what saves them now, which is why Moore's law works. But the time will soon come when our more analytical approaches will be important.

TECHNOLOGY TRANSFER . . . There's a great need and many opportunities for technology transfer. In control and signal processing, maybe 90 percent of what is known in universities today isn't used in industry, except perhaps in aerospace and to a lesser extent in the chemical industry. However, technology transfer isn't easy. It must be done through people—students, postdocs, and research associates. It also takes a different scale of funding from what we are familiar with, at least on the systems side of engineering. It's an issue that deserves more attention, especially from faculty.

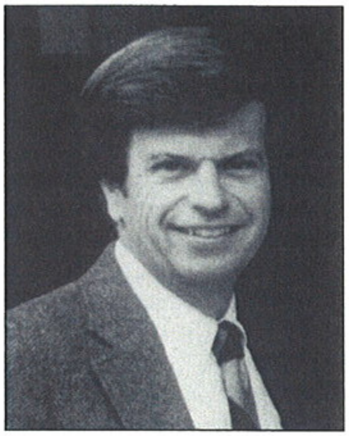
CHALLENGES . . . The process of research is always a challenge. For example, how does one enter new fields such as VLSI design and semiconductor manufacturing from scratch? It's certainly a test of what we profess to teach. It's also challenging to take an inexperienced student and have him or her cross the threshold as an independent investigator in four or five years. Another important yet difficult challenge is to organize the extensive bodies of knowledge that have built up through our research and publish them in textbooks and monographs. I hope to spend more time on that now. I also want to encourage the implementation and utilization of those ideas, which is something the progress of technology has made much easier to do now than even a decade ago.

REWARDS . . . It's been a joy to have worked in so many different fields with a stellar collection of more than seventy doctoral students and more than thirty postdoctoral scholars, many of whom are now leading figures in their fields. These efforts have also gained my family and myself a wide range of wonderful friends from around the world. In June 1995, my students and friends organized a four-day conference for my sixtieth birthday. One day was devoted to each of my research fields: communications, computing, control, and signal processing. There were more than 300 attendees from twenty countries.

Being involved in a high-tech venture has also been a great experience: learning the importance of discipline, product definition, and market analysis; understanding the financial imperatives and learning to live with Wall Street quarterly reports; and gauging the interpersonal dynamics within a company. There is much more to a technology company than just pure technology. Also, having watched the Silicon Valley grow since 1963 has been an inspiration and a thrill. There's a tremendously innovative and competitive atmosphere here. Everywhere there are people who are ready to seize or make opportunities to do something better or faster, or to do something completely new. Almost every company here, ISI included, has spun off or inspired several others.

JAMES C. BLISS

President and CEO, Sensory Technologies, Inc.



James C. Bliss

James C. Bliss (PhD '61) is cofounder of Telesensory Systems, Inc. (now TeleSensory Corporation) of Mountain View, California. A graduate of Northwestern (BS '56) and Stanford (MS '58) universities, Dr. Bliss worked with Professor Samuel Mason in RLE on sensory aids for the blind from 1958 through 1961. During his tenure as associate professor of electrical engineering at Stanford and manager of bioinformation systems at the Stanford Research Institute (SRI), he established TeleSensory in 1970 with Dr. John G. Linvill (ScD '49).

TeleSensory is the world leader in electronic information systems for the visually impaired and the blind. In pioneering this industry, its products have included closed-circuit television systems for electronic magnification, computer screen enlargement hardware and software, Braille and synthetic speech systems for computer access, Braille printers, and the Optacon reading system. Dr. Bliss served as TeleSensory's president and CEO from 1971 to 1992, and vice chairman in 1993. He is currently forming a new company, Sensory Technologies, Inc., of Los Altos, California, that will provide ophthalmic instruments and low-vision products to enable greater reading speed.

MEMORIES . . . I wanted to learn circuit theory from Ernst Guillemin, but when I arrived at MIT in 1958, circuit theory was at its end, and Guillemin was going on sabbatical. I decided the next best thing was to do a thesis with Sam Mason, who became my technical mentor. Sam had stopped doing circuit theory and signal flow analysis and had just started doing things for the blind. Most of our work was done in the famous Building 20, where Warren McCulloch and others in RLE were working on bionics and cybernetics. My thesis, *Communication Via the Kinesthetic Sense,* showed how one could communicate using movement. I built a kind of reverse typewriter with eight keys, and each key moved in three dimensions. I programmed it using the TX-0 computer and paper tape. We would see how fast people could learn and receive information that way. When Sam introduced me to John Dupress, it was my first experience with someone who was blind. When I graduated MIT and went back to the SRI, John helped me get the funding to continue what I had worked on at RLE.

BEGINNINGS . . . I originally joined SRI in 1956 while working on my master's at Stanford. After MIT, I returned there and started a group that worked on tactile communication and vision. Then I ran into John Linvill, who had an idea for a reading machine for the blind. We joined forces and over the next five years developed what became the Optacon. Between SRI and Stanford, we developed ten prototypes. Various people used it including students, SRI employees, and people in the community. It eventually led to major funding from the United States Department of Education because people were actually using it.

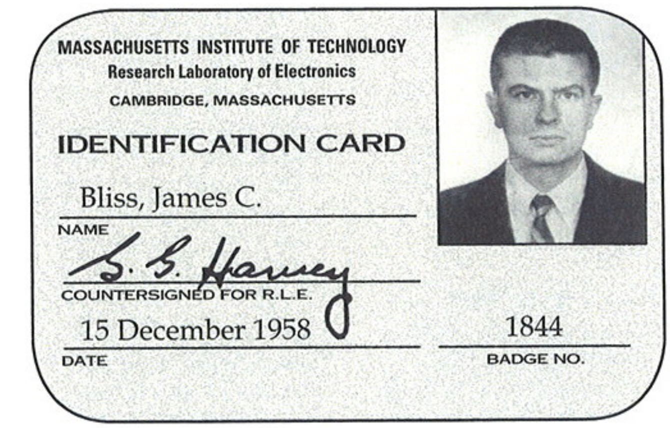
Since this was before microprocessors, we used some innovative technologies. The Optacon had two custom integrated circuits. One was the camera's retina and the other was the integrated circuit that drove the piezoelectric elements. The Optacon's tactile array and camera were developed at SRI, while its electronics and integrated circuits were developed at Stanford. The retina was the first big integrated circuit done at Stanford's Integrated Circuits Lab. It was a photosensor array with 144 phototransistors arranged so we could multiplex them to output the information. The same design is still used today. It was very innovative then, but today the Optacon is a dead product because we have optical character recognition (OCR), and much more information is available electronically. In addition, the pace of life today is such that people don't want to read slowly or expend the effort to learn how to read with an Optacon. A lot of training is involved, and you can read only very slowly. The Optacon does well in Japan because they don't have accurate, low-cost OCR for their characters.

TeleSensory's second product was the Speech Plus calculator, which had extremely compressed synthetic or prerecorded speech. In those days, 16K of read-only memory was a lot of memory. We licensed a compression technique and built a twenty-four-word vocabulary into a hand-held calculator for the blind. That was three years before Texas Instruments came out with Speak 'n Spell. We also developed a piezoelectric Braille display that, in terms of blindness products, dominated the market. The Braille display business has grown to where it's now a separate activity of TeleSensory.

HALLMARKS . . . As TeleSensory evolved, what made us different from our competitors was our complete line of products. Most of our competitors had either one product for the blind or one product for low-vision. TeleSensory had everything, including our reading machine and a computer access machine that did Braille or speech. In 1991, TeleSensory had sales of $30 million and about 200 employees. By some venture capitalist standards that isn't exciting, but in terms of the field for the blind, it's huge. TeleSensory had a fairly dramatic influence around the world in terms of integrating blind people into society. We weren't the only company that did it, but TeleSensory certainly played a significant role in the process whereby blind people became accepted as being able to work and to be successful. The Optacon made people more accepted. The first Optacon designed at Stanford had a run of about fifteen years. When it came time to redesign it, TeleSensory did it cooperatively with Canon. Interestingly, customers of the redesigned Optacon were mostly people who were buying their second one. Their first one was provided to them by either the government or a foundation. Now, they were employed and able to buy a second one with their own funds.

FUNDAMENTAL SCIENCE VS. ENGINEERING APPLICATIONS . . . The problem with Braille displays is how to move a zillion little pens up and down just a small amount. They must be extremely reliable. The only technology that's been successful and widespread is piezoelectric technology. It's expensive because its materials are like black magic and suppliers can't supply them consistently over a long period of time. Another area where basic science is needed is in making paper Braille. It's an archaic technology that's always on the verge of not working because we want to make the dots as high as we can. Paper isn't uniform, so it's impossible to get nice dots everywhere. Occasionally, we hit a weak spot and it breaks through the paper. So we need something totally different, such as hard dots deposited on regular paper.

CHALLENGES . . . There are always these tough problems that aren't in one field, as opposed to a lot of endeavors where you can continue in the same direction. Although the problems are broad, the results may be focused. So we continually have to learn about new technologies in different fields. For example, we must solve the problems with materials and software. Ten to fifteen years ago, the big challenge was how to give a blind person access to an IBM PC running DOS. The biggest challenge now is giving them access to Windows because the graphical user interface is tough. Because people wanted it, Microsoft has acquired rights to some software for the blind. Windows '95 was developed so the blind could have access, and other suppliers can access the same rules as long as they fit. Microsoft is now paying attention, and there may be new product opportunities if they can solve this problem.



CORPORATE CULTURE . . . For the twenty-two years I was at TeleSensory, we prided ourselves on being at the forefront, technologically and engineering-wise, and continuing to do innovative things rather than having a "me too" product. Our employees were dedicated to helping the disabled community. They'd say, "I've never worked anywhere else where I've had such close contact with the people who use our products." Blind people would come in to test our products, and we also had blind employees. People learned to accept them like everyone else.

OBSTACLES . . . The biggest obstacle has been getting investors and managing the growth of the company. What's expected of American companies, particularly by investors, is dramatic growth. Investors like to see minimum growth of 15 percent a year in sales and earnings. When you're in a niche-specialty market with a limited population, it takes a lot of innovation to do that. The biggest obstacle is keeping investors happy in a limited market.

THE FUTURE . . . The market for the blind isn't growing because the population of blind people has become pretty static. It hasn't grown with the rest of the population because of medical advances. The biggest area of growth in this field is senior citizens. Twenty-five percent of people over eighty-five have a vision impairment that can't be corrected with eyeglasses. Fifteen percent of people over sixty-five have a severe visual problem. As the population gets older, low vision will become a growth area. It's a big marketing challenge, and one that my new company, Sensory Technologies, is focused on. We're going to do two synergistic things: ophthalmic instruments for ophthalmologists and low-vision products for patients who can't use normal glasses to correct their vision, but who are not blind. We're taking a new look at large character displays because magnification helps only some people to a degree. Magnification also results in a slower reading rate because the field of vision is smaller. Using image processing, we've discovered ways to improve readability for people with a central blind spot or scotoma, which includes the majority of low-vision people over sixty-five years old. A lot of development has been done recently in image processing, which is applicable to this problem. We've also discovered some processes to make the letters more readable, allowing the person to read with less magnification so they can read faster. We're getting reading rates of more than twice those one can get with only a magnification system.

REWARDS . . . Seeing people use our products to be successful and having it have a significant effect on their lives is rewarding. It's rewarding to see people like Candy Linvill become successful. [Editor's note: TeleSensory cofounder John Linvill's daughter was an original Optacon tester and is a continuing user.] When she was two, she had retinal blastoma, which is like a cancer of the optic nerve, and she completely lost her vision. She's now a PhD psychologist at a hospital in Redwood City. She proved to the world that you can be successful. An article in the *San Francisco Chronicle* described a scientist at NASA Ames who is totally blind and a leader in the search for communication from extraterrestrial space. He has an array of equipment and most of it is TeleSensory. Another Optacon user started his own company that makes products for the blind. He is totally blind himself, and he did it based on our products.

SIGNIFICANT ACHIEVEMENT . . . I was involved in the technical part of the Optacon, but after that I was more involved in setting directions for TeleSensory. The most significant achievement was proving that a commercial company could provide this kind of equipment and be successful at it. We were the first commercial company to do it.

IVAN E. SUTHERLAND

Vice President and Sun Fellow, Sun Microsystems, Inc.

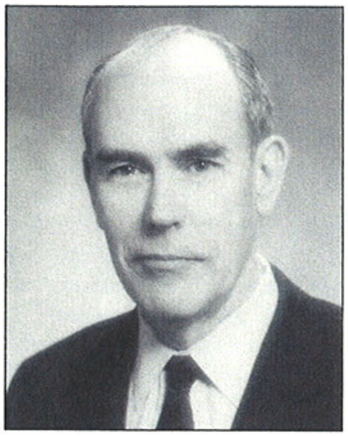
Ivan E. Sutherland (PhD '63) is vice president and fellow at Sun Microsystems, Inc., in Mountain View, California. From 1960 to 1963, Dr. Sutherland was a graduate student in RLE working with Professor Claude E. Shannon on interactive computer graphics. His thesis, called Sketchpad, *was supervised by Professor Shannon and is widely recognized as the pioneering work in computer graphics. Sketchpad enabled users to convey graphic material to a computer by drawing on a cathode ray tube with a light pen.*

From 1964 to 1966, Dr. Sutherland served as director of information processing techniques at the Advanced Research Projects Agency (ARPA). He was an associate professor at Harvard from 1966 to 1968. With David C. Evans, he founded the Evans and Sutherland Computer Corporation (E&S) in 1968. Dr. Sutherland worked at E&S and as a professor at the University of Utah from 1968 to 1974. Subsequently, as Fletcher Jones Professor of Computer Science at Caltech, he went on to establish and lead computer science activities there.

In 1980, Dr. Sutherland and Robert F. Sproull started a small consulting firm—Sutherland, Sproull & Associates (SSA). They were joined by William R. "Bert" Sutherland (SM '63, PhD '66), Ivan's older brother who was also a doctoral student of Claude Shannon. SSA provided management and technical consulting and advised Advanced Technology Ventures, a Boston and Menlo Park venture capital firm. Sun Microsystems bought SSA in 1990 and placed its three principals into key positions at Sun.

MEMORIES . . . When I was a master's student at Caltech, I heard Marvin Minsky describe computing at RLE and I wanted to get in on the action. It was a rare opportunity to get my hands on a whole computer. On-line computing was the high point of my MIT experience. What a wonderful thing was the TX-0 computer, and the PDP-1 after that. Time sharing was new: Fernando Corbató had just built his compatible time-sharing system. I was fortunate to have Claude Shannon as my thesis supervisor. Another good thing was hooking up with Jack Raffel's group at Lincoln Laboratory so I had access to the TX-2.

BEGINNINGS . . . After MIT, I spent two years in the army assigned to ARPA. I directed the office responsible for computer research as its second director following J.C.R. Licklider. MIT's Project MAC was one of my contracts. After ARPA I took a teaching job at Harvard's Division of Engineering and Applied Physics. We pursued three-dimensional computer graphics research, devising the first system for what is now called virtual reality. The ideas were brand new. We had to learn everything. We wanted more realistic three-dimensional images. The folks in Utah had been working on better images, so I joined with Dave Evans to form Evans and Sutherland in Salt Lake City and spent six years there. Today, E&S's mainstay is realistic simulation for pilot training. I've crashed a DC-10 twice trying to land at O'Hare Airport, because I'm no pilot. Fortunately I did it at United's training center in Denver.



Ivan E. Sutherland
(Photo courtesy Mock Photography)

HALLMARKS . . . E&S has always led the field in high-quality computer images. In a way, E&S is a supercomputer company. Its biggest display systems are supercomputers in terms of transistor count, power consumption or billions of multiplications per second. E&S has the best technology; we understand the technology and big customer needs. That gave us the lead in our early days. We made the first commercial hidden surface displays and the first night-only visuals for pilot training. When the FAA approved night-only simulators for pilot training, the airlines snapped them up, making E&S a success.

NEW DIRECTIONS . . . I joined the Caltech faculty to start a computer science activity with Carver Mead, and we focused on integrated circuit design. Caltech had a major influence on academic institutions worldwide by demonstrating that we could teach students to design integrated circuits. I like to think our Caltech group made integrated circuit design a respectable field for academic research and training. I left in 1980 to start a tiny consulting company with Bob Sproull and my older brother Bert. Sun bought us, which is why we're all here today. Sun calls me a "fellow," but nobody quite knows what a fellow does, which is how I like it.

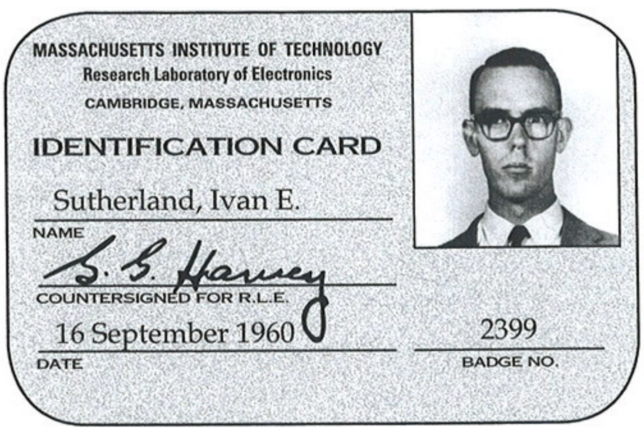
FOREIGN COMPETITION . . . It's scary. I see a national weakness in our investment behavior. Let's divide the number of shares that exist by the trading rate to find how long it takes to turn over completely either a market or a company ownership. Twenty years ago the New York Stock Exchange took seven years to turn over completely; on average, American shareholders held shares for seven years. Today, it turns over completely in less than two years. It's nice that the market is more liquid, but it's bad because owners who don't stick around don't care about a company's future or its R&D program, only about immediate profits. They think of R&D as an expense rather than as an investment. Such shareholder thinking dampens management's will to invest in the long term because management responds to near-term stock price pressure. You may retort that there's a steady base of long-term shareholders who do care about the future. Maybe so, but they don't set the stock price; the quick traders do.

In the United States today we have share renters rather than share owners. The renters get rid of a stock when it's not doing well rather than fix the company. In that environment, American industry is at a disadvantage to foreign competitors who have long-term owners thinking about how to take over whole industries in ten or fifteen years. Industry in the United States can't have such a long-term view because of the way our financial markets work. I wish we had owners instead of renters.

GOVERNMENT RESEARCH . . . Fred Brooks and I cochaired a study for the National Research Council (NRC), looking at federal investment in high-performance computing research. It documented nine areas where early federal research investments created whole industries that now gross more than a billion dollars a year each. We found it took ten to fifteen years for these ideas to go from wild-eyed academic research to industrial return.

In the United States, our federal government supports the long-term thinking that our industry can't. How could we do it better? Federal research investments in academic institutions seem to produce better returns than federal research investments in industry. When government puts R&D money into a company, the fruits of that research remain under control of one management and may languish unused. When government puts money into an academic institution, the fruits of that research are eagerly licensed to anyone by the university development office. Such technology becomes the nation's property rather than the property of one company, giving it a far better chance for rapid adoption.

When new companies spin off, the government gets back its investment because it already has a profit-sharing program in place called taxes. For example, Sun Microsystems spun off from ARPA-funded research programs at Berkeley and Stanford. The taxes from Sun and its payroll have repaid Uncle Sam's research cost many times. Another example is the University of California at Davis, which leads R&D for the wine industry. From the State of California's financial viewpoint, UC/Davis is a fabulous investment. The state puts in small amounts of money for research and gets back an entire wine industry and its jobs and its taxes. The same is true of federal investment in new technology. It pays back in taxes alone many times over, to say nothing of its payback in jobs, exports, balance of trade, and enjoyment of new products. But the payback takes fifteen years. The hard task is convincing legislators that such long-term investment is valuable.



LIMITATIONS . . . Two things affect the flow of technology. You don't have a technology without somebody who knows how to do it. I once visited the Oregon Research Institute where two people made the world's supply of cold cathodes for electron microscopes. Now that's very high tech indeed. The second thing is the confidence of management in sources of supply. Everyone would like to have multichip modules, but where can you buy them? A few companies offer them, but such suppliers haven't been around for more than a couple of years and there's no reliable backup source. No sane corporate executive would depend on such flimsy technology for serious products.

I heard a wonderful comment from Gordon Moore of Intel. The NRC's manufacturing technology board met with Intel's management to encourage adoption of advanced computing methods in manufacture. Until there was a $100-million-a-year pilot plant, Intel said, they couldn't risk the billion dollars it would cost to adopt such new technology. I needled Gordon by observing that the NRC didn't seem to have any more success convincing him of a new future than he had had with his management at Fairchild before starting Intel. Gordon responded, "It's always easier to raise venture capital than it is to get existing management to do something new." It's a perfect statement of why Silicon Valley is the great place it is.

DANGER IN SUCCESS . . . When you're successful, you say to yourself, "I must be doing something right." Then the world changes. Sure enough, you were doing something right, but not anymore. The hardest thing is to stay abreast of what's happening now despite being successful.

CHALLENGES . . . Teasing understanding out of complexity is most challenging. Solutions seem simple in retrospect, but they can be extremely hard to find. We long thought that making computer pictures of curved solid objects was difficult. Our best pictures had flat facets. One day one of my students, Henri Gouraud, handed me a computer picture of an apparently smooth torus. He simply changed each facet's shade of gray so you couldn't see the edges between them. It's now a widely used technique known as Gouraud shading. Now it's easy to make smooth-looking objects, but we worked hard and unsuccessfully at it for a couple of years before Gouraud discovered a simple answer. Virtual reality also makes a similar point. Before the idea even had a name, I thought if a computer could change an image to match the direction in which you were looking, it could deceive you into thinking you were in an artificial three-dimensional world. It was a simple insight, but beyond the capability of computers then. We had to invent clipping, devise perspective algorithms, and build special equipment in order to demonstrate it. With more knowledge and faster computers it's now lots easier.

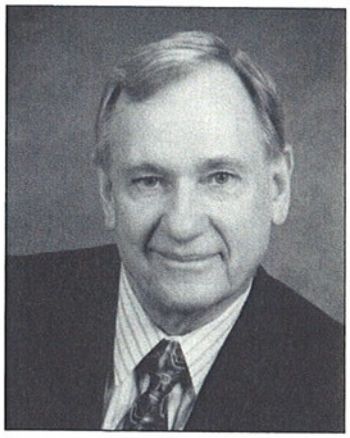
ETC. . . . Graduate education is a process whereby students teach the faculty. They're teachers because research is a joint activity where students and faculty join in learning things for which there is no curriculum. The young people must invent the curriculum. Not knowing what can't be done, they go ahead and do it, to the surprise and delight of the older generation. And they ask the damnedest questions.

Donald H. Steinbrecher

Chairman of the Board, Steinbrecher Corporation

Dr. Donald H. Steinbrecher (SM '63, PhD '66) is founder and chairman of the board of Steinbrecher Corporation in Burlington, Massachusetts. The company has been involved in many different technologies since its founding in 1973. According to Dr. Steinbrecher, the technology threads woven into the fabric of the company had their origins in RLE and in the many associations that began there during the 1960s. The company's principal activity today supports wireless telephony. Steinbrecher Corporation is well known internationally as a principal supplier of wideband digital base stations for cellular telephone systems.

Dr. Steinbrecher graduated from the University of Florida in 1960, then completed the master's program at MIT in 1963 and its doctoral program in 1966. He remained at MIT and RLE to teach and conduct research on solid-state devices. He was promoted to associate professor of electrical engineering in 1969.


Donald H. Steinbrecher

Steinbrecher Corporation began as an R&D firm focused on using computers to design and manufacture microwave systems. From the beginning, the company was bound to the concept of achieving the highest possible linear performance in analog systems. Analyses of nonlinear effects led to the development of advanced test equipment, ultralinear components, software tools, and design procedures to optimize the linear performance of analog signal-processing systems throughout the radio-frequency and microwave spectrum. In this way, the company bootstrapped itself into a position of world leadership in the design and manufacture of the highest quality ultralinear receivers—a position it maintains today.

Motivation . . . I came to MIT with the idea that I would eventually have my own company. My father and grandfather were self-employed, as were most of my other role models. Also, I taught math at the University of Florida and discovered that I enjoyed teaching. So, for a while, I was torn between a teaching career and an entrepreneurial career. The latter won.

Memories . . . My best memories of RLE are the many lifelong associations that began there. Most of my research at RLE involved devices in microwave circuits. Test equipment was unavailable and computers were new to the field. I developed a mathematical concept called *deimbedding,* which allowed us to use computer-aided analysis on microwave circuits. Deimbedding reduces a two-port network to a conformal mapping described by a table of numbers. We used it to characterize many microwave devices. In fact, we were the first to characterize the properties of the avalanche region of diodes. This work, which comprised Dean Peterson's (SM'69, PhD'71) master's thesis, resulted in the first published design equations for stable microwave IMPATT diode amplifiers.

Our original computer-aided design (CAD) programs were written in MAD, which evolved into FORTRAN. Our CAD terminal was a teletype machine. Several years later, we got APL and Paul Penfield (ScD'60) wrote some neat programs to do CAD in APL.

Manuel Navarro's (SM'72) master's thesis extended our CAD tools to another level. Many microwave circuits use a single-diode junction to perform a task. Mixers, modulators, frequency multipliers, phase shifters, and attenuators are all built in this way. The design of such circuits can be reduced to mapping the device states to specified network reflection coefficients. Manuel reduced this problem to a set of simple calculations that could be added to our CAD programs. His work changed the way we did microwave circuit design. It's a useful concept. On one occasion, Lincoln engineer John Solmon and I designed 900-MHz phase modulators with two-dollar space-qualified computer diodes. We saved the money it would have cost to space qualify PIN diodes. The CAD work continued to expand through the 1960s and became the core technology of Steinbrecher's business plan.

Firsts . . . In the early 1980s, we helped Chuck Counselman of MIT's Earth, Atmospheric, and Planetary Sciences Department conduct global positioning system (GPS) satellite experiments at Haystack. The accuracy of the results was impressive, and I got the idea that we might be able to build a commercial GPS land surveying instrument. Chuck and I formed a joint venture to develop the commercial product. We called our venture Macrometrics, and we called the system a Macrometer™. We developed the Macrometer over several years; it was the first surveying tool to use GPS satellites that was certified by the National Bureau of Standards. We were first to measure absolute sea level. One history-making night, about midnight, Chuck was on top of Mount Wachusett in a blinding rainstorm with a Macrometer set on a National Geodetic Survey (NGS) marker. We learned from those measurements that the NGS-determined altitude was off by about one meter from the true altitude above earth center. It took several years to agree on who was correct; Chuck finally won. Today, surveying with the GPS satellites is commonplace.

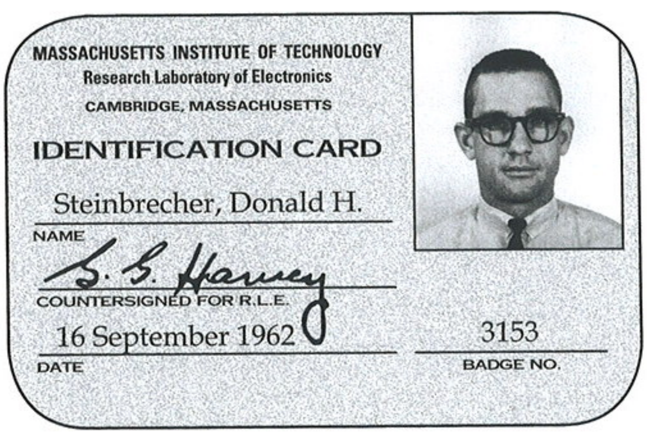
Perhaps the most interesting first actually began in RLE in the late 1960s. I asked Bob Snyder (SM'69) to verify the fundamental limits on the linearity of a unique frequency translator I had developed. His laboratory model exhibited incredible performance that was thousands of times better than the state of the art then. He discovered some little-known useful properties of driven P-N junctions. Years after forming Steinbrecher, I discovered a way to practically realize the performance that Bob had observed. I called this the Paramixer™ and obtained a patent and trade-

Steinbrecher

mark for the design. The success of the company is largely due to this patented circuit and the many products that have evolved based on its performance. The linearity of the Paramixer frequency translator is still the best available. Bob Snyder became our first full-time engineer.

More recently, we introduced a new concept to the cellular telephone industry. In this concept, we use our broadband digital radios to digitize a cellular band and employ digital signal processing to detect modulation type and to process signals. Our cellular base stations can work simultaneously with several modulation types. This is another industry first. I have extended this concept to what I call the *generic telecommunications infrastructure,* or GTI. Within the GTI, the interface between the atmosphere and a network becomes seamless. As a result, wireless applications can be realized as software that is supported on a GTI platform in the same way applications like word processors and spreadsheets run on a personal computer platform. I believe this concept will lead to a new software industry segment focused on wireless mobile computing.

CORPORATE CULTURE . . . Steinbrecher began as a consulting group. Most of its initial business was to provide professional services in computer-aided microwave circuit design. Angela Markert was my secretary at MIT and became my first full-time employee. We developed a culture that was essentially "RLE," and that atmosphere is still prevalent in the company. As our business base expanded and the payroll got bigger, we instituted a tuition reimbursement plan for all employees. Angela was the first to take advantage of the program and acquired an MBA. Our corporate culture is still very much rooted in its academic beginnings, and it doesn't have the feel of a classic corporate environment. We've worked hard to create a stable working environment, and many people have remained with the company for extended periods. Today, we have more than 125 employees and we're growing.



OBSTACLES . . . There are always a lot of detractors for any new technology. It's hard to find the early adopters and to establish a beachhead with a new technology. We've always had difficulty introducing new technology and probably always will. The greatest obstacles occur when one company's proprietary technology is the foundation of another company's product. It seems to be easier if there is a second source.

When we introduced the Macrometer Surveyor, every potential customer posed some new test to prove that the accuracy was not as we had stated. The State of Texas Highway Department placed two stakes in the ground separated by about ten meters and then asked us to measure the vector distance between the stakes. It sounds simple, until I tell you that we were required to determine the distance by measuring five other vectors that, together, described a 75-mile path between the two stakes. Our measurement was accurate within a few centimeters, and the Texas Highway Department became an early adopter of the Macrometer system.

SIGNIFICANT ACHIEVEMENT . . . I think that my most significant achievement is being called "Dad" by six wonderful children. Next to that, I'm proud of having created more than one-thousand person-years of employment, of laying a foundation that will continue to provide employment for hundreds of people for many years into the future, and of the many careers of others that I have launched and nurtured. Looking back, getting into MIT and persuading the faculty to confer my PhD was certainly one of the major personal achievements of my career. I'm also proud of the many ground-breaking technical accomplishments of the employees in my company and of its excellent international reputation.

TECHNOLOGY TRANSFER . . . Corporate downsizing has curtailed the corporate-sponsored basic research programs that were prevalent in the 1960s and 1970s. Money for basic research was plentiful when the United States was primarily concerned with staying ahead in the fear-driven cold-war economy. Now that the cold war is over and capitalism has won, our new "point-of-sale" economy is fueled by individual disposable income. Basic research is a liability because it increases the manufacturing cost of products that must be sold competitively. These conditions have created an opportunity for universities to productize intellectual property and to market and sell their products to raise money for basic research.

THE FUTURE . . . GTI meshes well with Nicholas Negroponte's concept of being digital, with a body net that links a lot of devices you carry around on your person. I can visualize that our homes, cars, and offices will have wireless nodes that link up to our body nets and personalize our surroundings as we enter the coupling range of a node. We will be able to continuously link to the global grid through a cellular-like personal communications provider and have continuous access to anyone and anything that is also interfaced with the grid.

My cellular phone has a follow-me feature so that the system can locate me almost anywhere in the United States when someone calls my Boston number. Consider marrying this feature with a body net that provides links to an earphone and a microphone. Then, with voice-operated dialing, two people could speak to each other virtually anywhere and any time. Is this a form of mental telepathy? MIT alumnus Robert Metcalf has been credited with noting that the productivity of a set of computing nodes increases by the square when the nodes are connected by a network. One wonders if this applies to humans as well.

STEVEN G. FINN
Consultant, Matrix Partners


Steven G. Finn
(Photo by John F. Cook)

Steven G. Finn ('68, SB/SM '69, ScD '75) was a member of RLE's Cognitive and Information Processing Group from 1972 to 1975. After working at Codex Corporation, Dr. Finn cofounded Bytex Corporation of Southborough, Massachusetts, in 1980. The company became known for its matrix switch products, communication switching equipment that enhances the operating reliability and control of data communication networks. Dr. Finn served as CEO until 1988, and then as chairman and vice chairman of Bytex's board until the company was sold in 1993. Currently, Dr. Finn is a consultant with Matrix Partners, a Boston venture capital firm. He is also a senior staff member at Lincoln Laboratory, a principal research scientist at MIT's Laboratory for Information and Decision Systems, and a lecturer in the Department of Electrical Engineering and Computer Science.

MEMORIES . . . I was always interested in math and science, so I came to MIT as an undergraduate in 1964. I decided to do a dual major in electrical and mechanical engineering. However after fourteen hours of trying to machine a bar straight in the mechanical engineering lab, I knew mechanical engineering wasn't for me, so I became an electrical engineering major. At MIT, instead of bureaucracy, I found a flexible educational environment. I spent many hours on the PDP-1 and learned about computers as much as from playing with them as from my courses. One of my most exciting undergraduate experiences was being an instructor in Professor Francis Lee's course on minicomputers and operating systems. As a research assistant, I had the opportunity to work on the Apollo program and was in the MIT communications room when Apollo 11 landed on the moon. With Paul Penfield, I developed demos and built the first digital labs for 6.001. I also worked on the AP Wirephoto project with Don Troxel and Bill Schreiber. It was this project that sparked my interest in networking, and it became my thesis topic. This experience set the direction of my career towards data communications and computer networking.

BEGINNINGS . . . At Codex, I started out as a diagnostic programmer for a new multimicroprocessor communications switching project. I became an expert on the product and was promoted to director of networking product development and then director of the networking research group. I met my future business partner, Bang-woel Lu, at Codex. Most engineers dream about starting a company, and I had always thought about it too. Bang-woel quit Codex in 1980 because he wanted to start a company, but he didn't have a product idea. I talked with him after he quit and decided this is the person who I would want to start a business with. So I also quit Codex to work full-time on starting a company. The two of us were now out of work, and we gave ourselves a year to do something. Of course, we also had the support of our wives. I had three children and Bang-woel had two. We felt that we were good engineers, and if we failed in our venture we'd get real jobs. We laughed at the thought that we might end up opening a Chinese restaurant if things didn't work.

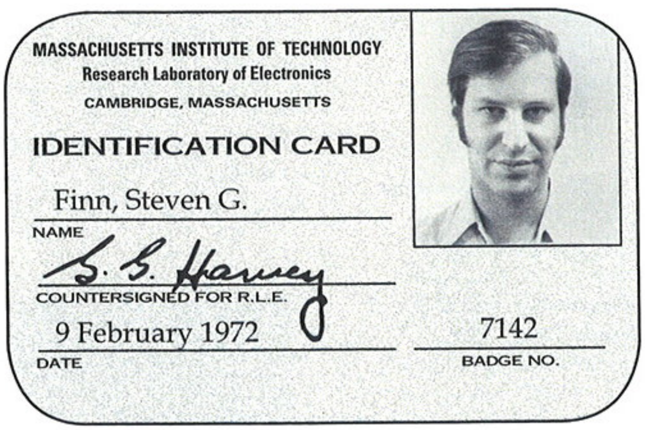
Initially we came up with several ideas. We focused on products that people already needed. We felt that we weren't going to convince the world it needed what we wanted to build. We made sure the product was intellectually difficult enough to create so we would have time to develop it and that it couldn't be duplicated in a week by someone else. We spent three months figuring out what to do and came up with the matrix switch. Then we had to figure out how to finance it and turn it into a company. When we actually got to build Bytex, we had to use a lot of engineering know-how.

The need for the matrix switch was driven by network technology. The first modem networks existed in the 1970s, and networks were becoming important corporate resources. As networks started to grow, we realized they had to be more reliable. They were becoming more mission critical for the organizations they served, and the situation was getting worse because people were putting in more networks and depending on them more. At that time, electromechanical methods were used to achieve reliability. We knew it didn't make sense to have megabit transmissions controlled by mechanical relays. So we applied modern technology, integrated circuits, and microprocessors to the networking technical control business. This involved management, control, and the maintenance of network infrastructures. Bytex delivered its matrix switch to customers such as the New York Stock Exchange, the Pentagon, the White House, AT&T switching centers, NASA, airlines, and railroad companies.

Our switch helped customers in the following way. Before a train leaves its home station, it must get approval on its up-to-date maintenance status. Prior to the existence of networks, someone would need to send a piece of paper or get on the telephone to accomplish this. Eventually the procedure relied on electronics, using a teletype. If the network went down, the train couldn't move because it couldn't be verified that the engine was in a maintenance period. As railroads and airlines became dependent on networks, it became essential to develop new methods to fix and diagnose the networks to keep them reliable. Bytex changed this from a manual mechanical system to an automated electronic system that included distributed equipment, fault-tolerant processing system designs, and self-recovering, self-synchronizing software systems. Of course, back then, nobody called it these things. We built a packet network so switches could talk to each other. If there was a problem in one city, our switches could re-route network connections through an alternate city. The control of our switches was done through a dynamically routed packet network. The routing algorithms for our product came out of my MIT thesis research.

FIRSTS . . . Bytex was the first company to apply microprocessors, integrated circuits, and fault-tolerant processing and switching to tech control. We built large networks, fault-tolerant hardware and software, and self-synchronizing software code. This software could discover its own errors, so if bugs appeared, it would self-correct. Many times when we visited customers who were running our systems, we would find that the software had detected a bug and re-executed the program. The system stayed up, and the customer didn't even know there was a problem. The technology we implemented to solve this problem was quite advanced for the industry.

HALLMARKS . . . As a small company, we couldn't afford a field service force. We considered the alternative and that was to make products that didn't break. It actually became Bytex's philosophy. Every product had redundancy built in to it. We focused on stable technologies that we could engineer and be confident in selling. When we built equipment and wrote software, we did everything we could to make it a reliable, solid, and proven technology. We needed to give the customer confidence in moving from a simple mechanical switch to a complicated computer. One of our first turndowns was a sale we lost to IBM. They had a big network with millions of dollars worth of computers and thousands of users. They wouldn't let their network depend on a microprocessor-driven electronic device, they wanted switches to make sure the wires were connected. We couldn't tell prospective customers they needed reliable networks. They had to figure it out for themselves. But customers don't always know or aren't aware of all possible solutions. In that sense, you must educate and inform them that your solution meets their needs in a better way.



When you consider air traffic control systems or every time you use your VISA card or all the mission-critical things people do, they're probably going through one of our switches. We made networks reliable so corporations could deploy them, keep them running, and put more data into the network world. Larger and more reliable networks could then be built and staffed with fewer people. Our equipment could go into an unattended closet. It was a risk for the network provider, but by doing that they could back up equipment and fix things remotely.

FOREIGN COMPETITION . . .Twenty-five percent of our business was overseas, but we had a problem selling in Japan. In the Japanese culture, you weren't supposed to diagnose another person's problems. You called NTT and waited for them to fix it. It wasn't polite to call a third party when some equipment was broken. Our equipment identified faults and then routed around them so the network could stay up, but they thought you had to fix something. So in those days, diagnosis and test equipment for data networks had a cultural stigma attached to it. In that sense, our equipment wasn't easily marketable in Japan.

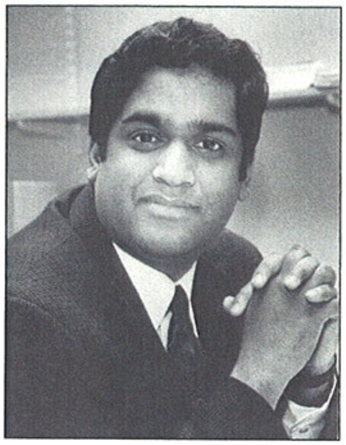
NEW DIRECTIONS . . . I always saw myself as a PhD from MIT, not a businessman. So in 1987, I hired a new CEO. We branched off into local area network (LAN) products and went public in 1988. In 1990, I resigned as an active officer, but stayed on as chairman and then vice chairman until Bytex was sold in 1993. Bytex is now in the LAN business. It still sells matrix switches, but not quite the ones we were building in 1980.

ISSUES . . . Markets in the communications business are changing very rapidly with asynchronous transmission mode (ATM), LANs, and the Internet. We have to figure out how they will fit together and how the corporate networks, which are the real drivers, will evolve. A big challenge is recognizing the Internet as an infrastructure, not as a network. Instead of dialing up a mainframe to get customer information, you now go to a company's Web page. It means that the network must be more available and the bandwidth must be different. It will be interesting to see how the connectionless Internet and the connection-oriented ATM network will fit together.

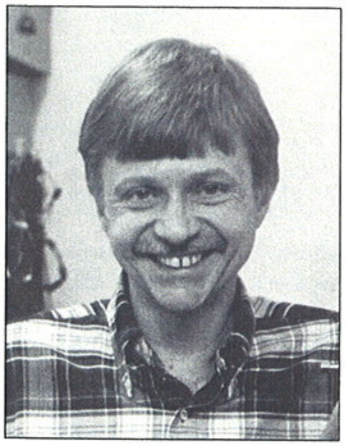
REWARDS . . . It's rewarding to have people use the things that I've developed. It's the ultimate reward when one builds a product and people pay money for it. The rewarding aspect is to make a contribution and have it be meaningful. That continues in what I do today. I supervise thesis students, teach, and do research at MIT's Laboratory for Information and Decision Systems. I also work with a high-speed optical network group at Lincoln Lab that's involved with all-optical wavelength division multiplexed networks and with another group investigating optical time-division packet photonics. For the past fifteen years, I've also been associated with Matrix Partners, a venture capital firm in the Boston area. I help to identify good technology opportunities and assist entrepreneurs in putting together business plans that Matrix Partners would be interested in funding.

CHALLENGES . . . On the teaching side, keeping my data communications course up to date is a challenge. The course is a real fire hose and a tremendous amount of information is always changing. On the research side, the optical world is moving rapidly. We can do things we couldn't do two years ago, and we're now thinking about building optical memories. Figuring out how to put these systems together is an issue. Funding new companies has also been a challenge. You come to realize how difficult it is to mentor entrepreneurs, invest in them, and figure out what are the good ideas and who are the good people.

circuit breakers



Dr. Anantha P. Chandrakasan joined RLE's Circuits and Devices Group in September 1994. Concurrently, he was appointed as assistant professor and to the Analog Devices Career Development Professorship in MIT's Department of Electrical Engineering and Computer Science. Professor Chandrakasan came to MIT from the University of California at Berkeley (BS'89, MS'90, PhD'94), where he recently completed postgraduate research in low-power integrated circuit design. Professor Chandrakasan's research interests include low-power techniques for portable real-time applications, video compression, computer-aided design tools for VLSI design, and system-level integration. These have applications to digital signal processing and wireless communication technologies. Professor Chandrakasan is a member of Eta Kappa Nu and Tau Beta Pi.
(Photo by John F. Cook)



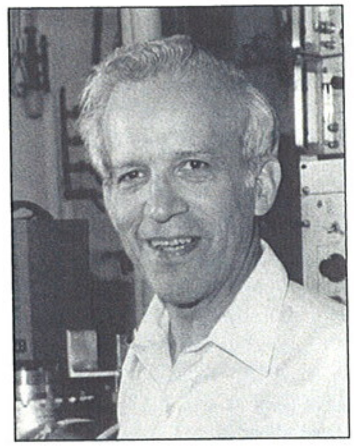
Dr. Dennis M. Freeman (SM'76, PhD'86) was appointed Assistant Professor of Electrical Engineering, effective September 1, 1995. Professor Freeman joined RLE in 1978 as a research associate in the Auditory Physiology Group and was appointed research scientist in 1986. His research seeks to characterize the signal processing properties of the peripheral auditory system and to understand its implications. In connection with this work, he and his colleagues have developed microscopic photodetection methods and high-resolution image processing techniques to measure the motions and physical properties of inner ear structures. Since 1987, Professor Freeman has also been a research associate in otolaryngology at the Massachusetts Eye and Ear Infirmary. A graduate of Pennsylvania State University (BSEE'73), he is a member of the Association for Research in Otolaryngology and the Association for the Advancement of Science.
(Photo by John F. Cook)

Dr. Hermann A. Haus, Institute Professor, was awarded the National Medal of Science by President Clinton on October 18, 1995. The medal, which is the United States' highest scientific honor, was presented to Professor Haus for his fundamental and seminal research contributions to the fields of quantum electronics, noise, and ultrafast optics and for his outstanding service to the engineering profession through teaching. His research in RLE's Optics and Devices Group involves quantum optics. Professor Haus is widely recognized for his work on the generation of ultrashort optical pulses and developing the soliton method of signal transmission. His contributions to the field of laser optics have been applied to long-distance fiber-optic communications. During his distinguished forty-year career, he has received numerous awards. The most recent was the 1994 Frederic Ives Medal of the Optical Society of America. He is a member of the National Academy of Engineering and the National Academy of Sciences, and a fellow of the American Academy of Arts and Sciences, the IEEE, the American Physical Society, and the Optical Society of America. *(Photo by John F. Cook)*

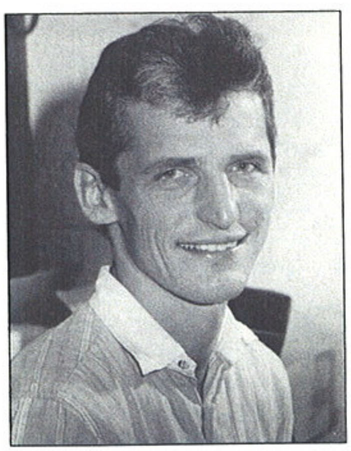
Dr. Jacqueline N. Hewitt (PhD'86), Class of 1948 Associate Professor of Physics, was announced as the recipient of the 1995-1996 Harold E. Edgerton Award on May 17, 1995. MIT established the award in 1982 to recognize young faculty members for distinction in teaching, research, and service. Earlier in the year, Professor Hewitt also received the American Physical Society's 1995 Maria Goeppert-Mayer Award sponsored by the General Electric Foundation. The award recognizes outstanding achievements by a woman physicist early in her career and provides opportunities to present these achievements through public lectures. Professor Hewitt was cited for her pioneering work in the detection of gravitational lenses, including the discovery of the first Einstein ring, and their detailed investigation using polarization, time-delay, and other measurements. With her colleagues in RLE's Radio Astronomy Group, she has identified several gravitational lens systems and has detected emissions from low-temperature main-sequence stars using very-long-baseline interferometry. Professor Hewitt received the Goeppert-Mayer Award at ceremonies held during the American Physical Society meeting in San Jose, California, on March 20, 1995. *(Photo by John F. Cook)*

band Michael and son Philip (SB'56). It is presented biennially to junior faculty members with interests in condensed matter, atomic, and plasma physics. *(Photo by John F. Cook)*

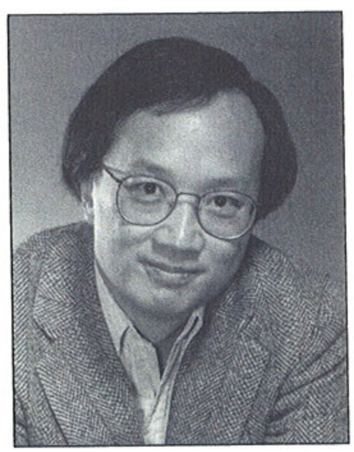
Dr. Qing Hu was promoted to associate professor in the Department of Electrical Engineering and Computer Science, effective February 1995. Professor Hu, a graduate of Lanzhow University (BS'82) and Harvard University (MA'83, PhD'87), was a postdoctoral fellow at the University of California at Berkeley before joining the MIT faculty as an assistant professor in 1990. He held the KDD Career Development Professorship from 1991 to 1993. In RLE's Optical Communications Group, Professor Hu's research has focused on the response of solid-state devices to high-frequency radiation. He continues to work on the development of superconducting electronic devices, semiconductor quantum-effect devices, and solid-state infrared lasers; all of which have applications to space-to-ground communications and high-frequency, high-speed signal processing. *(Photo by John F. Cook)*



Dr. Daniel Kleppner, Lester Wolfe Professor of Physics and RLE's associate director, was awarded the 1995 James R. Killian, Jr. Faculty Achievement Award. Professor Kleppner's wide range of work in RLE's Atomic, Molecular, and Optical Physics Group focuses on atom interactions with static electricity, magnetic fields, and radiation. Professor Kleppner came from the Harvard University faculty to the MIT faculty in 1966. From his early research on the hydrogen maser at Harvard (PhD'60) to his pioneering studies of Rydberg atoms, Professor Kleppner's work is widely recognized in the international atomic physics community. His other research interests include quantum optics and ultraprecise laser spectroscopy. He is a fellow of the American Academy of Arts and Sciences, the American Association for the Advancement of Science, and the Optical Society of America; and a member of the National Academy of Sciences. *(Photo by John F. Cook)*



Dr. Wolfgang Ketterle, Assistant Professor of Physics, was named recipient of the 1994 Michael and Philip Platzman Award by MIT's Department of Physics. Professor Ketterle, a principal investigator in RLE's Atomic, Molecular, and Optical Physics Group, was cited for his emerging leadership in the field of laser cooling and trapping of atoms at high density. This research, carried out in collaboration with Professor David E. Pritchard, focuses on the cooling or slowing of atoms by isotropic light and the dark spontaneous force optical trap (called "dark SPOT") to trap the cooled atoms. This new technique greatly improves the density of trapped atoms to study their collective physical properties and may have applications in atomic lithography, high-resolution atomic microscopy, and atomic optics. The Platzman Award was established in 1990 by a contribution from Mrs. Michael Platzman to honor her hus-

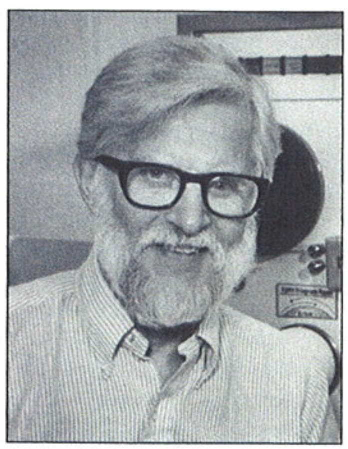


Dr. Patrick A. Lee (SB'66, PhD'70), William and Emma Rogers Professor of Physics, received a 1995 J.S. Guggenheim Fellowship. Professor Lee, a principal investigator in RLE's Quantum-Effect Devices Group, was among 152 artists, scholars, and scientists selected for the award. During his fellowship he plans to conduct research on a theory for high-temperature superconductors. Professor Lee's other research has included the investigation of physics in small devices, transport through quantum dots, and the quantum Hall effect in confined geometry. He joined the MIT faculty in 1982 after ten years at Bell Laboratories. Professor Lee is a fellow of the American Physical Society and a member of the National Academy of Sciences and the American Academy of Arts and Sciences.
(Photo by John F. Cook)

Dr. Miklos Porkolab, Professor of Physics, was appointed director of MIT's Plasma Fusion Center (PFC), effective February 1, 1995. Professor Porkolab has served as PFC's associate director for plasma research since 1991, as well as acting head of the center's Toroidal Confinement Division since 1994. He succeeds the interim directorship of Dr. Dieter Sigmar and Dr. Bruce Montgomery. Professor Porkolab received his BASc from the University of British Columbia in 1963 and his PhD from Stanford in 1967. He joined the Plasma Physics Laboratory at Princeton University in 1967, becoming a senior research physicist, lecturer, and professor in the Astrophysical Sciences Department. In 1976, he received the U.S. Senior Scientist Award from the Humboldt Foundation. Professor Porkolab joined the MIT faculty in 1977, and has become recognized as a preeminent experimentalist in the area of plasma-wave interactions. He has made important contributions to the Alcator C, Alcator C-MOD, and Versator II tokamak programs. As a principal investigator in RLE's Plasma Physics Group, his research has included the introduction of techniques for fast-wave current drive, the use of a gyrotron source for electron cyclotron heating and plasma start-up, and studies of the "second stability" regime made for the first time on a tokamak. *(Photo by John F. Cook)*

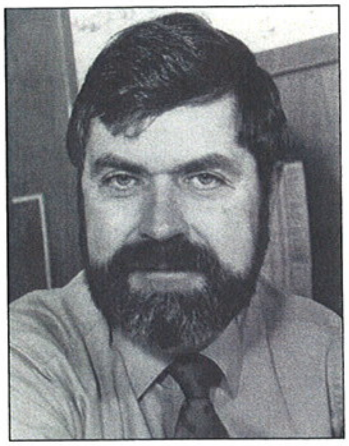
Dr. William M. Siebert (SB'46, ScD'52), Ford Professor of Engineering, announced his retirement in 1995, after serving forty-five years at MIT, forty-three of those on the faculty. Professor Siebert came to RLE in 1950 as a research assistant. With an interest in network theory, he joined the staffs of RLE's Radar Group and Project Lincoln, the forerunner of Lincoln Laboratory. He was appointed to the MIT faculty in 1952 and became full professor in 1963. His many research contributions have been in the fields of signal detection methods, linear circuit theory, and communication biophysics. In 1988, he was recognized for the development of pulse-compression radar when he was named corecipient of the IEEE Pioneer Award of the Aerospace and Electronic Systems Society. In recent work in RLE's Auditory Physiology Group, Professor Siebert has developed mathematical models for peripheral mechanical and neural structures in the auditory system. *(Photo by John F. Cook)*

Dr. Henry I. Smith, Joseph F. and Nancy P. Keithley Professor of Electrical Engineering, was named the recipient of the 1995 IEEE Cledo Brunetti Award for his contributions to microfabrication science and technology, notably microlithography. Professor Smith is a principal investigator in RLE's Quantum-Effect Devices Group and director of MIT's NanoStructures Laboratory. Under Professor Smith's direction, investigators in the NanoStructures Laboratory have pioneered technologies in submicron structure fabrication and have explored deep-submicron metal oxide semiconductor field-effect transistors as well as quantum-effect electronics. Professor Smith's research focuses on nanofabrication, methods for preparing semiconductor-on-insulator films, electronic devices, and quantum effects in sub-100-nanometer structures. The annual Brunetti Award, which recognizes outstanding contributions in the field of miniaturization in the electronic arts, was presented to Professor Smith during the International Electron Devices Meeting in Washington, DC, on December 12, 1995.
(Photo by John F. Cook)

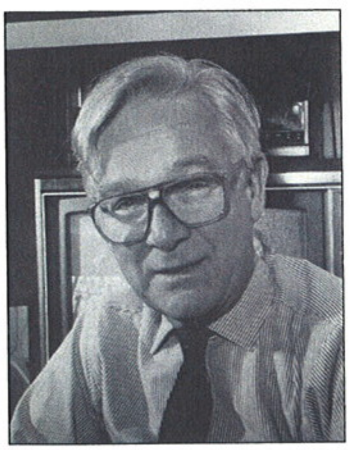


Dr. Kenneth N. Stevens (ScD'52), Clarence J. LeBel Professor of Electrical Engineering, was awarded the Gold Medal of the Acoustical Society of America on June 1, 1995. Upon receiving the society's highest honor, Professor Stevens was cited for his leadership and outstanding contributions to the acoustics of speech production and perception. As the senior member of RLE's Speech Communication Group, he has conducted fundamental research in speech synthesis and the analysis of speech production processes. He received the society's Silver Medal in Speech Communication in 1983. Professor Stevens is a fellow of the Acoustical Society of America, the American Academy of Arts and Sciences, and the IEEE, and a member of the National Academy of Engineering. *(Photo by John F. Cook)*

In 1995, The National Academy of Engineering announced the election of two RLE faculty members:



Dr. Arthur B. Baggeroer (SM'65, ScD'68), Ford Professor of Engineering, was cited for his contributions in signal processing that have been applied to sonar. As a principal investigator in RLE's Digital Signal Processing Group, Professor Baggeroer uses advanced signal processing techniques to explore underwater acoustics and geophysics. He has served as chief scientist at six field experiment stations in the Arctic marginal ice zone, where large aperture arrays are used to gather seismic data. This information is used in conjunction with measurements of long-range propagation, reverberation, ambient noise, and tectonics in the Arctic. From 1983 to 1988, he served as director of the MIT-Woods Hole Joint Program in Oceanography and Ocean Engineering and collaborated on the development of the first high data-rate digital acoustic telemetry system. Since joining the MIT faculty in 1973, Professor Baggeroer has held faculty appointments in the Department of Ocean Engineering as well as the Department of Electrical Engineering and Computer Science. He is a fellow of the IEEE and Acoustical Society of America.
(Photo by John F. Cook)



Dr. William F. Schreiber, Professor Emeritus of Electrical Engineering and Computer Science, was cited for his contributions to image processing, television technology, video compression, and color graphics. Professor Schreiber has pioneered developments in the field of image processing, electronic imaging systems, and transmission coding for over four decades. Most recently, his work has focused on the emerging technology of high-definition television and graphic arts color processing systems. Professor Schreiber joined the MIT faculty and RLE's Cognitive Information Processing Group in 1959. He was appointed director of RLE's newly established Advanced Television Research Program in 1983 and served until his retirement from the faculty in 1990. Professor Schreiber is a four-time recipient of the Society of Motion Picture and Television Engineers Journal Award and was awarded the society's 1990 David Sarnoff Gold Medal. He was also awarded the 1989 Albert Rose Electronic Imager of the Year by the Institute for Graphic Communications and the 1991 Gold Medal from the International Society for Optical Engineering.
(Photo by John F. Cook)

Two RLE faculty members were awarded tenure, effective July 1, 1995:

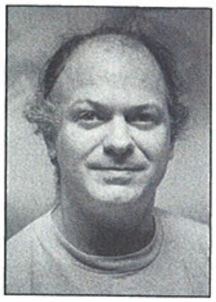
Dr. Srinivas Devadas, Associate Professor of Electrical Engineering and Computer Science, conducts research in the Circuits and Systems Group on the computer-aided design of very large-scale integrated (VLSI) circuits and systems. His work focuses on the synthesis for testability and the formal verification of VLSI circuits, providing circuit and system designers with high-quality circuit design tools. Professor Devadas joined the MIT faculty in 1989, was appointed Analog Devices Career Development Assistant Professor from 1989 to 1991, and was promoted to associate professor in 1992. A graduate of the Indian Institute of Technology (BTech'85) and the University of California at Berkeley (MS'86, PhD'88), he is a member of the IEEE and the Association for Computing Machinery.
(Photo by John F. Cook)

Dr. Leslie A. Kolodziejski, Esther and Harold E. Edgerton Career Development Associate Professor in the Department of Electrical Engineering and Computer Science, investigates II-VI and III-V materials in RLE's Materials and Fabrication Group. Since coming to the MIT from the Purdue University faculty in 1988, she has established an important ultrahigh vacuum facility for the epitaxial growth of II-VI and III-V semiconductor materials. She was named Karl R. Van Tassel Career Development Assistant Professor in 1991, promoted to associate professor in 1992, and received her current appointment in 1993. A graduate of Purdue (BS'83, MS'84, PhD'86), she is also a member of the American Physical Society, the Materials Research Society, the Optical Society of America, and the IEEE. *(Photo by John F. Cook)*

RLE's New Research Staff

Merry A. Brantley was appointed as a research specialist in RLE's Sensory Communication Group, effective December 18, 1995. As a licensed and certified audiologist, she has worked at both the Brigham and Women's Hospital and Beth Israel Hospital in Boston. Ms. Brantley, a graduate of California State University at Long Beach (BS'85), will participate in laboratory and field studies of prototype hearing aids. She is currently a doctoral candidate at Boston University.

Dr. Julie E. Greenberg (SM'89, PhD'94), a visiting scientist in RLE's Sensory Communication Group, was appointed as a research scientist, effective January 1, 1996. Dr. Greenberg joined RLE in 1989 as a graduate student and has conducted research on digital signal processing for multimicrophone hearing aids. She will continue to design, develop, and evaluate microphone arrays for these devices.



Francis G. Taylor (SB'89) was appointed as a research engineer in RLE's Sensory Communication Group, effective December 22, 1995. Mr. Taylor was previously a senior software developer for ConnectSoft in Bellevue, Washington. At RLE, he will perform computer system management and participate in the design of simulation systems for virtual environment training programs.

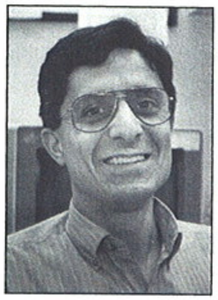
Andrew R. Brughera was appointed as a research specialist in RLE's Sensory Communication Group, effective July 1, 1995. A graduate of Syracuse University (BS'86) and Boston University (MS'95), Mr. Brughera will provide electrical engineering and digital signal processing support to the group's hearing research laboratory.

David S. Lum (SB'94, MEng'95) was appointed as a research engineer in RLE's Sensory Communication Group, effective August 1, 1995. Since joining RLE in 1993 as a student, Mr. Lum has worked on various projects in the Sensory Communication Group. In his current position, he will assist investigators using digital signal processing techniques to develop aids for the hearing impaired and the deaf.

Dr. Reiner Wilhelms-Tricarico was appointed as a research scientist in RLE's Speech Communication Group, effective September 1, 1995. He joined RLE in 1993 as a research affiliate and postdoctoral associate working on the simulation of the tongue's biomechanical behavior. A graduate of the University of Göttingen (BS'76, Diplom '81, ScD'87), his research will further understanding of phonological feature correlates and speech motor control.

Dr. Kyeongjae Cho (PhD'94), a postdoctoral associate in RLE's Surfaces and Interfaces Group, was appointed as a research scientist, effective October 1, 1995. Since joining RLE in 1990 as a research assistant, Dr. Cho's research has involved *ab initio* calculations on parallel supercomputer platforms. He will be continuing this work to perform realistic simulations of scanning tip microscopy on semiconductor surfaces.

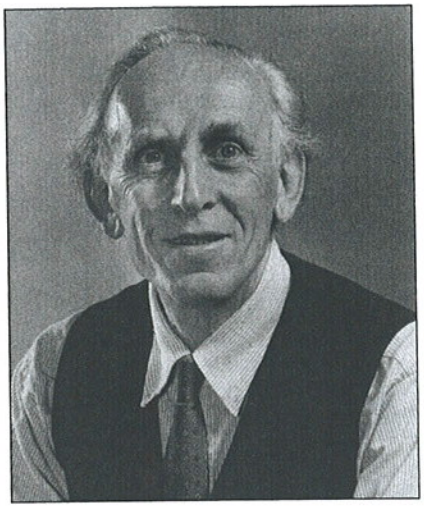
Mark K. Mondol was appointed as a research specialist in RLE's Quantum-Effect Devices Group, effective February 22, 1996. A graduate of Lansing Community College (AAS'86), Mr. Mondol came to RLE in 1991 as a technician. He will be responsible for operating and maintaining the group's scanning electron-beam lithography system and focused ion-beam system.



Majid Zandipour was appointed as a research specialist in RLE's Speech Communication Group, effective February 20, 1996. He is currently a master's candidate in applied physics at the University of Massachusetts/Boston. Mr. Zandipour served as laboratory supervisor in the school's psychology department for the last ten years. At RLE, he will provide engineering and technical support for research in speech motor control.

(Photos by John F. Cook)

IN MEMORIAM



Professor Emeritus George Bekefi, 70, died August 17, 1995, at his home in Brookline, Massachusetts, following a battle with leukemia. Since 1957, Dr. Bekefi was a plasma physicist in RLE and a member of the MIT physics faculty for thirty-four years. His internationally recognized contributions to plasma physics include the development of high-powered microwave generators and free-electron lasers.

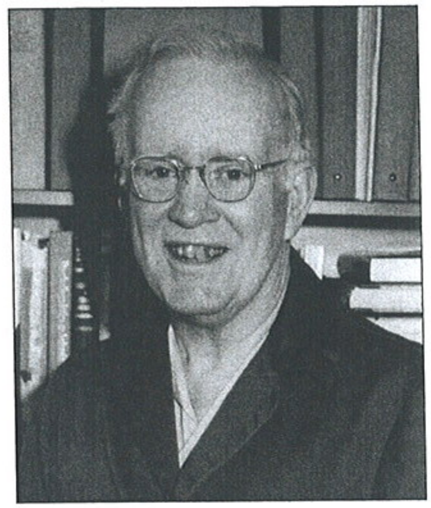
Dr. Bekefi was born in Prague, Czechoslovakia in 1925. During the Nazi occupation in 1939, he came to England as part of British rescue operations for Jewish children. He graduated from University College (BS'48) in London with first-class honors in physics and mathematics, and McGill University (SM'50, PhD'52) in Montreal. Dr. Bekefi stayed at McGill until 1957 as a lecturer and assistant professor. He joined the MIT physics faculty as an assistant professor in 1961, and was promoted to associate professor in 1964, and to professor in 1967.

His interest in electromagnetism and the effects of wave diffraction on the aberrations of optical systems brought him to RLE's Center of Gaseous Electronics in 1957, where he worked with Professors Sanborn C. Brown and William P. Allis. Their research on gaseous electronics later played an important role with the discovery of the laser in 1960. Dr. Bekefi wrote about their studies in his book *Principles of Laser Plasmas.* With the declassification of thermonuclear fusion research in 1958, Dr. Bekefi began investigations into wave propagation in hot plasmas and various emission processes. This work is described in his classic monograph *Radiation Processes in Plasmas.*

In the early 1960s, initial work in solid-state plasmas was led by Drs. Bekefi and Abraham Bers in RLE. This work was interrupted as attention turned to lasers and quantum electronics, but resumed in the 1970s with Dr. Bekefi's interests in relativistic electron beams. The first narrow-band free-electron laser, which was tunable over a wide range of frequencies, was achieved by Dr. Bekefi and his colleagues in RLE's Plasma Physics Group. His work on free-electrons lasers continued until his retirement in 1995. Together with Dr. Miklos Porkolab, Dr. Bekefi established the Versator II tokamak research program at RLE. Versator was the first tokamak to demonstrate the feasibility of driving substantial plasma current with plasma waves. In 1976, Dr. Bekefi and Dr. Thaddeus Orzechowski developed a radiation source that produced microwave bursts fifty times more powerful than the largest conventional microwave generators then in existence.

As the co-author of the textbook *Electromagnetic Vibrations, Waves and Radiation,* Dr. Bekefi held seven patents and published more than 180 scientific papers. His awards include the 1995 Free-Electron Laser Award from the American Physical Society; the Gold Honorary Medal for Merit in Physical Sciences from the Academy of Sciences of the Czech Republic in 1994; the IEEE's 1989 Plasma Science and Applications Prize; and a 1972 Guggenheim Fellowship. He was a fellow of the American Physical Society and chairman of its Division of Plasma Physics in 1978.

Dr. Bekefi is survived by his wife, Chaia; a son, Ariel; and a daughter, Tamara, all of Brookline. Donations may be made in Dr. Bekefi's memory to One Generation After, an organization that explores the significance of the Holocaust. Remembrances may be sent to: One Generation After, 1726 Beacon Street, Brookline, MA 02146.



Donald Keith North (SB'54), 67, died February 9, 1995, at his home in Cambridge. Mr. North, a project technician in RLE's Speech Communication Group, was affiliated with the laboratory for forty years. During his many years of dedicated service, he provided support to students, faculty, and staff members while maintaining a variety of equipment for speech recording and analysis. Many students received practical training from Mr. North in the construction and maintenance of electronic equipment. His devotion was recognized in 1989 when he received the James N. Murphy Award for sustained contribution to MIT community life.

A Florida native, Mr. North received his bachelor's degree in chemistry in 1954 at MIT. He was hired in 1959 as a technician by Professor Kenneth N. Stevens, the current head of RLE's Speech Communication Group. "I think it's fair to say that MIT was his real home," Professor Stevens said. Mr. North left most of his estate to MIT. His generous gift will support student projects and enable students to attend conferences and present their papers.

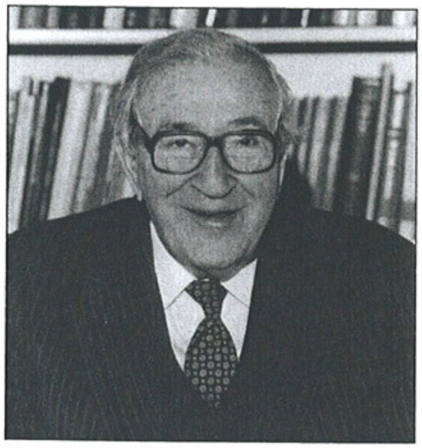
(Photos by John F. Cook)

IN MEMORIAM

MIT President Emeritus Jerome B. Wiesner, 79, died of heart failure on October 21, 1994, at his home in Watertown, Massachusetts. Although Dr. Wiesner had recovered from a stroke in 1989 that hampered his speech and ability to walk, he suffered from an unspecified illness at the time of his death. His distinguished record of service to government and MIT includes RLE director, MIT provost, MIT president, and presidential science advisor to Presidents John F. Kennedy and Lyndon B. Johnson. As a scientific statesman, Dr. Wiesner shaped national policy and programs related to science and technology. As a scientist, his studies in communication science and engineering included ionospheric scattering techniques to transmit radio waves. As an educator, he actively promoted and enriched the institute's programs in social science, humanities, and the arts.

Dr. Wiesner was born in Detroit, Michigan, in 1915, and raised in nearby Dearborn. He graduated from the University of Michigan at Ann Arbor (BS'37, MS'38, PhD'50). From 1940 to 1942, he was chief engineer at the Acoustical and Record Library in the Library of Congress. During this time, he worked on the development of the library's advanced sound recording facilities. With folklorist Alan Lomax, he recorded American folk music on a tour through the South and Southwest for the library's archives.

In 1942, Dr. Wiesner joined the staff at MIT's Radiation Laboratory to work on X-band radar components. He became an associate member of the laboratory's steering committee and group leader for Project Cadillac, a forerunner of the AWAC airborne radar system. Following the Radiation Laboratory, he spent one year at the University of California's Los Alamos Laboratory, where he worked on the development of electronic components used at the Bikini Atoll atomic bomb tests. Dr. Wiesner returned to MIT in 1946, and joined the faculty as assistant professor in the Department of Electrical Engineering. He was promoted to associate professor in 1947 and full professor in 1950. He also



MIT President Emeritus Jerome B. Wiesner
(Photo by John F. Cook)

served as the department's acting head from 1959 to 1960.

Dr. Wiesner was appointed assistant director of RLE in 1947, became associate director in 1949, and served as director from 1952 to 1961. During his tenure in RLE, the laboratory's research broadened from its original emphasis on physics and communications. RLE began to attract researchers from around the world while developing its own multidisciplinary style of research. It was this style, according to Dr. Wiesner, that was passed on to Lincoln Laboratory when it was founded in 1951.

Dr. Wiesner was a devoted advisor to government officials on issues related to science and technology. Under President Dwight D. Eisenhower, he served on the President's Science Advisory Committee in 1957, and as staff director of the United States delegation to the Geneva Conference in 1958. In 1961, he took a three-year leave of absence from MIT to become President John F. Kennedy's special assistant for science and technology and to chair the President's Science Advisory Committee. Dr. Wiesner also served briefly in these roles during President Lyndon B. Johnson's administration.

From 1962 to 1971, Dr. Wiesner held the rank of institute professor. In 1964, he returned to MIT as dean of the School of Science. From 1964 to 1981, he also continued to serve on the Technology Advisory Council of the Office of Technology Assessment. Dr. Wiesner was appointed MIT provost in 1966, and became the institute's thirteenth president in 1971. He served as president until his retirement in 1980, when he resumed the rank of institute professor.

As an advocate of nuclear arms control, Dr. Wiesner helped to establish the United States Arms Control and Disarmament Agency and to restrict deployment of antiballistic missile systems. His efforts led to the 1963 Limited Nuclear Test Ban Treaty signed by the United States, the Soviet Union, and Great Britain. This historic treaty banned all nuclear tests, except those underground. His books addressing the issue of nuclear arms control include *Where Science and Politics Meet* and *ABM: An Evaluation of the Decision to Deploy an Antiballistic Missile System.*

During his retirement years, Dr. Wiesner promoted teaching and research in technology policy and social issues. His efforts helped to establish MIT's Program in Science, Technology and Society. A founder of MIT's Media Laboratory, he promoted the creative use of technology and computers in education and the arts. In 1985, the Wiesner Building, which houses MIT's Media Lab and the List Visual Arts Center, was dedicated to Dr. and Mrs. Wiesner. He also fostered the development of research in brain and cognitive sciences.

As a founding member of the International Foundation for the Survival and Development of Humanity, Dr. Wiesner joined other scientists and educators to raise funds for research on global problems. He also continued to speak out against the nuclear arms race. In 1993, along with MIT scientists Philip Morris and Kosta Tsipis, Dr. Wiesner published *Beyond the Looking Glass: The United States Military in 2000 and Later.*

Dr. Wiesner's many professional and public service awards cited his steadfast efforts to use science and engineering in solving humanitarian problems. The National Science Board honored him in 1992 with the Vannevar Bush Award, recognizing his role to further public understanding of the risks of nuclear testing. In 1993, he was awarded the National Academy of Sciences' Public Welfare Medal for his devoted and successful work in science policy, education, nuclear disarmament, and world peace. His many other awards include: the President's Certificate of Merit (1948), the IEEE Founder's Medal (1977), the IEEE Centennial Medal (1984), and the National Academy of Engineering's Arthur M. Bueche Award (1985).

Dr. Wiesner is survived by his wife Laya (Wainger) Wiesner; three sons, Stephen J. of Mitzpeh Ramon, Israel, Zachary K. of Watertown, and Joshua A. of Cambridge; and a daughter, Dr. Elizabeth A. of Branford, Connecticut. Remembrances for Dr. Wiesner may be sent to the Spaulding Rehabilitation Hospital, 125 Nashua Street, Boston, Massachusetts 02114, or to Mount Auburn Hospital, 330 Mount Auburn Street, Cambridge, Massachusetts 02238.

Jerome B. Wiesner • 1915-1994

Top left: After four years at the Radiation Laboratory and a brief stint at the University of California's Los Alamos Laboratory, Dr. Wiesner returned to MIT in 1946 as an assistant professor of electrical engineering.

Top right: Dr. Wiesner met fellow mathematics major Laya Wainger at the University of Michigan, and they were married in 1940. Here, they share a quiet moment on the eve of Dr. Wiesner's departure from MIT in 1961 to serve in President Kennedy's administration.

Middle: After an Oval Office conference in 1963 (from left): Dr. Wiesner; Joseph H. McConnell, president of Communications Satellite Corporation; President John F. Kennedy; and J. Harlan Cleveland, assistant secretary for international organization affairs in the Department of State.

Bottom left: On October 15, 1969, MIT Provost Jerome Wiesner led almost 4,000 anti-war prostesters on a peace march from MIT to the Boston Common.
(Above photos courtesy MIT Museum)

Bottom right: At his inauguration as MIT's thirteenth president in 1971, Dr. Wiesner reminisces with four institute presidents emeriti (from left): Dr. Wiesner, Dr. Vannevar Bush, Dr. Howard W. Johnson, Dr. Julius A. Stratton, and Dr. James R. Killian.
(Photo by Margaret Foote)

RLE's 50th Anniversary – November 1 and 2, 1996

A celebration to commemorate the 50th anniversary of RLE will take place at the MIT campus on Friday and Saturday, November 1 and 2, 1996. This special two-day event will mark RLE's "50 Years of Technological Impact and Innovation," focusing not only on RLE's contributions to science and technology, but also on the laboratory's impact on society.

Highlights will include:

• A laboratory open house, poster session, and welcoming reception will be held on Friday afternoon, November 1. RLE's research groups invite you to take a tour of their unique facilities and meet with faculty, staff, and students.

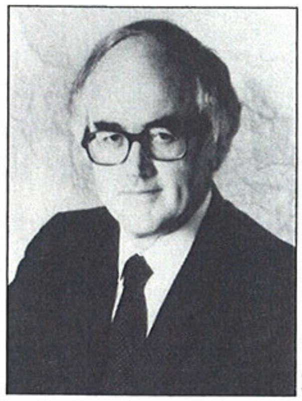
• On Friday evening, a gala reception will accompany the opening of RLE's exhibit in the Compton Gallery. The new exhibit will feature historic artifacts and photographs from RLE's first 50 years.

• A reunion breakfast will be held on Saturday morning, November 2, at the MIT Faculty Club. All students, faculty, and staff who have been part of RLE since the laboratory's founding in 1946 are invited to attend and reminisce.

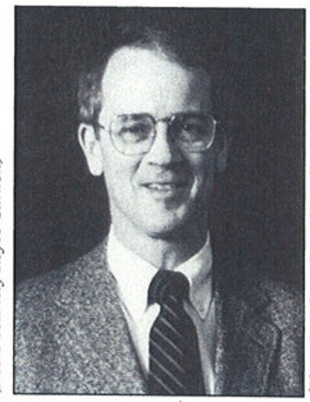
• On Saturday, an all-day symposium will showcase the broad range of RLE's current research. Presentations and demonstrations will be made by RLE's faculty and students. Invited guests from government, industry, and academia will also participate in several technical sessions planned for the day. In the afternoon, keynote addresses will be delivered by award-winning science historian James Burke and MIT President Charles M. Vest. Mr. Burke will detail the history of communication and describe the role that RLE has played in this discipline. Dr. Vest will comment on the role of research universities in society and how RLE can contribute to the solution of important societal needs.

• To cap off the two-day celebration on Saturday evening, a jubilee dinner party will be held at Morss Hall in MIT's Walker Memorial.

For more information, please mail the enclosed postcard or contact the laboratory at 617-253-4653. Web browsers can also view the laboratory's web page at: http://rleweb.mit.edu/ for up-to-date information on RLE's 50th anniversary. A limited number of hotel rooms has been reserved for this special occasion. If you would like to guarantee a room, please call RLE at 617-253-4198.



(Photo courtesy Royce-Carlton)



(Photo by Eduard McCluney)

One of the keynote addresses at RLE's 50th anniversary symposium will be delivered by award-winning television host and author James Burke (left). Mr. Burke's best-selling books and television series include: Connections, The Day The Universe Changed, After the Warming, Masters of Illusion, *and* Connections². *In addition, MIT President Charles M. Vest (right) will speak on science policy in America and the role of research universities.*

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