Hermann A. Haus

1925–2003

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
Erich P. Ippen

NATIONAL ACADEMY OF SCIENCES

HERMANN ANTON **HAUS**

August 8, 1925–May 21, 2003

Elected to the NAS, 1987

By Erich P. Ippen

An expert in the theories of noise, ultrashort-pulse generation, and soliton communications, Hermann A. Haus was born in Ljubljana, Slovenia, to parents of Austrian descent. and died suddenly, after riding his bike home, in Lexington, MA on May 21, 2003. As a professor at the Massachusetts Institute of Technology (MIT) for 49 years and an Institute Professor there for the last 15, he left a legacy of five books and over 300 journal publications. Hermann was a member of the National Academy of Sciences, the National Academy of Engineering, and the American Academy of Arts and Sciences. In addition to major awards from many other professional societies and foundations, he received honorary doctorates from Union College, the University of Vienna (Austria), and the University of Ghent (Belgium). In 1995 President Bill Clinton presented him with the National Medal of Science.

Hermann's early education, in Ljubljana, focused on languages and the classics; but he spent much of his spare time as a youth designing and flying model gliders. At age 18, just as he was about to enter the university to begin studies in engineering, the Germans invaded Slovenia and the university was closed. To avoid the draft, Hermann became an electrician trainee in a local aluminum factory and continued working there until after the end of the war.

During that period, several events occurred that were particularly memorable and would play important roles in his future. Hermann lived alone with his mother, Helene Hynek, who had by then separated from his father, Otto Maximilian Haus, a noted physician and tuberculosis specialist. One evening a woman partisan who had escaped from a German prison appeared at their house and asked to be hidden. In spite of the risk, they helped her; and she was able to flee safely the next day to the countryside. A year later, following liberation from the Germans by Tito's communists, Hermann and

One night, without warning or time to grab belongings, Hermann and his mother were hauled out of their house by the communist authorities, put on a train in an unheated cattle car, and deported to Austria.

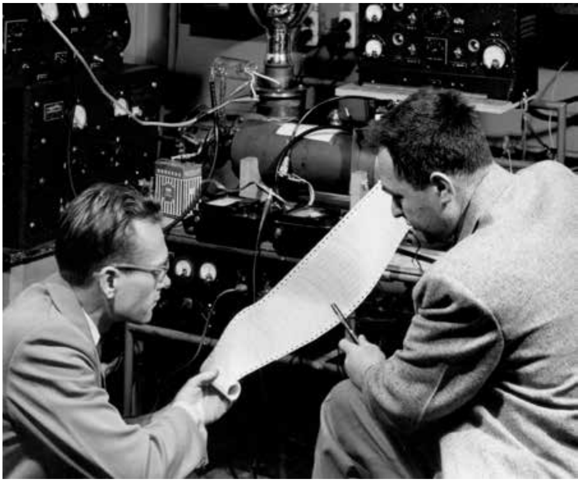
his mother were rounded up and put in jail as possible dissenters. Then after two weeks, without explanation, they were suddenly released. It seems that the woman partisan they had once protected had been made minister of education in the new government and she arranged to free them.

Hermann returned to the factory and a warm welcome from his coworkers, who had come to like and trust him. He was even elected as company overseer of their adherence to communism because they knew he wouldn't betray them. This period of freedom for Hermann, however, lasted less than nine months. One night, without warning or time to grab belongings, Hermann and his mother were hauled out of their house by the communist authorities, put on a train in an unheated cattle car, and deported to Austria. One of the other passengers on the train, a chemistry professor that Hermann recognized, lamented the entire time about having to leave a career's worth of research notes behind. Hermann then vowed to himself never to rely on anything so complex that he couldn't keep it in his head. This vow greatly affected his later career. He was adamant about giving lectures without notes, and in his research he often created new and elegant derivations of well-known results as well as the completely original and foundational formulations for which he became renowned.

After arriving in Austria, Hermann and his mother lived in two refugee camps in succession until Hermann secured a job as an electrician with the British occupying forces. He knew some English, he said, from reading *Gone with the Wind*. They moved to Graz, and in 1946 Hermann enrolled in the Technical University there. He chose power engineering in order to learn the principles of the electric motors that he had worked with in the factory. This gave him his first encounter with Maxwell's Equations, which were to provide the foundation for much of his future career's work.

Hermann's high school (gymnasium) in Ljubljana had taught him Latin and Greek, but no calculus. He had some catching up to do. Nevertheless, he quickly distinguished himself and, after discovering an error in a well-known electromagnetics text, learned not to believe everything written in a book. Hermann had determined for himself that a statement in the text, "The curl of a vector is always perpendicular to that vector," was not rigorously true. Emboldened to pursue more modern applications of Maxwell's

Equations, he transferred to the Technical University of Vienna to study microwave engineering.



Haus, left with Louis Smullin, 1950's.

In Vienna, Hermann heard about a scholarship program for study in the United States, and he applied. But after waiting for what seemed to him too long without a response, he wrote to U.S. Army General Mark Clark and suggested that Austrians seemed to be discriminated against in the granting of scholarships. Whether that letter turned the tide or not, Hermann soon received the offer of a scholarship to study at Union College in New York. With credit for his studies in Graz and Vienna, he graduated after one year (in 1949) from Union with a B.Sc. He then applied to Bell Laboratories for a job and was turned down. He applied to MIT for graduate school and was turned down. He applied to Rensselaer Polytechnic Institute (RPI) and was accepted and given a teaching assistantship.

While working on his master's degree at RPI, Hermann obtained a summer job at MIT with Prof. Louis Smullin. That experience led to his acceptance in 1951 into the doctoral program of MIT's Department of Electrical Engineering. Although he continued to work with Smullin on traveling wave tube (TWT) experiments, it was his thesis advisor, Professor Lan Jen Chu, who mentored him in TWT theory and, Hermann later said, taught him the value of simplifying a problem to its bare bones without losing its essential features. His thesis proved that the noise output of a TWT had a lower limit proportional to (G–1), where G is the power gain (Haus 1954); he received his Sc.D. from MIT in 1954 and joined what is now its Department of Electrical Engineering and Computer Science that year.

Evaluation of noise and the limits it imposed was to be a continuing theme throughout Hermann's career. In work with Richard Adler, he extended his analysis to linear electronic amplifiers in general. The two researchers showed, in their 1959 book, that every linear amplifier could be characterized by an optimum noise measure, M, the lowest value of which was (F–1)/(1–1/G), where F–1 is the excess noise figure (Haus and Adler 1959). Intrigued by the fact that there was no classical lower limit to M, Hermann pushed further and, with James Mullen, found the quantum limit: in their 1962 paper they revealed that the amplified spontaneous emission (ASE) power in a single-mode amplifier had a minimum value of $(G-1)\hbar\omega_0 B$ (Haus and Mullen 1962). Elegant quantum noise experiments with Charles Freed then followed. With an early helium-neon laser, Haus and Freed proved the theoretical prediction that photon statistics changed at laser threshold—from degenerate Bose-Einstein below threshold to Poissonian above—a result they documented in 1965 (Freed and Haus 1965).

Young professor, circa 1955.

During this period, Hermann was also further cementing his mastery of electromagnetic theory. His thesis advisor Chu had recently extended Wolfgang K. H. Panofsky and Melba Phillips's theory of moving polarized media to moving magnetized media. Chu had done so in simple and insightful fashion by modeling the magnetic dipole, in analogy with the electric dipole, as two magnetic charges separated by a small distance. This approach was quickly challenged in a paper by Bernard Tellegen, who showed that the force on two magnetic charges in a time-varying electric field was not the same as that on a current loop—the conventional physical model for a magnetic dipole.

Chu never responded to this critique; but Hermann and one of his former students, Paul Penfield, took up the challenge. They showed that Tellegen had erred by assuming that the current distribution in the current loop was itself unaffected by the varying electric field. By including the correct induced-charge accumulations, Haus and Penfield proved that Chu's simple formulation was in fact relativistically self-consistent and led to the correct answers. Empowered by this result, they developed the theory of electrodynamics of moving media further and wrote a definitive 1965 book on the subject (Penfield and Haus 1965).

In 1974–75, Hermann spent the first of three very productive sabbaticals at Bell Labs in Holmdel, New Jersey. At that time, two emerging technologies attracted his interest: ultrashort-pulse lasers and integrated optics. Femtosecond-duration pulses had recently been produced for the first time by Erich Ippen and Charles Shank, using a passively mode-locked dye laser. Hermann put himself to work developing a theory for how such short pulses were produced in a laser—given the fact that none of its elements could respond on such a fast timescale—though Geoffrey New of Imperial College had shown via computer simulations that this laser effect could happen.

In 1975 Hermann provided an elegant analytic theory that could be used to determine stability criteria, optimum operating conditions, and output characteristics. This theory of mode-locking with a "slow saturable absorber" became one of his most widely acclaimed works (Haus 1975a). For comparison and completeness, Hermann formulated later in 1975 an equally elegant analytic theory for mode-locking with a "fast saturable absorber" (Haus 1975b). At the time such a "fast absorber" was merely a mathematical construct; but it was prescient. With the discovery some 15 years later of artificial fast absorbers made possible by reactive nonlinearities in solid-state and fiber lasers, this latter paper joined the other among his most highly valued and used works.

An amusing nontechnical aspect of this sabbatical was the location of the rental home that Bell Labs obtained for Hermann, his wife Lennie, and youngest daughter Mary. Hermann had mentioned to his initial host, Herwig Kogelnik, that he liked to ride a bicycle and in fact rode 15 miles every workday from his home in Lexington, MA, to MIT and back. This was somehow understood to mean that Hermann wanted a house at least 15 miles away from Bell Labs so that he could maintain his biking routine, though it was not his intention. Indeed, the traffic on narrow country roads of rural New Jersey near the Holmdel facility made them not particularly amenable to bicycle riders.

During the same sabbatical Hermann was also attracted to the concept of lasing in a periodic structure, as put forth by Kogelnik and Charles Shank. Such a "distributed feedback" (DFB) laser in its simplest form exhibited two equally likely lasing frequencies. Hermann very quickly devised a solution to this uncertainty and, with Shank, published a paper describing the concept of a DFB structure with a quarter-wave shift in the middle (Haus and Shank 1976). DFB structures in semiconductor diode lasers would subsequently achieve widespread use as one of the most important components of optical-fiber communication systems; and they remain critical devices for achieving the wavelength precision needed in advanced high-capacity systems. Ultimately, however, Hermann's quarter-wave shift, while an elegant and effective invention, turned out to be difficult to manufacture, and other methods were found to achieve the same result in practice.

With Erich Ippen, 1990s.

Upon his return to MIT, Hermann put several of his students to work on ideas for mode-locking and integrated optics that he had developed at Bell. No one had mode-locked a semiconductor diode laser, but Hermann saw similarities between these devices and the dye lasers he had recently studied. Not having the fabrication facilities to make a semiconductor device that incorporated both a saturable absorber and a gain section, he opted for active mode-locking, which was induced with an applied electrical modulation. By 1978 he and his student Ping Ho had produced picosecond pulses with the first mode-locked semiconductor laser (Ho et al. 1978). This result triggered several decades of widespread research on semiconductor mode-locked lasers for high bit-rate optical communications and clocking.

At the same time, Hermann was also developing ideas for optical signal processing in integrated optics. He focused on the design of a switch in which one (control) optical pulse changed the path of another (signal) optical pulse, at picosecond speeds and without changing the wavelength of the switched signal pulse. In 1983 he and his student Annalisa Lattes were successful in this seminal effort. Using an integrated waveguide Mach-Zehnder interferometer that could be imbalanced by the nonlinearity induced by the control pulse in one arm, they demonstrated the first ultrafast all-optical switch (Lattes et al. 1983). This approach inspired further developments of such architecture over several decades with a variety of material technologies.

In 1980, with the help of Peter Wolff, director of the Research Laboratory of Electronics (RLE) at MIT, Hermann attracted Erich Ippen from Bell Labs to MIT. Together they grew laser and optics research at MIT into an internationally leading activity known for its successful synergism between theory and experiment, particularly in the area of ultrashort-pulse and ultrafast-phenomena optics. This “Optics and Quantum Electronics Group” in the RLE was to expand still further and achieve even greater success with the faculty appointments of James Fujimoto in 1985 and Franz Kaertner in 2001.

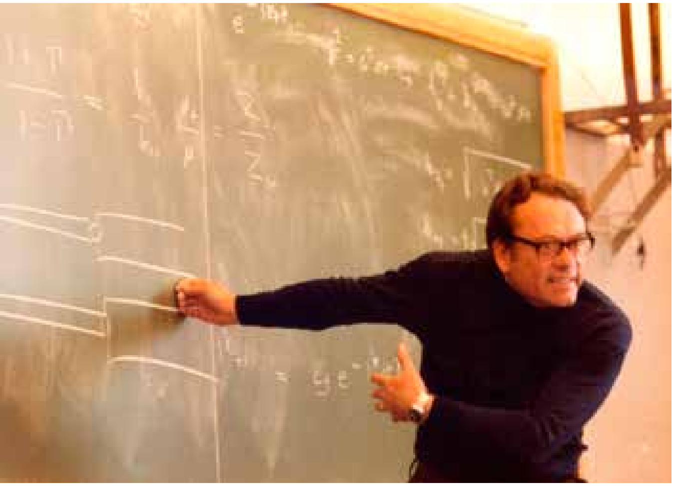
Also in the 1980s, Hermann returned to his interest in noise. During a second sabbatical at Bell Labs, he teamed up with Jim Gordon to quantify the effects of amplifier noise on the propagation of soliton pulses in optical fibers (Gordon and Haus 1986). They

In the lab, 1988.

found that the frequency jitter caused by the ASE noise of the amplifiers produced, in the presence of group velocity dispersion, random shifts in pulse arrival time after transmission through the fiber. Accounting for, and overcoming, this "Gordon-Haus effect" has remained an important aspect of the development of ultrashort-pulse optical fiber devices for timing and synchronization. Hermann and postdoc Antonio Mecozzi subsequently showed that simple filtering can limit the random frequency walks so that the timing jitter only grows linearly rather than with the cube of the distance (Haus and Mecozzi 1992). Hermann would return again to this topic, a few years later, with a most comprehensive review of both the theoretical aspects and technological challenges of solitons in communication systems (Haus and Wong 1996).

In 1986, in a definitive and oft-cited paper, Hermann and Yoshihisa Yamamoto addressed the preparation, measurement, and information content of quantum optical states in general (Yamamoto and Haus 1986). Hermann and Yinchieh Lai extended the analysis of quantum noise, specifically and in detail, to solitons in optical fibers (Lai and Haus 1989). One motivation expressed in these works was the possible manipulation of noise by "squeezing" it out of one variable of the optical field and into another—complementary—variable. Hermann and his student Keren Bergman ultimately achieved this objective in a fiber interferometer experiment in which the amplitude noise of signal pulses was squeezed below the classical shot-noise limit by more than 3dB (Bergman et al. 1993).

With the emergence in the 1990s of fiber lasers as potentially important sources of femtosecond pulses, Hermann again led the way both with theory and experiment. He developed the theory of additive-pulse mode-locking (APM) to guide the use of the self-phase modulation nonlinearity in fibers for the creation of artificial instantaneous saturable absorbers (pulse shapers). He and his student Kohichi Tamura used this approach to achieve femtosecond pulses with a soliton laser (Haus, Ippen, and Tamura 1994) and then extended it to the demonstration of a new configuration, the stretched-pulse laser



Teaching, 1970's.

(Haus et al. 1995). This latter system, which achieved shorter pulses and higher powers, was soon licensed to industry and remains the model for many commercial systems.

In 2000, at the age of 75, Hermann brought together all of his insights and theory formulations on ultrashort-pulse generation in a comprehensive review article titled simply "Mode-Locking of Lasers" (Haus 2000a). Meanwhile, Hermann's theory of stretched-pulse mode-locking was providing the foundation for modeling femtosecond solid-state lasers, which subsequently achieved pulse durations of only a few cycles of light and created the ability to explore the next ultrafast frontier—the attosecond time domain.

In the late 1990s, as interest developed in optical nanostructures and photonic crystal behavior, Hermann's profound understanding of guided-wave phenomena and coupled-mode theory put him at the center of these emerging technology efforts as well. He was a strong believer that the most practical approach to densely integrated photonic circuits was through the development of high-index-contrast waveguide devices and circuits. He took on new students, obtained funding, and with his team began inventing and demonstrating an array of new integrated silicon photonic devices for filtering, interconnections, polarization rotation, and input/output coupling. He and his student Christina Manolatou turned her Ph.D. thesis into a book titled *Passive Components for Dense Optical Integration* (Manolatou and Haus 2002).

Hermann was known at MIT as an extraordinary teacher both for his course-defining textbooks and his dynamic in-class personality. With James Melcher he wrote *Electromagnetic Fields and Energy* (Haus and Melcher 1989) for the MIT electrical engineering undergraduate course in electromagnetics for which, in successive semesters, he alternately lectured and taught sections. In teaching classes he would gesture dramatically, convey awe of the subject and the phenomena it explained, and lecture without notes. In living by the lesson he had learned on the train from Slovenia to Austria as a refugee, it helped that he had the ability to re-derive everything from the ground up, on the spot, if a problem arose.

In the lab, 1993.

For his yearly graduate course, Hermann had written the textbook *Waves and Fields in Optoelectronics* (Haus 1984); and in 2000, at the age of 75, he created yet another course and corresponding major text, *Electromagnetic Noise and Quantum Optical Measurement* (Haus 2000b), which unified his life's work on the theory and experimental manifestations of noise.

Hermann and his wonderful wife Eleanor "Lennie" Haus (nee Laggis), who outlived him for five years, were married for just short of 50 years. They had four children—Bill, Stephen, Cristina, and Mary—and were devoted grandparents to four grandchildren and two step-grandchildren. In addition to their home in Lexington, MA, Hermann and Lennie kept a family apartment in Vienna, Austria, where the Haus name was still recognized. Hermann's grandfather, Anton von Haus, had been the commander-in-chief of the Austro-Hungarian naval fleet under Emperor Franz Joseph during World War I. Vacations to gather the family were regularly held on Nantucket and later in Hawaii, where both Bill and Stephen had settled.

Hermann was always about much more than science and engineering. He inspired colleagues with the stories of his experiences as a young man and with his command of literature, history, and art. He regularly led students to lectures on diverse subjects, to local museums and art exhibits, and in his personal tours of campus sculpture—and he was always quite clear about what he liked and didn't like. He liked the Henry Moores; he did not like the Nevelson on East Campus. Away from MIT too, at conferences, he regularly organized long hikes, mountain climbs, and excursions for lake swimming.

Hermann cherished the successes of his students and friends. He never failed to have them celebrated with a champagne toast or a dinner out. The parties that he and Lennie hosted at their home have left generations of students and visitors with particularly fond memories. At their annual summer barbecue, Hermann, with towel rolled under his arm, would lead the charge to the neighborhood pool for the obligatory pre-dinner swim before returning to cook chicken over a real-wood fire. Each year there was also a Christmas party, often with one of the students playing the piano for singing and always with Hermann's famous punch bowl.

Portrait, 2003.

Even as he approached the age of 78, Hermann showed no signs of slowing down. Since officially retiring at the age of 70 he had continued to teach, written a completely new 562-page textbook, and maintained an active and forward-looking research program with graduate students. His sudden death on May 21, 2003, which happened during his usual bicycle commute home, stunned and saddened all who knew him.

Not long thereafter, MIT created the Hermann Anton Haus Room for seminars, conferences, and group meetings at the Research Laboratory of Electronics (RLE). An annual Hermann Anton Haus Lecture also was established in the RLE to honor Hermann's memory and to help bring distinguished speakers to the laboratory so as to continue the process of openly collaborative dialogue that Hermann promoted throughout his life.

ACKNOWLEDGEMENT

In addition to the author's personal recollections, this memoir relies on an autobiographical manuscript that Hermann prepared shortly before his death for a 2003 Gordon Conference on Nonlinear Optics. The resulting article was published in 2004 by the *Journal of Modern Optics* (51:1873–1888).

EMPLOYMENT HISTORY

1954–1958 Assistant professor, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology

1958–1962 Associate professor, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology

1962–1973 Professor, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology

1973–1987 Elihu Thomson Professor, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology

1987–2003 Institute Professor, Massachusetts Institute of Technology

1956–1990 Consultant, Raytheon Corporation

1959–1960 Visiting professor, Technische Hochschule, Vienna, Austria

1959, 1972–1973, 1978–1990 Consultant, Lawrence Livermore National Laboratory

1968 Gordon MacKay Visiting Professor, University of California, Berkeley

1974–1975 Visiting scientist, Bell Laboratories, Holmdel, NJ

1980 Visiting professor, Tokyo Institute of Technology, Tokyo, Japan

1984 Visiting scientist, Bell Laboratories, Holmdel, NJ

1984 Visiting scientist, Bell Communications Research Laboratories, Holmdel, NJ

1985 Visiting researcher, NTT, Japan

1985 Visiting professor, Technische Universität, Vienna, Austria

1988–1990 Consultant, Kokusai Denshi Denwa, Japan

1989 Visiting scientist, Cambridge University, England

1995 Visiting professor, Eidgenöschische Technische Hochschule (ETH), Zürich, Switzerland

1995 Visiting scientist, Bell Laboratories, Holmdel, NJ

AWARDS AND HONORS

1959–1960 Fellow, Guggenheim Foundation

1962 Fellow, Institute of Electrical and Electronics Engineers (IEEE)

1976 Member, National Academy of Engineering

1981 Fellow, American Academy of Arts and Sciences

1982 James R. Killian Award, Massachusetts Institute of Technology

1984 Fellow, Fulbright Foundation

1984 Quantum Electronics Award, IEEE

1986 Fellow, Optical Society of America

1987 Member, National Academy of Sciences

1987 Charles Hard Townes Prize, Optical Society of America

1989 Honorary doctorate, Union College

1990 Honorary Doctorate, Technische Universität Wien, Vienna Austria

1990 Outstanding Paper Award, IEEE Transactions on Education

1991 Fellow, American Physical Society

1991 Education Medal, IEEE

1991 Centennial Medal, IEEE

1994 Frederic Ives Medal, The Optical Society

1994 Honorary Doctorate, Universiteit Gent, Ghent, The Netherlands

1995 National Science Medal, presented by the president of the United States

1997 Ludwig Wittgenstein-Preis, Austrian Research Foundation

2001 Willis E. Lamb Medal, Physics of Quantum Electronics Conference

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